Impact of Technological Advancements on Food Supply Chains

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ABSTRACT

In the backdrop of challenging business environments and sustainability imperatives, the beef supply chain contends with multifaceted obstacles. This research explores the potential of RPA to address sustainability concerns in this sector. With a focus on identifying risks to RPA adoption and its implications for sustainability, the study utilises secondary data to develop a process model, simulate 'what-if' scenarios and analyse the results. This research is focused on the geographical scope of the United Kingdom, encompassing regions such as England and Wales, Scotland, and Northern Ireland. Through a comprehensive examination, the study aims to provide actionable insights for beef manufacturers. The beef industry operates within highly competitive markets, necessitating innovative approaches to enhance sustainability and maintain a competitive edge. RPA emerges as a strategic tool to mitigate risks and streamline operations in this context. By automating repetitive and strenuous tasks, RPA holds the promise of improving beef quality, safety, and shelf-life while optimising costs and energy consumption. However, despite its potential benefits, the adoption of RPA faces significant challenges and risks within beef supply chains. These risks often stem from organisational inertia, inadequate awareness, or lack of knowledge about the technology. Addressing these risks requires a nuanced understanding of the factors influencing adoption process. To bridge this gap, this research employs a simulation-based approach to explore various scenarios related to RPA adoption. Through scenario analysis, the study provides an opportunity to identify risks and bottlenecks associated with beef supply chains. The analysis of the simulation results also offered strategies to respond and/or avoid potential risks and mitigate pertinent challenges for robust RPA adoption. By simulating different scenarios using various significant parameters such as beef quality, safety, shelf-life, and financial aspects, the research provides valuable insights into the adoption process. The findings underscore the importance of adopting RPA to achieve sustainability goals while enhancing operational efficiency and reducing production costs. Moreover, the proposed business process model offers a simple, yet structured framework for decision-making, aiding beef manufacturers in navigating the complexities of RPA adoption. By facilitating informed decision-making, the generic process model contributes to the long-term viability, competitiveness, and efficiency of beef supply chains. Furthermore, this study also advances academic research by emphasising the socio-economic benefits of RPA implementation in the beef sector. By optimising productivity and reducing operational costs, RPA enables beef

supply chains to create sustainable value, and resilience in beef production. The successful adoption of RPA improves beef supply chain performance, efficiency, and sustainability by allowing decision-makers to be more strategic and systematic.

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ABBREVIATIONS

AHDB	Agriculture and Horticulture Development Board
BPM	Business Process Management
CSR	Corporate Social Responsibility
CO2e	Carbon dioxide emissions
DES	Discrete-Event Simulation
EUROP	E-Excellent, U-very good, R-good, O-fair, P-poor
EU	European Union
FSC	Food Supply Chain
FSCM	Food Supply Chain Management
FCC	Food Chain Centre
IT	Information Technology
IS	Information Systems
KPI	Key Performance Indicator
MORE	Measure Of Risk and Error
RBV	Resource-Based View
RPA	Robotic Process Automation
ROI	Return on Investment

RMIF	Red Meat Industry Forum
SC	Supply Chain
SSC	Sustainable Supply Chain
SCM	Supply Chain Management
SD	System Dynamics
TOE	Technology-Organisation-Environment
TBL	Triple Bottom Line
UK	United Kingdom
UI	User Interface

CHAPTER ONE: INTRODUCTION

1.1 Research Background

Supply chain is a wide and broad term from the perspective of business world and organisational procedures. It is explained as a network of goods, information, and services in accordance with supply and demand of the organisation (Min *et al*., 2019; Calignano and Mercurio, 2023). In the food industry, products and services are produced to meet the needs and requirements of people. Food supply chain management operates and assures food safety and quality through effective ways of production, distribution, and consumption. Food supply chains are distinct from other supply chains because of their complexity and difficulties in administration and management. There are many factors that contribute to the complexity of supply chains, such as food safety, food quality, traceability, and freshness of food products. Technological breakthroughs and advancements such as Robotic Process Automation (RPA) refer to the deployment of software robots or "bots" to automate highly repetitive and routine-based tasks that are typically performed by human workers. RPA is considered as a powerful technological tool to streamline complex business processes and enhance supply chain performance to achieve sustainable value. RPA has brought about significant improvements, enhancements, and advancements in food supply chains by automating operations in food processing, manufacturing, packaging, and storage. Technology plays a vital and important role in ensuring production of food which has great nutritional value, health benefits and quality for greater and enhanced customer satisfaction. Food supply chains constantly strive to make their business processes faster and efficient to satisfy the consumer demand and gain competitive advantage in a fast-paced market. There are various complex manufacturing processes or practices in the food supply due to which it demands careful control and effective monitoring and evaluation (Zhong *et al*., 2017; Annosi *et al*., 2021). Food supply chains are difficult in terms of handling as they require vigilance, constant monitoring, and critical observation. This is because the supply of food is related with human health and consumption which makes it challenging to manage and control.

According to Singh and Raghuram (2017) supply chains have emerged over a period in terms of logistics, management, monitoring, technological adoptions and use of innovative strategies, product development and delivery and consumer satisfaction. The emergence and progress of business practices in supply chains has been through enhanced globalisation, value addition, competitive advantage, modernisation, and technological advancements in organisations. The competition in supply chains is the driving force for organisations to adopt innovations, innovative trends, greener production and efficient resource allocation and utilisation techniques (Hou *et al*., 2019).

Sustainability remains a challenge for supply chain systems and thus has gained valuable consideration and attention in this era of globalisation and competition. Businesses strive to achieve sustainable value from the three dimension i.e., social, economic, and environmental to add value to their business procedures. The emerging market trends suggest that sustainability in business operations can enhance organisations competitiveness through efficient use of materials and information and could potentially increase and improve employee-level motivation and satisfaction. This is because availability of advanced technology to support business processes simplifies tasks and reduce their complexity thus enhancing employee-level improvements. Moreover, technological innovations also pave way to achieve sustainability agendas and enhance operational and financial efficiency of supply chains thus making them more resilient and economical. The progression and development in supply chains have made them more advanced, fast-paced in production, well-coordinated and integrated and sustainable in process delivery and product development. Supply chain operations in the past faced challenges in satisfying the consumer demand and producing sustainable products; the advancements and fast adoptions of technology and wide range of technological choices have developed resilience in business procedures and practices. To achieve sustainable development in supply chains, there are various factors to be considered such as monitoring mechanisms, innovations and technological adoptions and collaborative interactions. Manufacturers seek to achieve green production and invest in sustainability or sustainable solutions like advanced technology or innovations, to gain competitive edge and add value to their business processes thus making processes less complex, challenging, and simpler (Li and Li, 2016; Deng *et al*., 2020).

Abideen et al (2021) further explains that food supply chains like the beef sector have developed and grown in a great degree because of the implementation of different technologies adopted to speed-up the supply chain processes, reduce human error, and risk factors and enhance consumer satisfaction. Technological innovations like RPA help in improving work-flow management systems, improve accuracy, and reduce costs by automating routine, rule-based tasks. By deploying software robots to handle these tasks, organisations can free up human workers to focus on more complex and strategic activities, thereby enhancing overall productivity and efficiency. RPA adoption enables food networks to be more proficient, sustainable, and fast-paced in production by automating tasks. The emergence of such technological choices and practices results in efficient, productive, and safe food supply from the perspective of human consumption. Food safety, security and quality is a constant concern and challenge for the food supply chains such as the beef market and technological implementation enhances quality food production and service. Achieving sustainability in food supply chains can enable organisations to gain social, economic, and environmental benefits (Patterson *et al*., 2003; Adams *et al*., 2021). Therefore, it is highly crucial for food manufacturing supply chains to adopt technological trends and practices like RPA to enhances their business operations and achieve sustainable value.

The beef manufacturing supply chains are crucial to understand in terms of their dynamics and characteristics (Chen *et al*., 2021). Firm and detailed understanding of the supply chain processes in beef manufacturing allows successful adoption and implementation of technology such as RPA. Beef supply chains constantly face challenges associated with management and monitoring, satisfying the consumer demand, operational risks and time and efforts consumed in beef processing. These challenges have an impact on the beef production levels, operational costs and health and hygiene concerns in beef processing. It is highly important to solve these problems and so technological adoptions like RPA can improve supply chain performance, reduce operational costs, and enhance beef safety, shelf-life, and quality. However, RPA full adoption remains a challenge due to the presence of potential risks in its adoption. RPA is an innovative technology which can potentially facilitate business operations, make supply chains less complex and help the beef sector to meet sustainability standards and produce high quality, safe and healthy beef for human consumption. Though as highlighted above, there are still challenges to its successful application which requires attention and focus.

The research allows decision-makers and mangers to prevent the potential risks in RPA adoption within beef supply chains thus paving way for sustainable beef production for human consumption. The study has been conducted in the United Kingdom considering the complex beef supply chains in the region which require smooth RPA implementation and adoption process to meet the growing sustainability, costs, and health and hygiene concerns. The geographical scope of this simulation study in the specific domain focuses on United Kingdom and includes regions that are England and Wales, Scotland, and Northern Ireland. The difficulties and obstacles related to sustainable beef production are growing because of the UK's extensive, complicated, and multi-player beef supply chains. Hence, this research focuses on the UK beef sector and concentrates on preventing the potential risks in RPA adoption within the respective geographical domain.

1.2 The importance and role of technological advancements in supply chains

The increasing role of technology and innovative ideas has been a game changer in business operations and processes. Advancements in technology have reduced the production times along with revolutionising the way in which organisations perform business activities in a progressive economy. The nature of business at present demands efficient interactions between organisations and its consumers. Enhanced interactions between the businesses and consumers allow provision of services in an effective manner and this helps gain competitive advantage. Moreover, understanding the fast-paced market culture and needs and requirements of the consumer helps to adopt the most suitable technology within supply chain systems. Technological advancements within businesses allows to strengthen supply chain systems and enhance synchronisation and coordination of business processes (Kandampully, 2002).

Supply chain systems are facing complex internal and external environments due to globalisation, digitalisation, innovative competitors, and technological evolutions. Given the fast-paced business environment, it is a constant struggle for organisations to improve their business efficiency and performance levels to survive in the market. In such aspect, it is highly important for firms to create and maintain competitive advantage through technological incorporations and adoption in business processes. It is therefore crucial for firms to adapt to fast-based business culture and implement innovative ideas and strategies for enhanced supply chain performance and excellence (Arlbjørn *et al*., 2011; Malacina and Teplov, 2022).

Cappellesso and Thomé (2019) highlights the role of technological innovations and the benefits it can bring to improve supply chain procedures. It is significantly important for businesses that seek value addition, competitive advantage, and sustainability to adopt new technologies in an efficient manner. The use of technology can improve managing system functions and support in efficient monitoring and controlling of business processes which can potentially reduce operational costs and increase production levels to satisfy growing demand. This impacts and improves the organisation's competitive advantage. Moreover, advanced technologies have increased demand and inventory visibility and facilitated communication systems between firms and customers. The emergence of new technologies such as RPA, 3D scanning, Artificial Intelligence etc have changed the face of business environments and enhance supply chain resilience and efficiency. The technologies also emerge to drive sustainable business management and handle supply chain issues and challenges. Technological adoptions and sustainability oriented innovative strategies enhance firm's performance levels and capabilities to alleviate risks in supply chains. Hence, supply chains have benefitted immensely from emerging technologies and gained competitive advantage by enhancing supply chain processing and improving production systems (Cappellesso and Thomé, 2019). Supply chain systems sometimes face certain risks to the adoption of technologies such as lack of technical expertise and experience, lack of flexibility towards new adoptions, lack of innovation capabilities and R&D etc. The manufacturing industry constantly seek for solution to these challenges and risks so that technology can be adopted with its full potential and firms could potentially gain operational and strategic goals. Hence, supply chain innovation strategies and practices are being widely focused by business owners to achieve sustainability goals (Gupta *et al*., 2020).

According to Dong et al (2021), achieving high-economic growth and meeting financial objectives is important for day-to-day functioning of supply chains; however, protecting the environment and adding social value to business processes is also crucial at present times. Technological advancements have allowed data mining, simulation and optimisation of supply chain processes thus enabling business owners to alleviate risk events in real-life scenarios. Technology plays a vital role in addressing prevailing concerns such as pollution, mental and physical health, resource efficiency, operational efficiency, and production costs. Food supply chains have complex business systems which require efficient management system and monitoring. The use of technological adoptions like RPA can ensure process excellence and provides other promising benefits that improve organisational, financial, and employee-level efficiency (François *et al*., 2022).

McClements (2021) explains that the modern food supply chains are complex and difficult in management and thus face many challenges. The population continues to grow and so the demand for food products also seems increasing with progressing time. Production of high-quality food with minimal damage to society and environment is prioritised in the food sector. The highly integrated food supply chains are susceptible to risks and disruptions such as economic stress, natural disasters, policy changes etc. Considering such challenges, innovative ideas and strategies and technology can help improve supply chain operations and functions. Pertinent technological advancements such as RPA improve supply chain stages such as farming, manufacturing, distribution, and consumers. Such technological adoptions improve quality, safety, nutrition, and sustainability with regards to food supply. Incorporation of technologies ensure resilience, efficiency, and coordination in food production systems (McClements *et al*., 2021; Kazancoglu *et al*., 2023).

The food supply chains face considerable sustainability issues and therefore concern food producers, policy makers, manufacturers, consumers, and researchers who remain interested in mitigating these challenges (Kumar *et al*., 2024). Practical challenges in real-life working environments such as maintenance of food quality, hygiene concerns, environmental safety, financial aspects, product traceability, social issues etc., are prevailing and crucial worries for food manufacturing supply chains especially post the COVID-19 pandemic (Aday and Aday, 2020; Paciarotti and Torregiani, 2021). Due to their increased knowledge, consumers now want access to up-to-date, real-time information about the foods they consume via digital media. Additionally, consumers are becoming more and more inquisitive about whether the food they eat is sustainable in terms of both the environment and society. For this reason, food manufacturers, distributors, retailers, and farmers now have serious concerns about food product traceability, safety, and sustainability. Other significant challenges the food supply chain faces include identifying creative logistics strategies and creating dynamic supply chain systems that may increase customer satisfaction and enable stakeholders to be profitable. These issues are brought on by advancements in technology, heightened competition, and profit-driven business agendas combined with creating sustainable value (Gholian-Jouybari *et al*., 2024). However, supply chain digitalisation has greatly improved and allowed food supply chains to be progressive, well-integrated, responsive, resilient, and efficient thus benefitting and contributing towards sustainable food production (Kittipanya-Ngam and Tan, 2020). Cloud data solutions, simulation techniques, well-integrated systems, smart packaging, technological applications, and several other sustainability-oriented strategies have revolutionised food sector and allowed higher productivity and efficiency levels (Chen *et al*., 2020). The deployment of advanced machinery, and smart technologies has paved way for green and sustainable production where food manufacturing supply chains can prevent potential risks, reduce food loss, and waste, and minimise the environmental impact caused due to food production. Food supply chains at present times in real-life scenarios, are implementing waste recovery practices and smart packaging techniques within the food sector to meet the sustainability criterions and to also contribute positively to social and environmental domain (Ciccullo *et al*., 2021; Krishnan *et al*., 2020).

The beef supply chains play an important role in producing meat for human consumption and contribute towards global beef demand from the perspective of customer. The beef supply chains have been a late adopter of technology and mainly have been manual or human centric due to complex supply chain processes (Mishra *et al*., 2016). Meat represents important sources of nutrients for human consumption like proteins, fats, iron, phosphorus, magnesium, vitamin B6, vitamin B12 etc and so remains high in demand for consumption. The beef supply chains are widespread and have many layers of business procedures and practices due to presence of various complex stages. Beef supply chain is mostly manual centric, hence satisfying the consumer demand has always been challenging. Technological advancements in beef sector play a vital role in beef supply chain management and improve beef production and processing. Innovations in beef supply chains allow tasks to be completed with less complexity and technological implementations ensure safe, healthy, and nutritious beef productions. Technology integration in beef manufacturing lines also reduce beef waste and human error while improving management and decision-making capabilities of business owners (Greenwood, 2021).

1.3 RPA adoption as a sustainability booster: The context of Beef Supply Chains

The beef supply chain system is widespread, fragmented, and large with regards to system management, monitoring and controlling. This is because it comprises of complex and difficult stages which are challenging with respect to their management. Due to globalisation and growth in population there is increasing beef demand which needs to be addressed. The beef supply chain struggles to satisfy the growing consumer demand and produce sustainable beef for improved customer satisfaction. However, as the beef supply chain is a late adopter of technology, hence it is challenging to implement innovation techniques within supply chain processes. Adoption of innovative technologies helps organisations in improving managerial practices and enhance decision-making skills of stakeholders. It is highly important to effectively monitor the different stages of beef supply chain such as slaughtering, cutting and boning, packaging, storage, and distribution. All these stages are essential with aspect to efficient planning and controlling as beef production is dependent on them.

RPA has gained a lot of attention, focus and interest as the facility of software bots provides the opportunity to perform strenuous, rule-based, and repetitive tasks that were previously performed by humans. The transformative innovation allows maximised revenue generation through task automation and solve operational issues such as high work volume, employee shortage, high operational costs, and other supply chain complexities. RPA has revolutionised business processes and manufacturing in supply chains such as the beef industry and facilitates optimum workflow to ensure streamlined business operations, increased productivity, and cost-effective procedures (E-Fatima *et al*., 2023). The innovative technology is a game changer in the manufacturing supply chains as it efficiently addresses long-standing obstacles. As beef production requires critical handling and monitoring, hence, the adoption of RPA technology makes the supply chain stages less complex and difficult to deal. The beef sector is now focusing and showing interest on innovations and technological adoptions like RPA as it performs repetitive tasks and simplifies business processes thus enhancing organisational and employee-level efficiency. The adoption of RPA technology in beef supply chains enhances production systems with respect to time, effort, and finances. RPA provides process excellence and reduces operational costs by minimising time and human efforts thus creating sustainable value. Moreover, organisational culture and its distinctive dynamics play a vital role in the adoption of RPA and can potentially transform businesses (E-Fatima *et al*., 2022).

Lynch et al (2022) shed lights on sustainability-focused innovation, which has been a topic of debate within the beef sector due to the complex management and attributes of its supply chains. Recently, the beef supply chain has faced many challenges related to human health, animal welfare, biodiversity, greenhouse gas emissions, quality, shelf life and high costs of beef production. The beef industry seeks to implement sustainable approaches and solutions to cater to all these problems and to gain sustainable beef production for human consumption. Achieving sustainability remains a multi-dimensional issue within the beef supply chain and it requires attention and focus. This is because the structure of the beef supply chain is broad and wide-spread, and its procedures are not fully automated due to their individual complexities. Therefore, the supply chain still requires human involvement and handling. The use of RPA in the beef sector allows tasks to be automated, less complex, and improve beef quality and safety. RPA also enables organisations to enjoy long-term financial and social gains by reducing operational costs, minimising beef wastage during processing, and preventing any accidents or environmental hazards. Innovative efforts such as RPA could bring socio-economic gains and help business owners gain a sustainable competitive advantage in beef production and processing (E-Fatima *et al*., 2023).

The beef supply chain faces significant challenges and disruptions due to a complex and vast management system which involves several players. The production and manufacturing of beef involves issues related to environmental threats, worker safety, greenhouse gas emissions, beef loss and waste, cold working conditions, labour shortages and other supply chain risks which have an adverse impact on the beef supply chain system (de Camargo Barros and de Almeida, 2024). The pandemic has also strained the beef supply chains and the stakeholders in the respective sector due to issues such as plant closures, high operational costs and health and safety concerns. As the supply chain is demanding and difficult in terms of management and control due to harsh working environments, health and safety risks, and vulnerability therefore meeting sustainability goals along with high operational efficiency has become considerably challenging for beef manufacturers at present times (Sumrow *et al*., 2024). According to Choma *et al* (2024) red meat production remains one of the prominent sources of greenhouse gas emissions such as carbon dioxide gas. Therefore, the beef sector requires intervention and implementation of innovative strategies to lower the environmental impact caused by beef production and reduce high operational costs associated with it. As greenhouse gas emissions have a negative and destructive impact on climate change, therefore researchers suggest an average person to lessen by 75% on beef consumption and alternatively gain energy from other food sources (Choma *et al*., 2024). Moreover, a recent study conducted by the Department for Environment, Food and Rural Affairs (DEFRA) also highlighted and found that beef waste and loss during its production and manufacturing stages remains a prevailing and critical challenge for beef supply chain in the UK. The study also claimed that in the United Kingdom around 20-31% of beef goes to waste due to packaging issues. Therefore, sustainable packaging to ensure beef freshness and quality is also crucially significant for beef manufacturers to avoid health, safety, and quality issues. Beef waste due to supply chain disruption and inefficiencies not only negatively contributes to social hazards but also has high environmental concerns due to increasing landfills (Kohli *et al*., 2024). Technological solutions like RPA not only revolutionise production systems, but also ensure higher operational efficiency levels, lower production costs and reduced environmental and social issues caused by beef production (Rejeb *et al*., 2024; Kumar *et al*., 2024).

To summarise, RPA emerges as a strategic catalyst to create sustainability through process automation which allows organisations to be cost effective in business procedures and enhance operational and financial efficiency thus adding value to the supply chain networks. RPA enables digital transformation and improves process delivery by facilitating routine-based, strenuous tasks which are performed by software bots (Schmitz *et al*., 2019). The adoption of RPA in beef supply chains could help reduce bottlenecks at different, complex stages of the supply chain such as slaughtering stage, cutting stage, fat trimming and packaging stage. These respective stages comprise of boring tasks and the incorporation of RPA can potentially reduce human error in beef production. The adoption of RPA can also benefit the supply chain other important aspects such as ensuring faster production line with less human handling thus leading to safer and nutritious beef production with longer shelf-life. As RPA reduces and replaces human workforce, thus this also minimises the chances of beef contamination and beef wastage due to less human intervention and handling. Minimum human workforce working on the processing line reduces human error and risk factors such as beef contamination and waste produced; also, it enables humans to rather work on judgement or skilled-based jobs which reduces human exertion. RPA adoption also enhances employee-level satisfaction as they could potentially focus on other monitory or skilful areas which require judgement and analytical capabilities. Given that RPA offer a lot of benefits to the beef supply chains by enhancing its functionalities and provides competitive advantage thus creating sustainability; it also has potential risks to its adoption which require immediate attention and focus. There are potential risks and factors that hinder its full adoption. It is crucial for beef supply chains to adopt RPA with its full potential and alleviate any operational or financial risks in its adoption process. Successful RPA adoption and incorporation allows businesses to enjoy its full services and gain enhanced performance levels and accuracy (Bu *et al*., 2022; E-Fatima *et al*., 2022).

1.4 The significance of research

This research project focused on the role and impact of RPA adoption in beef supply chains from sustainability lens. The emergence of RPA technology has improved business processes as bots perform tedious, repetitive, and strenuous tasks thus reducing human error, effort, costs, and time (Farinha *et al*., 2024). The revolutionary RPA technology facilitates complex supply chain systems as a sustainability-oriented tool that automates manual, strenuous, and rule-based tasks and help in reducing supply chain issues by making them more resilient, viable and well-synchronised (Fernandez *et al*., 2024). However, full utilisation and adoption of the emerging RPA technology remains a challenge for beef manufacturing supply chains due to considerable risks in its deployment which require attention and focus. Literature in the past mainly focuses on the emergence of RPA technology and its key capabilities, however no thorough assessment has been conducted previously regarding its potential risks in beef supply chains which creates a research gap (Kakade, 2024; Payal *et al*., 2024). Therefore, this doctoral study focuses on the adoption process of RPA and its impact on the beef supply chains from sustainability aspect. It further assesses the role and significance of RPA implementation in beef supply chains. The research also carried out investigation and identification of the potential risks in RPA adoption in beef supply chains. The existing literature relevant to beef supply chains and RPA adoption was used in this research to provide an in-depth understanding and analysis of the research topic and solve the research problem amicably. The findings of the research significantly contribute to the existing scientific knowledge by creating detailed and thorough understanding of the role of RPA in beef supply chains along with focusing on its adoption process. The findings and results also observed the aspect of sustainability and how RPA adoption served as a value addition in beef supply chains and met sustainability standards by enhancing beef production, quality, and efficiency. The research offers a business process model to practitioners to adopt the emerging technology in a robust manner within their business environments. The process model provides stakeholders with the opportunity to adopt a more systematic and strategic approach for RPA implementation in beef supply chains and improve supply chain processes. The doctoral project used a simulation method to analyse different scenarios through the development and assessment of a business process model in Simul8 software. The study supports the beef supply chains through the identification of potential risks in RPA adoption and provided the opportunity to the stakeholders to alleviate these in advance. The simulation analysis was also seen from the lens of sustainability through process simulation. The simulation to process model helped in identifying the potential risks in RPA adoption and detect the risk factors present at various phases of beef supply chain. This helps organisations to achieve strategic, economic, and operational goals by eliminating the risk factors. The scenario testing and analysis through simulation of beef supply chain also allows organisations to meet their sustainability goals and agendas and gain a competitive advantage through robust adoption of RPA technology. As an outcome of this study, the proposed business process model helps the beef supply chains to identify the possible risks and alleviate them in advance, hence enhancing and improving the RPA adoption process. This enables beef supply chains to adopt RPA within their working environments in a robust manner and increase beef safety, quality, and security. RPA efficient adoption process through elimination of risks beforehand also allows business users to enhance beef productivity and capacity and cut down high operational costs. The business process model presented and proposed in this research has been generalised for use in real-life scenarios and can be utilised or modified by business owners or stakeholders as per their own business needs or requirements. The successful adoption of RPA allows beef supply chain to be more sustainable, viable, well-coordinated, integrated, and efficient in terms of their operations and functionalities. RPA also serves as a sustainability driver in beef supply chains and its successful adoption allows beef supply chains meet their sustainability goals and reduce costs, energy, and time to manufacture and produce high-quality, nutritious beef.

1.5 The research rationale

The rationale of conducting this study was to support the beef industry by offering a generic process model which can be used by managers, decision-makers, and stakeholders for effective and robust adoption of RPA in beef supply chains. The proposed business process model has been designed in a simple and standard manner and generalised for use within beef supply chains. The model can be modified according to the needs and circumstances of organisations or business users in the beef business. Over the past years, a lot of interest has been taken in the adoption of RPA in the beef supply chains (Kamal *et al*., 2024; Suriyan *et al*., 2024). However, research in the past lack exhaustive evaluation and investigation of the potential risks in RPA adoption within beef supply chains (Lahtinen *et al*., 2023). As evident, there is a gap in research which requires thorough investigation hence this research focuses on the detection of main bottlenecks in RPA implementation and assesses its potential from sustainability aspects within beef supply chains. This research is unique and significant as it evaluates different scenarios to identify the potential risks in RPA adoption beforehand, using Simul8 simulation software. Also, the study is distinctive in its approach as it assesses 'what-if' scenarios from sustainability perspective. Moreover, the study also examines the role and impact of RPA in beef supply chains from sustainability dimensions and identifies the potential risks for efficient adoption of RPA technology. The study findings contribute to academia and practitioners as it investigates the risks in RPA adoption in beef supply chain and allows managers to utilise the process model for effective RPA adoption and meet sustainability criterions in beef production. Enhanced RPA potential allows beef supply chains to achieve strategic, financial, and operational goals and alleviate possible risks in terms of beef quality, safety, security, and costs. Successful adoption process of RPA also allows business organisations to create sustainable value in beef processing and production. It further makes supply chains more efficient and enable increased beef production at low operational costs. This research employed a simulation method to analyse the adoption of RPA in beef supply chains, developing assumed scenarios and considering significant parameters like beef capacity, shelf-life, safety, and financial aspects. Assumed scenarios were developed and tested using Simul8 software to evaluate RPA's potential in creating sustainability and detect bottlenecks across the beef supply chain system. The study aims to enhance managers' decision-making skills in the competitive global beef market by streamlining RPA adoption, reducing supply chain complexity, and improving operational and financial efficiency. This facilitates meeting sustainability goals and gaining a competitive edge through value addition.

The research also guides stakeholders and managers in the business in adopting RPA efficiently to increase production, meet quality and safety standards, and reduce operational costs, ultimately leading to more efficient, resilient, profitable, and sustainable beef supply chains. Therefore, the rationale behind this research was to ease the adoption process of RPA so that its services and facilities can be fully utilised to reduce supply chain complexity and enhance operational, functional, and financial efficiency.

1.6 Problem Definition and Research Aim and Objectives

The beef supply chain has been challenging due to its complex processes, activities, and management. The beef industry has relied heavily on the human workforce in the past and has been a late adopter of technologies such as the RPA. However, fast-paced market and innovate trends in business operations have created more awareness within the beef market it has progressed in technological adoption like RPA in present times. A lot of interest has been taken in the adoption of RPA within UK beef supply chain to deal with constant challenges in beef production like quality, safety, and security of beef. To deal with health concerns in beef production, economic benefits and environmental and social gains, the beef market strives to adopt RPA in a successful manner for efficient process delivery. However, there is no thorough assessment of the potential risks in RPA adoption within UK beef supply chain, which creates a literature gap. This literature gap contributes to both practical and academic aspects as it examines and identifies the hinderances in RPA adoption within UK beef supply chain. Therefore, in-depth study and analysis was done in this research to investigate the potential risks or hinderances and enable successful adoption of RPA and overcome the possible risks. The solution to this problem offers support to the beef supply chains to achieve strategic, operational, and financial goals and alleviate possible risks in terms of beef safety, quality, shelf-life, and costs in real-world situations through efficient RPA adoption process. It further enables identification of risks in RPA adoption, at early stages of the beef supply chain process. A business process model was proposed as the outcome of this research which eases adoption process of RPA in UK beef supply chain and provides an opportunity to the beef manufacturers or business users to meet sustainability gaols through sustainable beef production. The simulation approach to analyse and test 'what-if' scenarios also helped to detect the main bottlenecks in the beef supply chain stages in this simulation study. The simulation analysis conducted in this research provides the opportunity to business owners to pre-plan and alleviate all risk elements in real-life, practical environments. Moreover, simulation approach in this study evaluated the supply chain performance through testing of different scenarios and offered the best approach to adopt RPA to the beef industry. The solution to research problem improves the decision-making and management in real sense and provides advantages in practical aspects to the beef supply chain. The proposed process model has been presented as a business solution that allows the business owners to have a firmer and detailed understanding of the beef supply chain stages and further assessment to this allows them to evaluate where RPA is best suitable for process delivery and excellence. It further provides the opportunity to have a better understanding of the nature of RPA and in which business environment and setup it works and performs best. The process model also allows business users to conduct a thorough analysis on the costs and business operations and choose the best approach in RPA adoption within beef supply chains. The proposed process model helps improve the adoption process of RPA through identification of risks in advance and allows decision-makers or stakeholders to achieve sustainable value and gain competitive advantage in the production and processing of beef within the beef industry.

To further explain and describe, this doctoral project aimed to critically examine and investigate the potential risks in the adoption process of RPA to meet sustainability criterions within the UK beef supply chains.

This aim included and focused on the following objectives:

1. The role of RPA within UK beef supply chains from sustainability aspect.

2. The impact of RPA adoption in UK beef supply chains, focusing on its role from a sustainability perspective and broader environmental aspects.

3. The potential risks in the adoption process of RPA within UK beef supply chains.

4. Providing recommendations to the UK beef sector to effectively adopt RPA to achieve sustainability objectives.

1.6.1 Research Questions

The researcher used a pragmatic philosophical position and a simulation-based approach to answer the following research questions:

1. What is the role and impact of RPA adoption in UK beef supply chains from sustainability aspect?
2. What are the potential risks in the adoption of RPA and how can they be avoided or eliminated within the UK beef supply chains to create sustainable value?

The research findings shed light on the pivotal role of RPA within beef supply chains, particularly in enhancing sustainability efforts in beef production. By offering insights into RPA adoption processes and its impact, the study aids both researchers and practitioners in understanding how this technology can streamline supply chain tasks and contribute to sustainability goals. Decision-makers and stakeholders can leverage the study's recommendations to implement RPA effectively, optimising processes and mitigating potential risks. Through scenario analysis, the research also identifies risks and bottlenecks, enabling proactive measures to ensure smooth RPA adoption and maximise its benefits. The adoption of RPA not only enhances operational and financial efficiency but also promotes safer, healthier, and higher-quality beef production by reducing human error and energy costs. Overall, successful RPA integration accelerates supply chain processes, enhances cost-effectiveness, and generates sustainable value across social, environmental, and economic dimensions. Additionally, the research offers comparative insights into how RPA-driven innovations propel beef supply chains towards greater sustainability and integration, addressing prevailing concerns in the sector.

1.7 Contribution to academic knowledge

The beef market aspires to successfully implement RPA for achieving sustainable value to address quality, safety, and financial concerns in beef production. However, there is a gap in research regarding the potential risks to the adoption of RPA in beef supply chains. Previous studies also lack critical assessment on RPA's facilitations to meet sustainability agendas and produce safe beef in beef supply chains. This study used simulation method to identify the main bottlenecks and risks in RPA implementation in beef supply chains and evaluated different scenarios from sustainability lens, which has been lacking in prior studies. The simulation study also assessed different scenarios to investigate the role and impact of RPA in beef supply chains from the three dimensions of sustainability that are social, economic, and environmental. The research findings contribute to academic knowledge as it provides insights and information regarding the adoption process of RPA in beef supply chains. The research findings are important for the successful adoption of RPA in the beef industry since they provide decision-makers with the knowledge to remove or prevent potential risks, thus advancing and accelerating RPA adoption. The findings of the simulations study are significant as they support decision-makers to adopt RPA systematically and achieve sustainability goals. In the past, limited studies and literature has focused on the factors or parameters that influence the adoption process of RPA within beef supply chains to create sustainable value. In this research, different scenarios were tested based on various parameters that impact RPA adoption in beef supply chains and the main bottlenecks or risks were identified using process simulation, thus contributing to scientific knowledge. The research findings also advance knowledge in academia by highlighting the socio-economic advantages of RPA adoption and its potential benefits for process excellence to create sustainable value. The simulation findings contribute to academic domain as assumed scenarios were tested and assessed from sustainability lens to analyse RPA's capabilities in aiding beef manufacturers to produce sustainable, safe, and high-quality beef for human consumption. Successful RPA adoption can help beef supply chains to produce high quality, safe and nutritious beef for human consumption at low operational costs through removal of risks.

1.8 Contribution to professional practice

The research findings also contribute to practical aspects by supporting the beef manufacturers who aim to achieve sustainability in beef supply chains. The research proposes a generic business process model that managers or decision-makers can adapt and apply in accordance with their own business demands and requirements. The process model can be generalised for application in practical aspects in beef supply chains. The study findings can be utilised to enhance ethical decision-making and management skills of stakeholders and managers and increase the ease, potential, and accuracy of adopting RPA. The proposed business process model allows robust RPA adoption through identification of potential risks in advance and enables beef supply chains to adopt RPA using the best approach through removal or prevention of risks beforehand. This enables beef manufacturers to gain operational, financial, and employee-level efficiency and gain competitive advantage in beef supply chains. Efficient RPA adoption also facilitates managers and provides them the opportunity to produce sustainable beef at low operational costs and meet sustainability standards, which is a constant concern for beef supply chains in present times. The research findings also provide decision-makers, who frequently deal with financial and operational challenges, the opportunity to undertake an exhaustive cost analysis and alleviate any financial risks in RPA adoption. The study findings also shed light on the costs related to the implementation of RPA and supply chain operations using simulation-based approach. Identification and alleviation of potential risks accelerates the adoption of RPA and helps beef manufacturers to increase beef productivity, capacity, quality, and shelf-life and produce sustainable beef at reduced operational costs. The beef industry benefits from efficient RPA adoption in terms of competitive advantage, sustainability, and enhanced supply chain resilience. This research also offers potential future options for study in this specialised domain and field, and this has been discussed in detail in chapter seven.

1.9 Research Motivation

The beef supply chain, with its complex processes and reliance on human labour, has been slow to embrace technological advancements like RPA (Kamalapuram and Choudhury, 2024). However, as market dynamics evolve, there's a growing recognition in the UK beef industry of the benefits of adopting RPA to address various production challenges such as quality, safety, and security. RPA is viewed as a solution to improve health standards, enhance economic outcomes, and promote environmental and social sustainability (Franceschetto *et al*., 2024; Kamal *et al*., 2024). Despite this emerging trend, a comprehensive assessment of the risks to RPA adoption within the UK beef supply chain is lacking, indicating a gap in current literature (Vern *et al*., 2022; Willcocks *et al*., 2024). With an increased interest and aim to fill this gap, the researcher adopted a simulation-based approach to address this and conduct thorough investigation. Furthermore, the researcher's interest in understanding how sustainability-focused innovations can enhance the effectiveness and efficiency of beef supply chains prompted a comprehensive investigation into the adoption process of RPA. Given that RPA addresses three key dimensions of sustainability, it serves as a compelling driver for the researcher to delve deeper into the subject and uncover its complete potential within beef supply chains, given that there is gap in previous research within the domain which requires attention. Addressing the identified gap in literature allows stakeholders in the beef business to adopt RPA with greater ease and potential. RPA robust adoption also decision-makers to be more strategic, systematic and ensure production of sustainable beef for human consumption. Utilisation of RPA's full potential also supports managers in beef supply chains to meet sustainability goals and create value in beef production and manufacturing processes.

This research was thus a motivated attempt to critically investigate the role and impact of RPA in beef supply chains. The study detected the main bottlenecks in RPA adoption. Identification of potential risks was essential to adopt RPA successfully, at its full potential. The associated challenges and complexities of beef supply chains makes it crucial to adopt RPA in a robust manner to support business operations, reduce risks and speed-up processing line. The research findings provide support to practitioners and managers in beef sector and allows them to implement RPA systematically and gain maximised benefits of the innovative technology. The researcher's motivation behind this research was to support stakeholders' decision-making and managerial competencies so that they can produce high quality, safe and nutritious beef at low operational costs by adopting RPA smoothly and successfully. The solution to the research problem enables organisations to achieve sustainability in the three dimensions and gain competitive advantage by adopting the best approach to RPA implementation.

1.10 Thesis Structure

The **Chapter 1** provides a detailed overview of the research background, focusing on beef supply chains and technological advancements like RPA. It discusses the significance and rationale for the study, addressing research gaps and emphasising the importance of filling these gaps in the literature. The chapter outlines the research aim, objectives, and purpose, along with the development of research questions for the simulation study. Furthermore, it discusses the study's positionality and motivation behind an in-depth exploration of this topic.

The **Chapter 2** presents a comprehensive literature review, structured around thematic analysis, exploring the adoption of RPA in beef supply chains. It includes a concept map outlining themes and sub-themes related to RPA adoption. The review covers supply chain systems, trends, and forecasts in the beef industry, as well as the role and impact of RPA technology. It discusses how RPA has evolved within supply chain systems, improving task performance, and creating sustainable value. The review emphasises sustainability-oriented innovations like RPA, highlighting their potential to help beef supply chains meet sustainability goals and gain competitive advantage. Furthermore, it examines the criteria and factors influencing the adoption of RPA in beef supply chains, providing a systematic overview of relevant aspects.

The **Chapter 3** introduces the theoretical framework employed in the research, focusing on the Technology-Organisation-Environment (TOE) framework. It elucidates the significance and suitability of TOE in addressing the research problem and filling the identified research gap. The chapter highlights the key parameters and theoretical propositions derived from the TOE framework, crucial for understanding RPA adoption in beef supply chains. It discusses theoretical concepts pertinent to RPA technology and its implementation in the beef industry. The chapter also explores how TOE framework is utilised to assess the role and impact of RPA from sustainability perspectives and to identify potential adoption risks. Overall, it emphasises how TOE framework guides the research process, aids in answering research questions, and facilitates the achievement of study aims and objectives, providing clarity for the subsequent research methodology.

The **Chapter 4** outlines the research methodology, approach, and design adopted for this study. It emphasises the choice of simulation-based research utilising secondary quantitative data for analysis. The research philosophy is pragmatic, aligning with the ontology, epistemology, axiology, and research strategy employed. The rationale for selecting simulation method and Simul8 software for process model development is explained, along with the utilisation of 'what-if' scenarios for simulation testing. The chapter details the resource inputs and discusses the approach towards sustainability through scenario analysis, focusing on social, environmental, and economic value addition.

The **Chapter 5** presents the results and discussions derived from simulating the business process model using Discrete-Event Simulation (DES) technique, specifically tailored for food supply chains like beef. It analyses and tests various scenarios based on different parameters influencing RPA adoption in beef supply chains, identifying potential risks and bottlenecks through 'what-if' scenario analysis. The chapter also thoroughly discusses simulation results, evaluating operational, financial efficiency, and supply chain performance by adjusting resource inputs. It compares simulation findings with previous studies, emphasising the unique contributions of this research. The discussion on the simulation results also focuses on how RPA adoption adds value and positively impacts beef processing sustainability across social, economic, and environmental dimensions. It outlines findings related to beef quality, safety, operational efficiency, shelf-life, and costs, highlighting the significance of automation in the beef sector.

Chapter 6 concludes the study by summarising the research, focusing on the sustainability perspective of scenarios and simulation results. It addresses the research questions and how they align with the study's aim and objectives. The chapter discusses the contribution of the study to academic knowledge and professional practice, proposing a standard business process model for robust RPA application in real-life scenarios. It highlights the identification of potential risks in the adoption process and acknowledges limitations while providing recommendations for future research. The chapter reflects on the motivation behind the research and concludes with a summary.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Literature review is one of the essential components of a successful research process (e.g., Torraco, 2016; Hart, 2018; Snyder, 2019). A literature review can be defined as a systematic and explicit design for evaluation, identification and analysation of existing knowledge and recorded documentation. Literature review aims to summarise and interpret research in a specific direction thus identifying research gaps to contribute to the research and theory (Seuring *et al*, 2005; Bhamra, 2011; Jaakkola, 2020). In addition to contributing to new interpretations of previous research, the literature review plays an important role in the research. (Kraus *et al*., 2021). It also helps in understanding the research problem and work in that direction. Also, it aids in resolving conflicts and differences amongst previous research which are contradictory (Cooper, 1998; Evans and Kowanko, 2000; Webster and Watson, 2002).

This study conducted a thematic narrative literature review, a type of review that offers current insights into a specific theme or topic. Unlike systematic reviews, which follows a structured approach, thematic narrative reviews provide a qualitative analysis. They play a crucial role in research by updating researchers on relevant themes and emphasising the significance of new studies (Snyder, 2019). Thematic narrative literature reviews centre on specific issues or topics rather than chronological progression, although time may still hold relevance within this framework. (University Libraries, 2019). The thematic narrative literature review method facilitates thorough investigation of topics, theories, and concepts by organising themes and sub-themes for analysis. It focuses on discussing, analysing, and summarising literature thematically, enhancing understanding of the research topic. This approach relies on existing literature related to RPA and its adoption in beef supply chains, with theme selection guided by the research question (Behl and Dutta, 2019).

With a focus on the beef sector in the UK food supply chain, the thematic narrative literature review evaluated the overall structure of the research domain. It searches for the key themes, identifies, and reviews the themes and finally provide contribution to develop a theory or framework and discuss results. The thematic approach focuses on different aspects of the research topic (Chatha and Butt, 2015).

The thematic narrative literature review focused on the peer-reviewed articles which were published in English. As the literature has grown substantially so boundaries were set for reviewing (Saunders *et al.*, 2003), and publications starting from year 2003-2023 of peer-reviewed articles were chosen for reviewing based on the theoretical themes and relevant concepts. The thematic narrative literature review spanned the past two decades, focusing on articles exploring supply chain systems, technological advancements, and sustainability in the context of the UK beef supply chain. The review delved into theoretical concepts and research models related to the adoption of RPA in beef supply chains, covering various perspectives and relevant information. The review encompassed definitions, theories, philosophical perspectives, and findings on RPA's impact, opportunities, challenges, and sustainability dimensions in the beef sector. Additionally, electronic textbooks and other sources were thoroughly examined to inform the research. The thematic narrative literature review examined RPA technology and its integration into UK beef supply chains, emphasising key themes and underlying relevant concepts. Articles were selected and critically evaluated to ensure a comprehensive and robust thematic narrative literature review, focusing on pertinent themes for thorough research synthesis.

The search strategy aimed to identify and select articles pertaining to RPA adoption and implementation in beef supply chains. Electronic databases and web-based searches were utilized, employing specific keywords to refine search results and enhance the research process. Google Scholar was particularly valuable for accessing scholarly studies and academic resources, while Google search helped specify keywords and evaluate relevant literature outlets, providing substantial papers for review. Paper extraction and analysis was done initially, and keywords, title or abstract were used for search in multiple databases online namely Google Scholar, Scopus and ScienceDirect. Keywords, title, and abstract was used to conduct the research. The following terms were used for identification of research papers/ articles, book chapters using keywords, title or abstract: “supply chain systems”, “food supply chain systems”, “technological advancements”, “Robotic process automation”, “Robotic Process Automation in food supply chains”, “meat industry”, “beef supply chain”, “Robotic process automation in beef supply chains”, “sustainable supply chains”, “RPA as sustainability tool”. There were highly suitable and relevant articles that were added manually as those publications lacked the usage of keywords or titles. These articles were added due to their importance and significance in providing suitable study, so additional research was carried out (Hall, 2010).

Before selecting articles, inclusion and exclusion criteria were established. Irrelevant articles were eliminated after thorough title or keyword scans. Only peer-reviewed, published articles meeting the inclusion criteria were considered to ensure credibility. After critical analysis, themes related to RPA in food supply chains and the beef sector were identified. Non-English articles were excluded due to language barriers, and those focusing on unrelated domains were also omitted as they did not align with the research focus. The review was aligned with the research focus and centred on key themes outlined in the literature review concept map. Through critical assessment, three main themes emerged from the relevant articles, which were carefully organised and summarised accordingly (Jesson *et al*., 2011; Pelletier and Cloutier, 2019).

After conducting the thematic narrative literature review, a concept map was created to illustrate the key themes and associated concepts regarding RPA adoption in UK beef supply chains, as previously discussed. Concept maps serve to organise these themes comprehensively, providing a visual representation in a structured and systematic format for easier understanding and explanation (Friedman and Smiraglia, 2013; Santana and Cobo, 2020). In the thematic narrative literature review, key themes were identified using a concept map, and literature relevant to these themes was critically examined. These themes were crucial for understanding RPA technology's impact on beef supply chains and the challenges and opportunities of its adoption in the beef industry. Figure 2.1 illustrates the concept map, explicitly outlining the key themes and relevant concepts related to RPA adoption in UK beef supply chains.

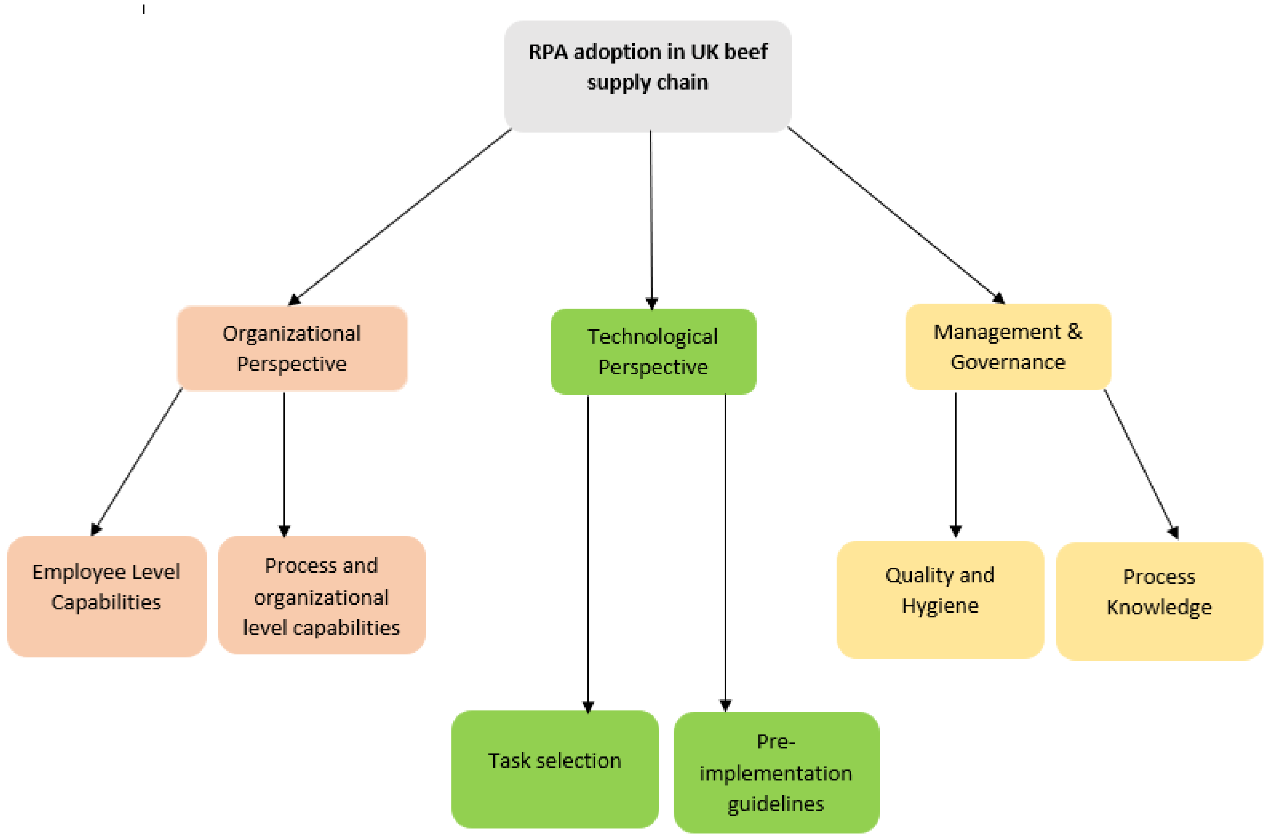


Figure 2.1: Concept map outlining themes and underlying relevant concepts (Source: Author)

The literature highlighted three key themes as depicted in Figure 2.1 that are organisational perspective, technological aspects, and management and governance. Organisational perspective, the first theme, delved into employee-level capabilities and process and organisational capabilities. Theme 2, focusing on the technological perspective, discussed task selection and pre-implementation guidelines. Theme 3 centred on RPA management and governance, covering quality and hygiene, and process knowledge. These themes were significant in understanding RPA adoption in the beef supply chain and addressed challenges faced by the sector. They also contributed to enhancing operational and financial efficiency in beef supply chains, promoting sustainable production, and ensuring quality, safety, and security. Further discussions on these themes are provided in this chapter.

As outlined previously, this research employed a thematic literature review, which involved consideration of the research questions to uncover themes relevant to the adoption of RPA in beef supply chains. This approach allowed for a systematic exploration of the existing literature, facilitating the identification of common patterns, trends, and insights related to the adoption of RPA technology within the beef supply chain context. The research conducted a comprehensive search of academic databases, journals, books, and other relevant sources for the identification of literature as highlighted before. The selected literature was systematically reviewed and analysed extracting key information, and themes related to the topic of study. The literature was organised based on the significant themes, and underlying relevant concepts considering the research questions of the study so that the aim and objectives could be met amicably. The identified themes namely organisational perspective, technological perspective and management and governance also had practical implications. The successful adoption of RPA in beef supply chains carries several practical implications considering organisational, technological and management perspective that includes improved production and efficiency, cost reduction, competitive advantage, sustainability, faster response times, risk mitigation, innovation, and continuous improvement. By harnessing the power of automation, organisations can unlock significant value and drive sustainable growth in the dynamic and competitive beef supply chain industry. Moreover, RPA full adoption frees up time and resources for employees to focus on innovation, problem-solving, and process optimisation, driving ongoing improvements in operational efficiency and effectiveness (Moderno *et al*., 2024). According to Shaharuddin (2024) and Syama et al., (2024) thematic literature reviews are valuable for providing a broad overview of the existing knowledge base, identifying research gaps, and informing future research directions. They are often used in exploratory studies where the goal is to gain a comprehensive understanding of a particular topic or area of interest.

The process of thematic narrative synthesis involves extracting and summarising themes, concepts, and relevant information from literature to provide a comprehensive understanding (Byrne, 2016). A concept map depicting these themes helps visualise the relationships between theoretical concepts. While this synthesis lacks explicit inclusion criteria, it offers up-to-date knowledge and addresses broader issues (Gregory and Denniss, 2018; Paré et al., 2015). Despite the weak form of evidence, this approach structurally synthesizes available literature according to themes. Thematic narrative synthesis is broad and theme-based, providing a well-structured overview of research. This format allows for a scientific and objective review, ensuring uniformity and enhanced objectivity (Weiss, 2016).

The literature review reveals a lack of theoretical understanding regarding potential risks to RPA adoption in food supply chains. Organisational behaviour, technology, and governance are crucial for successful RPA adoption (Syed *et al*., 2020). Chapter two focuses on UK beef supply chains and RPA technology as a sustainability booster, highlighting three key themes. Despite RPA's significance, there's insufficient research on risks or bottlenecks to its full adoption. This research addresses this gap, investigating risks to RPA adoption in the beef sector. Identifying these bottlenecks aids in achieving strategic goals and improving beef safety and quality. The chapter contributes through thematic narrative literature review, emphasising key themes and critical examination of relevant literature.

2.1.1 Theoretical Contributions within Existing Literature

Numerous theoretical contributions within the existing literature have been explored in this section, emphasising their relevance to the domain. It is crucial to underscore these theoretical contributions to gain a comprehensive understanding of sustainable supply chain management and the implementation of innovative strategies aimed at optimising processes and improving business systems. According to Li et al (2022), the Resource-Based View (RBV) is a theory in strategic management that focuses on the internal resources and capabilities of a firm as sources of competitive advantage. While the RBV theory is primarily applied to individual firms, its principles can be extended to supply chain management. The RBV emphasises the significance of dynamic capabilities – the ability to adapt, innovate, and reconfigure resources in response to changing market conditions. In supply chain management, dynamic capabilities enable organisations to be more responsive to speedy shifts in consumer demand, technological advancements, and competitive threats. The RBV acknowledges the significance of cooperation and mutual reliance among firms for value creation. In supply chain management, collaborative advantage denotes firms' capacity to utilize each other's complementary resources and capabilities to attain shared advantages. Collaborative endeavours like forming partnerships with suppliers, collaborating on product development, and establishing shared logistics networks can boost supply chain efficiency, foster innovation, and sustainability, and enhance responsiveness to customer demands (Agrawal *et al*., 2024). Overall, the Resource-Based View theory provides a valuable perspective on how firms can leverage internal resources and capabilities to create sustainable competitive advantage and add value in supply chain management. By identifying areas of strength and weakness, organisations can prioritise investments in supply chain capabilities that create the most value for customers and stakeholders (Ferreira and Ferreira, 2024).

Moreover, decision-making frameworks also play a crucial role in creating sustainable value in supply chain networks. The decision-making framework introduced in the seminal works of Schneeweiss (2003) and Stadtler (2005) provides a structured approach to decision-making in supply chain management. The framework involves several steps such as problem identification, data collection and analysis, model development and conceptualisation, scenario analysis, decision making and implementation and monitoring (Schneeweiss, 2003; Stadtler, 2005). The first step is to clearly define the problem or decision that needs to be addressed within the supply chain context. This may involve identifying inefficiencies, opportunities for improvement, or strategic challenges. Once the problem is identified, relevant data is collected and analysed to provide insights into the underlying factors and potential solutions. This may involve gathering information on demand patterns, inventory levels, production capacities, supplier performance, and other relevant metrics. Based on the analysis of the data, mathematical models or decision support tools are developed to represent the supply chain system and evaluate different courses of action. The developed models are used to evaluate various scenarios and decision alternatives to assess their potential impact on supply chain performance and objectives. This may involve simulating different demand scenarios, testing alternative inventory policies, or evaluating the implications of changes in production schedules or distribution strategies. Once the scenarios are evaluated, a decision is made based on the analysis of the results and consideration of relevant factors such as cost, risk, feasibility, and strategic alignment. The chosen decision or solution is implemented within the supply chain, and its implementation progress and performance are monitored over time. The decision-making framework introduced by Schneeweiss (2003) and Stadtler (2005) provides a systematic and structured approach to addressing complex decision problems in supply chain management, helping organisations make informed decisions that lead to improved performance and competitiveness (Jahani *et al*., 2024; Pérez-Perales *et al*., 2024).

Food supply chains are vulnerable to various disruptions such as natural disasters, extreme weather events, disease outbreaks, and geopolitical conflicts. Ensuring resilience in the face of these disruptions requires robust contingency planning, diversified sourcing strategies, and agile response mechanisms. Food supply chains face a myriad of complex and dynamic challenges due to the intricate nature of the food industry and the interconnected global marketplace (Haessner *et al*., 2024). Exploring neuro-fuzzy solutions in the context of supply chains involves leveraging the combined strengths of neural networks and fuzzy logic to address complex and dynamic challenges. Neuro-fuzzy systems can be used to improve demand forecasting accuracy by analysing historical sales data, market trends, and other relevant factors. Moreover, Neuro-fuzzy techniques help to optimise inventory levels by dynamically adjusting reorder points, safety stock levels, and order quantities based on real-time demand fluctuations and supply chain uncertainties. By incorporating fuzzy logic rules and neural network learning capabilities, neuro-fuzzy systems can adapt to changing market conditions and minimise excess inventory while ensuring adequate stock availability. Neuro-fuzzy models can potentially enhance supply chain risk management by identifying and assessing various sources of risk, such as disruptions, delays, and uncertainties. In the context of supply chains, neuro-fuzzy solutions offer a powerful approach to address the complexities and risks inherent in modern supply chain management (Goodarzian *et al*., 2024; Kosasih *et al*., 2024).

To summarise, while previous research has extensively explored theoretical frameworks and concepts related to supply chain management and sustainability in food supply chains, there has been relatively little attention given to the potential risks associated with adopting RPA technology to meet sustainability goals. Previous studies have focused on how to create sustainability in food supply chains and the significance of systematic decision-making approaches (Busch *et al*., 2024; Bag *et al*., 2024; Hoang *et al*., 2024). However, limited investigation has been conducted into the risks involved in the adoption of RPA technology, as highlighted by Gómez Gandía et al. (2024) and Kakade (2024). Furthermore, there is a gap in the literature regarding the critical examination of potential risks associated with RPA adoption within the beef sector. Therefore, this simulation study aims to assess the role and impact of RPA within beef supply chains from a sustainability perspective, while also identifying potential risks associated with its implementation.

2.2 Supply Chain System from the perspective of technology

Supply chain management is a critical aspect of business that encompasses the coordination of activities from raw material suppliers to end customers. It involves planning, implementing, and controlling the flow of goods, services, and information throughout an organisation and its network of suppliers, distributors, and customers (Hugos, 2024). Supply chain management (SCM) is vital in today's business landscape, enabling organisations to optimise their operations, enhance customer satisfaction, and manage risks (Oyewole *et al*., 2024). By adhering to fundamental principles and addressing challenges, businesses can streamline their supply chains, drive efficiency, and stay competitive in today's global economy. However, with growing concerns for the environment and social well-being, companies are now recognising the importance of integrating sustainability into their supply chain management practices (Ahmed *et al*., 2024).

Food supply chains are a significant component within the broader supply chain network. Food supply chain management is a complex and interconnected process that involves various stakeholders and components. Its goal is to effectively manage the flow of food products from producers to consumers, ensuring quality, safety, and sustainability (Yadav *et al*., 2024). By addressing the challenges and implementing innovative solutions, the food sector can ensure that consumers have access to a safe and nutritious food supply (Su *et al*., 2024). The beef sector significantly contributes to the economic dynamics of food supply chains. Effective management of the beef supply chain is essential for ensuring the efficient flow of products from farm to fork while meeting consumer demands and ensuring food safety and quality standards (Issa *et al*., 2024; Srivastava *et al*., 2024). Technological advancements such as RPA have improved and enhanced supply chain operations through task automation (Khan *et al*., 2022). RPA streamlines operations in food supply chains by automating manual and repetitive tasks. RPA promotes sustainability in food supply chains by optimising resource utilisation and minimising waste. RPA enhances the resilience of food supply chains, such as the meat sector, by improving agility and responsiveness to changing market conditions and disruptions. Automated processes enable faster decision-making, real-time monitoring, and adaptive supply chain management, helping businesses mitigate risks and maintain continuity during crises such as labour shortage, pandemics, or natural disasters. Despite advancements in technology, there is limited knowledge and understanding of how RPA impacts supply chain systems and the potential risks to its implementation (Choi *et al*., 2021). Moreover, prior research lacks assessment and investigation of the potential risks related to the successful adoption of RPA within beef supply chains, and this makes its full implementation and utilisation quite challenging for business owners (Leno *et al*., 2020). The following sections outlines and highlight the impact and implementation of RPA within the food supply chain systems focusing on the meat sector in UK. Moreover, the commencing sections also discuss the dynamics and challenges of UK beef supply chains. The literature relevant to RPA technology and its adoption in UK beef supply chains is also discussed in further sections. Additionally, this chapter also focuses on the key themes and underlying relevant concepts from the aspect of RPA adoption in UK beef supply chains.

Colicchia and Strozzi (2012) highlight that a systematic and structured supply chain system forms the backbone of organisations by reducing its complexities and uncertainties. The definition of supply chain management has kept changing with time. Its meaning is not the same and has evolved within the past 20 year's period with different perspectives from various scholars. The continuous evolution in the supply chain system has broadened its scope and has seen through scholarly directions and perspectives. SCM lacks a specific definition due to its multidisciplinary origins and the evolution of its concepts or perspectives (Giannakis *et al*., 2004). Reviewing papers helps in identifying and depicting the trends in the SCM. In-depth study also allows to explore various angels of these definitions of SCM as shown in Table 2.1 below.

Table 2.1: Definitions of SCM (Source: Author)

References	**Definition of SCM**	**Different aspects related to SCM**
Rossini et al (2023)	SCM can be explained as achieving a broader goal of competing in the digitally modern corporate world and ensuring efficient work-flow management significantly based on digital transformations, technological innovations, and adoption of sustainable business strategies to digitalise and automate processes.	Digital transformation
Hohn and Durach (2023)	The systematic approach and effort to manufacture and process goods and services to the customers in an efficient way to gain socio-economic benefits through incorporation of sustainability-oriented technologies is also defined as supply chain management.	Technological advancement
Seuring et al (2022)	SCM focuses on process digitalisation responsible for coordination and synchronisation of operational procedures to achieve sustainable value in three dimensions of sustainability i.e., social, environmental, and economic.	Socio-economic impact

Toorajipour et al (2021)	SCM is a network involving inflow and outflow of materials, logistics, information, finances, suppliers, production and purchasing to fulfil the demand and satisfy consumers.	Consumer aspect
Faheem and Siddiqui (2019)	E-procurement is the new perspective or dimension to supply chain management.	E-procurement perspective
Dubey et al (2017)	SCM can be defined as adding value to business processes by reducing product cost and enhancing customer satisfaction thus making it more sustainable.	Value addition and sustainability aspect
Parkhi (2015)	SCM is a process of making business practices more resilient, agile, and low risk thus making them more competitive.	Resilience and agility
Ahi and Searcy (2013)	SCM could be referred to as the ability or capability of a supply chain to recover from change, loss, or misfortune by developing resilience in the business network.	Change management aspect
Janvier-James (2012)	SCM can be explained as the integration of key business processes that add value to the goods, services and information provided to the end customer through supplier.	Value creation
Flint et al (2012)	SCM involves understanding of behaviours from individual and organisational perspective.	Organisational context
Melnyk et al (2009)	The definition of SCM focuses on the tactical and strategic implementation of business processes related to customer	Cost Effectiveness

	satisfaction, cost effectiveness and value addition to gain competitive advantage.	
Pagell et al (2009)	The definition of SCM can be derived as highlighting sustainability goals at organisational level other than traditional profit maximising goals to create a sustainable supply chain system and fulfilling corporate social responsibility.	Sustainability and corporate social responsibility
Walker et al (2008)	SCM has other dimensions to look at and being productive and efficient alone is not enough. Environmentally and socially friendly supply chains are more reliable, adds value to network and has long-term benefits.	Environmental and social aspect
Squire et al (2006)	SCM can be defined as systematic, coordinated, and tactical approach by organisations to gain long-term profits and improve the whole supply chain system.	Profitability aspect

Supply chain system can be explained in different ways and various theoretical perspectives as the term has emerged and evolved in the past years. The development of the term 'supply chain system' is due to ongoing scientific research in the domain based on technological advancements, globalisation, innovative business strategies and other aspects which contribute to its growth. Thus, in basic understanding, it can be said that supply chain systems are organised around process integration, collaboration, coordination, and cooperation as depicted in Figure 2.2 (Kozma *et al*., 2019).

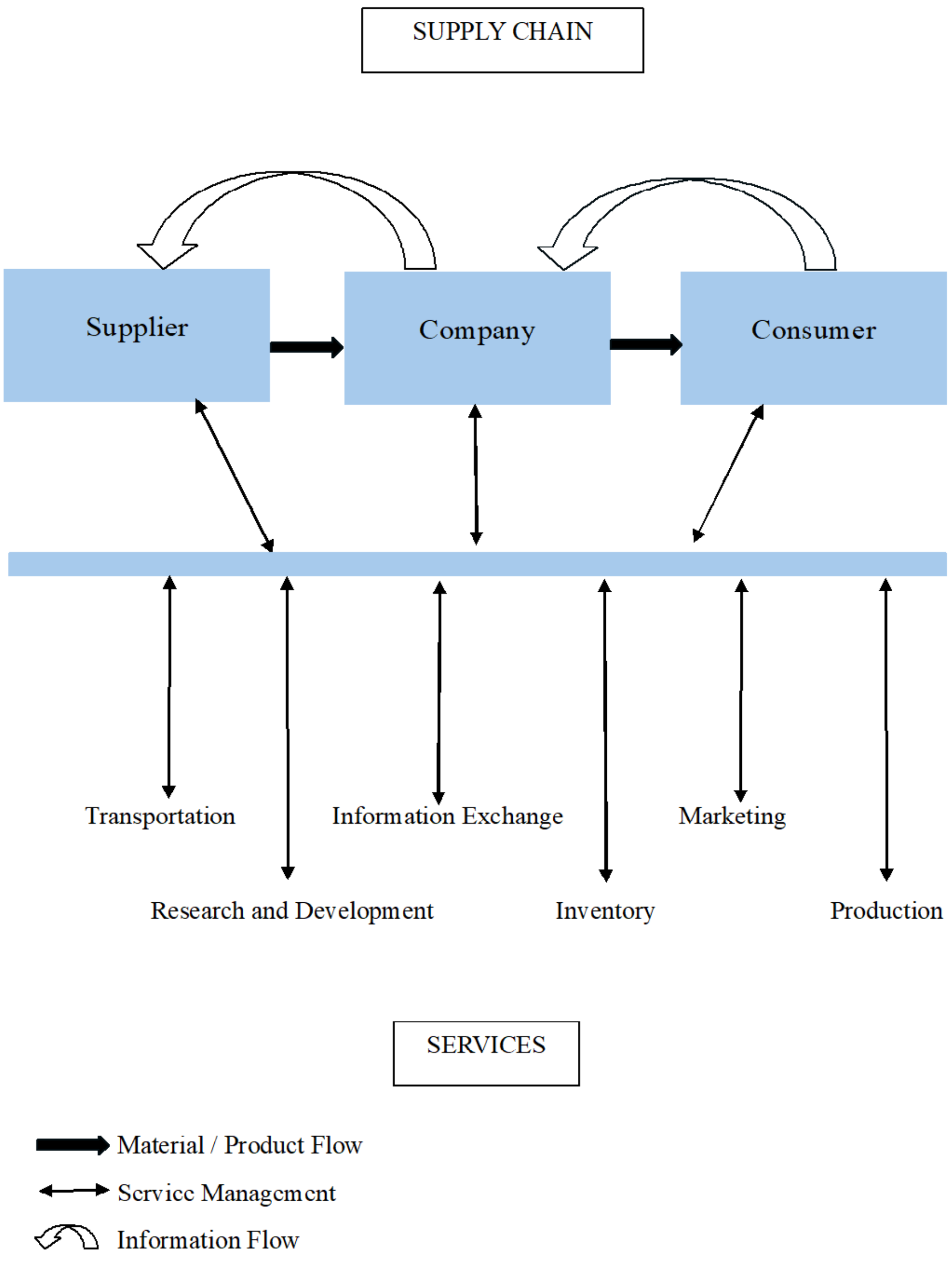


Figure 2.2: Basic Model of Supply Chain (Adapted from Kozma *et al*., 2019)

Supply chain systems experience complexities and challenges in terms of operations, increasing the possibility of risks (Safari *et al*., 2023). Identification of risks, implementation of risk control strategies and methods has become the prime and foremost task for firm at present times (Pettit *et al*., 2019).

Technological advancements have changed the face of supply chain systems and their operations (Sahoo and Lo, 2022). The role of information technology (IT) is crucial and holds significant importance to gain competitive advantage and value addition to business processes. Modern technological tools and inventories have encouraged transformations for efficient organisational processes and enhanced work quality (Kirchmer, 2017).

The growth and use of technology in supply chain systems improves business performance and creates value in organisations. Globalisation and technological solutions have urged businesses to incorporate latest techniques and strategies. The emphasis on technology and increased interest within supply chains of its usage have improved business and allowed organisations to be more resilient (Guo *et al*., 2022; Prajogo and Olhager, 2012). The role of technology within supply chain systems holds significance in terms of supply chain performance, efficiency, functionality, and processes. The integration and implementation of technology impacts the SCs in a beneficial way as it provides solutions to problems, lowers risks, enhances supply chain operations, reduces human error, and makes the supply chain processes much faster and less time consuming thus increasing consumer satisfaction level. The advantages of technological advancements also include cost reduction, process improvement and increased productivity. Also, technological solutions ensure more accuracy in information, improved product quality, timely production, and distribution. The accuracy of information, product reliability and product or services differentiation are also some of the advantages of IT thus making supply chain management more structured, systematic, and sustainable as depicted in Figure 2.3 (de Barros *et al*., 2015).

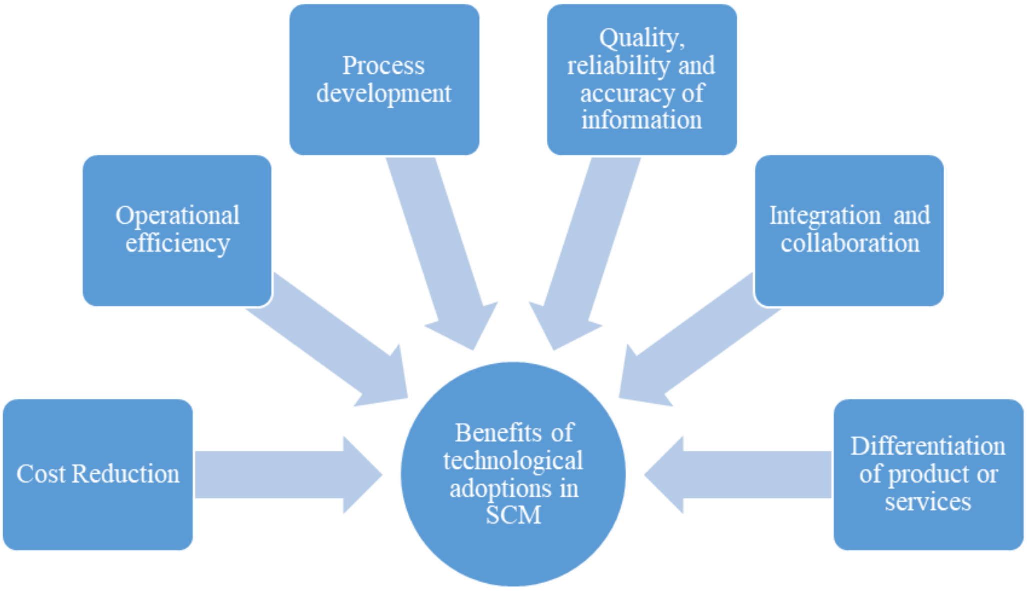


Figure 2.3: Benefits of technology adoption in supply chain management (Adopted from de Barros *et al*., 2015)

2.2.1 Supply Chain Evolution

According to historical perspective during 1960's, the competition between supply chain systems was local and the demand for product variation was minimal (Hou *et al*., 2017). There was also lack of integration and coordination within production systems and the duration of single product was quite sustained and long. The machines and overall control were mechanical and transfer lines were used to reduce the cost. Later, in the following years, organisations emphasise on the restructuring of processes and division of tasks for greater integration, flexibility, and speedy execution of tasks (Shaw *et al.,* 2005). During the 1980's, the global competition increased and forced organisations to enhance product quality and reduce production costs with introducing concepts of mass production and better integration. During the time of 1990's, organisations continued methods of managing firm's resources and improved supply and logistics function and focused on organisational learning to improve supply chain processing. Also, the concepts of mass customisation and lean production were explored for products as the markets expanded (Bessant *et al.,* 2003). There is a remarkable improvement observed in both the ideology and implementation of advance supply chain practices and metrics from 2000 year onwards. Academics also considered supply chain areas such as integration, collaboration, and trust. The last quarter of year 2008 and the year 2009's first quarter observed economic crisis due to visible changes in exports. Researchers in this period focused and evaluated the problems associated to effective functioning of supply chain system. Organisations gave more importance to business structures, organisational supply chain environment and sustainability. Interest and attention to supply chain management has increased noticeably in the last twenty years period. This is because the global market and supply chains have expanded and the advancement in technology also has its effects within organisations. Therefore, firms realise the importance of technology for efficient progress of supply chain systems and need for making the tasks less complex (Gopal and Thakkar, 2012; Manavalan and Jayakrishna, 2019).

Over time, SCM has developed by improving future productivity by integrating single or separate tasks. Figure 2.4 highlights how the supply chain system has evolved and shows the importance of different trends like integration, value addition, automation etc., as time passed. 1960's was the time of future productivity developments and improvements as the whole system was highly fragmented. In the 1970's and 1980's two distinct functions were formed i.e., materials management and physical functions. According to Ellram and Murfield (2019), the era of logistics emerged in the 1990's as globalisation enhanced functional integration within organisations. In the 1990's all the elements of supply chain became one, single unit from supply chain management perspective. The 2000's marked the time of supply chain management with enhanced use of information technology, strategic and systematic planning, improved marketing and sales and control of goods and services. Organisations in the 2000's aimed at adding value to the supply chain system and gain competitive advantage by improving the supply chain processes and methods. More recently, following 2010's the supply chains have become automated due to trends in digitalisation, and this makes the materials management and physical distribution easier and less complex. Jean-Paul Rodrigue (2020) highlights that there has been a remarkable interest and push in automation for instance material handling, storage and packaging within supply chain systems as demonstrated in Figure 2.4.

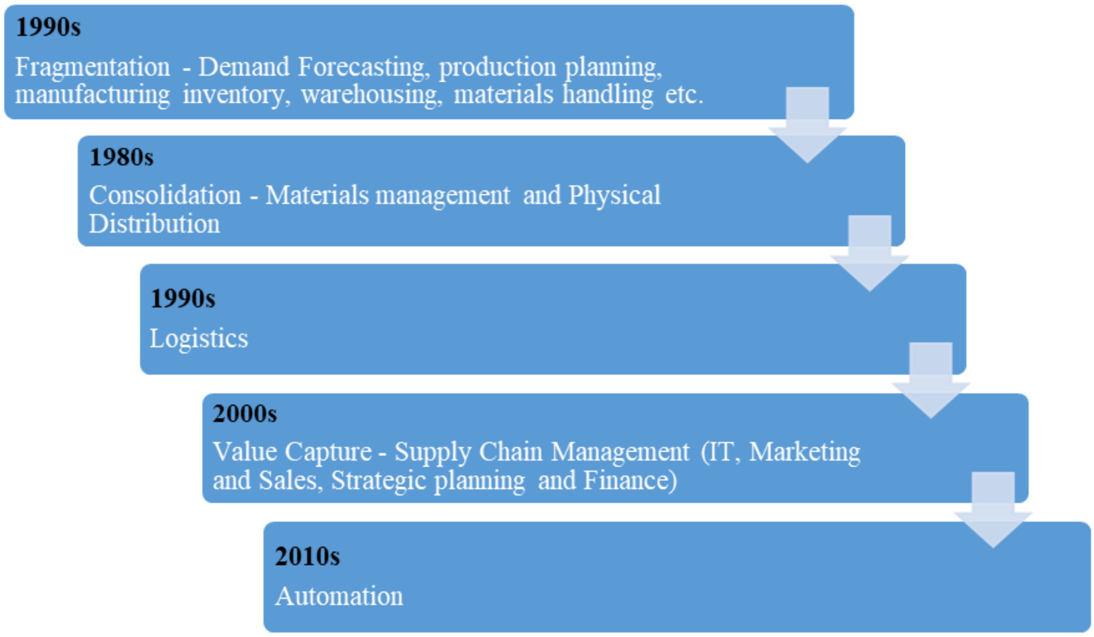


Figure 2.4: Evolution of Supply Chain Management (Adapted from Jean-Paul Rodrigue, 2020)

The process of supply chain system has become focused in terms of value addition in products, goods, and services. Since the business market now days has become technologically advanced hence integration between supply chain systems helps in meeting targets and complete tasks in the best possible way (Sindi and Roe, 2017).

2.3 Food Supply Chain System

Food supply chain management (FSCM) includes managing the flow of materials, information, and finances as food products move from farms to consumers (Oriekhoe *et al*., 2024). The Table 2.2 provides a set of definitions related to food supply chain management from different authors perspectives. The set of definitions are derived from various scholarly articles and demonstrate how definitions of FSCM have evolved over time, illustrating its different perspectives.

Table 2.2: FSCM definitions (Source: Author)

References	Definitions of FSCM	FSCM different aspects
Kuwornu et al (2023)	Food supply chain management focuses on the strategies and approaches to sustainable and green	Green production

	food production through adoption of technological innovations to enhance quality and safety standards.	
Luo et al (2021)	Food supply chain management can be defined as management and transport of food from farm to fork.	Managerial aspect
Annosi et al (2021)	FSC's focus on use of technology for transport of goods, services, and flow of information. This makes supply chain systems more resilient and sustainable.	Technological perspective
Lees et al (2020)	Food supply chain management is described and associated with food safety, food security and food traceability considering customer preferences and ethical responsibility.	Consumer aspect
Rathore et al (2017)	FSC's refers to managing and facing increasing pressures in respect to maintaining environmental and social responsibility due to fast-paced market.	Environmental impact
Zhong et al (2017)	Food supply chains have expanded drastically with usage of digital device or technology resulting in complex management systems. This requires analytical approach to manage data in large numbers and make supply chains more sustainable.	Digitalisation or technological advancement
Shokri et al (2014)	FSCM strives to achieve sustainability goals to create value addition and gain competitive advantage in growing businesses. This is the make concern	Competitive advantage

	for policy makers, supply chain partners and consumers.	
Manzini and Accorsi (2013)	FSC's primarily focus on efficient work-flow management systems, maintaining quality, efficiency, sustainability, and safety throughout the supply chain processes.	Work-flow management
Heikkurinen and Forsman-Hugg (2011)	Food supply chain management can be described as evaluating corporate responsibility to enhance economic-social performance. It adds value to the supply chain systems and enhances customer satisfaction.	Corporate social responsibility

Food supply chain management combines and consists of actors that work on management of both supply and demand of food products from supplier to end consumer. This includes strategies that are innovative, technologically oriented, and modern (Hsiao *et al*., 2010). The aim of producers, distributers, exporters, manufacturers, retailers, and importers is to add value to the whole supply chain system and strengthen networking (Bourlakis and Weightman, 2004; Tachizawa and Wong; 2014). The food supply chains are different from other supply chains due to their key characteristics for instance food perishability, food quality, food temperature control, labour skills and knowledge base, education about usage of modern technologies, seasonality. All actors are responsible for maintaining sustainability within the supply chain system to enhance the overall performance and profitability. The food supply chain can be defined as a combination of actors that work together to manage the inflow and outflow of goods and services by creating value addition within the system and delivering goods at low cost and high quality using sustainable food systems and digital technologies (Mantravadi and Srai, 2023).

Consumer behaviours tend to change over time, and this causes increased pressure on food industry and retailers to implement innovative strategies and use technology to gain competitive advantage and enhance customer satisfaction. According to Khan et al (2021), food supply chain systems have been mostly studied in the developed countries rather than developing countries. However, scholars should also pay attention and give importance to the studying and research of food supply chain systems in developing countries. This is because of increased consumer demand and emergence of various small and large supply chains which require to be well-integrated.

Manning and Baines (2004) focused on food supply chain systems and emphasised on how the meat supply chains work with one another in partnership to build a strong relationship keeping the innovation concept in consideration with the aim to achieve sustainability goals. This also helps them to cater the new customer demand and fulfil their requirements to enhance consumer satisfaction. The network perspective within FSC's is also studied by scholars and the research encouraged focal actors to work with other actors to gain sustainability and improve food supply chain management. Manders et al (2016) argue that the concept of food supply chain systems is widely perceived as an organisational network comprising of social and economic relationships allowing the production of goods and services within SC's.

The food supply chain systems constantly strive to achieve goals for instance quality, sustainability, food safety and efficiency as shown in Figure 2.5. It is highly crucial to achieve these goals at all stage of the food supply chain system to gain operational efficiency and effectiveness (Manzini and Accorsi, 2013). As observed in Figure 2.5, the goals of food supply chains are: efficiency, sustainability, quality, and safety within business process to enhance consumer and retailer satisfaction. It is highly important for food supply chains to meet these goals moving in a fast-paced environment. Attaining these goals contributes to value addition and competitive advantage in business processes and enhances supply chain systems.

Figure 2.5: A model depicting goals in FSC's (Adapted from Manzini and Accorsi, 2013)

Entrepreneurial characteristics are important within focal actors to make supply chain systems more integrated, connected, and sustainable (Dung *et al*., 2020). Marshall et al (2015) mentions entrepreneurial concept within food stakeholders as it has a direct impact on supply chains economic and social performance. The food supply chain involves different stages such as resource origin, agricultural production, food processing, manufacturing, and wholesale, food servicing, food retailing and food consumption (Wunderlich and Martinez, 2018).

2.4 Robotic Process Automation in Food Supply Chain Systems

The food industry plays a vital role in providing necessities to the humans and its management is the focus for organisations these days due to enhanced complexities (Zhong *et al*., 2017). RPA is a well-known technology being used in the food supply chain systems and management to make them more resilient, efficient, and low risk. RPA implementation enables increased food security, safety, and traceability. The advanced technology that is RPA, alleviates the human workforce and enhances operational efficiency (Syed *et al*., 2020). RPA is used within food supply chain systems to lessen its complexities, reduce human error, and streamline procedures and operations. RPA allows food retailers to install software bots to automate operational procedures throughout the supply chain process. RPA and software bots depend on artificial intelligence and machine learning for automating the processes correctly (Blume, 2021). RPA also allows the supply chain to perform faster and efficiently to meet the increasing customer demands thus maximizing customer satisfaction. Food processing and manufacturing are relying on automation solutions instead of conventional processes for increased production and cost reduction (Iqbal *et al*., 2017).

Nakat and Bou-Mitri (2021) points out that food industry provides necessities and products to cater human beings and their activities. Food supply chain management operates and ensures production, distribution of products and consumption to keep food safe and maintain quality using effective modes. The food supply chain is different from other food chains due its complexity and difficulty in management. The complexity is based on various factors like food safety, food quality, traceability, and freshness of food products and this makes it challenging (Trienekens and Zuurbier, 2008). Technological advancements like RPA have brought drastic changes and developments to the FSC's by automating tasks in food processing and packing of products which maintains food freshness ensuring its quality for increased customer satisfaction. As the FSC has many manufacturing phases or steps which requires efficient management. Information and knowledge about managing these stages is highly crucial and have a role in making the FCS's more efficient. Retailers also play a vital part in making the FCS's stronger and productive as thousands of products are under their control and require efficient monitoring and vigilance (Zhong *et al*., 2017). RPA allows businesses to perform automated tasks like humans do across systems and application. RPA has an interaction with present IT architecture and there is no complexity observed in integration within system. RPA doesn't require code development, nor it requires database or code accessibility of the applications. The food industry has traditionally relied on technologies for getting enhanced results and well-integrated food supply chain systems (Jain, 2019).

Kirchmer and Franz (2019) assert that RPA represents software agents that have the capability to interact with software systems by reducing manpower. RPA allows employees within organisations to configure robot to interpret and capture existing applications for manipulation of data, communication with different digital systems, processing transactions etc. RPA is a combination of technologies for instance automatic systems, artificial intelligence (AI) and robotics. RPA is one the digital enablers that has changed organisational behaviour and functions. It is a process technology which has transformed trends in many businesses in terms of efficiency, agility, customer satisfaction, compliance requirements and product deliverables. The term RPA refers to 'software robots' and not physical robots thus making it a software-based solution to automate processes that are specific and done previously. RPA offers enhanced service delivery by improving production and accuracy, reducing supply chain cycle time, and decreasing the ongoing training need. Robots work 24 hours a day unlike humans (Leshob *et al*., 2018). As depicted in Table 2.3 below, definitions of RPA are explained from different perspectives.

Table 2.3: RPA definitions (Source: Author)

References	**Definitions**
Patrício et al (2023)	RPA is a cutting-edge technological advancement with the ability to automate high-volume tasks and uses software bots for process execution; the state-of-the-art technology creates sustainability in business organisations and improves operational, financial, and employee efficiency.
Ribeiro et al (2021)	RPA can be explained as a technique that executes industrial, scientific, and administrative tasks.
Syed et al (2020)	RPA is defined as ‘robots’ that represent software agents that can interact with software systems by mimicking the actions of user thus reducing human interference.
Huang and Vasarhelyi (2019)	RPA is best described as software that used set business rules and procedures to complete execution of autonomous tasks, processes, and activities. Tasks could be for various software systems and results are to be provided with human exception management.
Ivančić et al (2019)	RPA is an emerging, modern technology which focuses on automation of tasks that are repetitive, human-based and routine.
Gao et al (2019)	RPA highlights collection of techniques and tools that make manual tasks automated and easier thus alleviating risk and error.
Lacity and Willcocks (2017)	RPA offers organisation to minimise their risks by eliminating human work or tasks and enhance customer and employee satisfaction.
Dalen (2017)	RPA is the use of ‘virtual workforce’ also called software, to operate applications effectively just like humans would do.
Joshi et al (2016)	RPA can be explained as tool available to automate tasks that are rather physically challenging, require energetic workforce and are repetitive.

RPA is the most rapidly growing software which has gained a lot of importance in a short span of time and its utilisation is popular across many industries. Compared with the year 2021, the RPA software market has grown to $2.8 billion in 2022. The RPA global market is expected to grow and attain double-digit rates by the year 2024. The key drivers for RPA projects are their capability to refine and enhance process quality, productivity, and speed to meet organisational expectations and demands of cost reduction (Gartner, 2023).

The Gartner study determined that global RPA software revenue reached a growth of 31% in the year 2021 and in 2022 it witnessed a rise of 19.5%. The RPA software revenue is also projected to grow by 17.5% globally in 2023 and experience an increase as depicted in Table 2.4.

Table 2.4: Worldwide RPA software revenue (Adopted from DataQuest, 2022)

	2021	**2022**	**2023**
Revenue ($M)	2,389	2,854	3,352
Growth (%)	30.9	19.5	17.5

In supply chain management, RPA is used for automating order, procurement, payment procedures and analysing low-cost levels. KeyBanc capital markets expect RPA global market to observe a rise of $100 billion in another 10 years' span (Key, 2023). The evolution of RPA technology is depicted in Figure 2.6 and mentions how RPA has reduced human interactions to perform tasks. Assisted RPA is automation where human intervention and help is required whereas unassisted RPA is where the machines work without human interaction. Cognitive RPA is perceived as automation using natural-language processing, semantic technology, and machine learning data mining. Autonomous RPA is explained as convergence of RPA, cognitive automation, Machine learning and AI (Comidor, 2020). Currently RPA is at the autonomous stage and adopted likewise in business organisations for enhancing supply chain processes. The Figure 2.6 depicts the evolution and adoption of RPA and outlines the improvements or developments to its characteristics with progressing time.

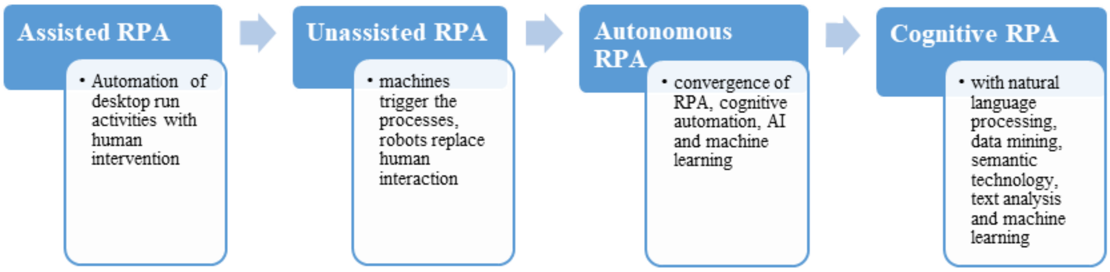


Figure 2.6: The Evolution of RPA (Adapted from Comidor, 2020)

RPA has compelling benefits within a workplace as it frees human employees from mundane tasks within supply chain systems and humans focus on business objectives. Moreover, RPA gathers and organises data which helps supply chain systems in future predictions and optimisation of processes. Mostly the tasks that RPA perform are structured, simple, and recurring for instance email query's that are automated. RPA adoption within supply chain systems have experienced evident savings related to full time equivalent (FTE) and it also impacts positively on business productivity and strategic goals (Hofmann *et al*., 2020). Robots interact with user interface due to which there is no modification required in applications thus making it more secure. It means that they are more capable of deploying new functionalities than other IT solutions. Robots are also able to adapt to demand, are more scalable and can use the components again to help in automation of other tasks. Businesses are likely to spend more on RPA technology due to its significant benefits within the supply chain systems making them more sustainable and competitive (Aguirre and Rodriguez, 2017; Willcocks *et al*, 2017; Santos *et al*., 2019; Asatiani *et al*., 2023). RPA has many characteristics which makes it unique, productive, and advance to be adopted within FSC's and makes the SC processes less complex and easier as depicted in Table 2.5.

Table 2.5: The main characteristics of RPA (Adapted from Jovanović *et al*., 2018)

RPA Characteristics
1. Business users training provided.
2. Work systematically with client's user interface.
3. Perform structured, computer-based, and repeatable tasks.

4.	It can work with different systems.
5.	Rules are predefined and set and work is done accordingly.
6.	Works efficiently 24/7 without any holidays.
7.	The program contains logs which can be configured to be sent via email at a specific frequency, point or date.
8.	Case is provided for analytics introduction.

It is of no surprise that organisations constantly look for ways and processes to reduce their costs and link legacy applications more speedily. RPA is now seen as a modern way to gain return on investment (RoI). Agents are provided by RPA to interact with various information systems thus partially replacing humans. By using machine learning and artificial intelligence, this could be done in a robust manner (Van der Aalst *et al*., 2018). The processes in RPA have gained increased interest within organisations and the early stages of RPA lifecycle can be improved using innovative methods for enhanced usage and adoption. A much common case is the automation of manual tasks or processes often being repetitive. The processes are normally carried out by the back-office employees using IS. The overall lifecycle of the RPA project begins with the analysis of the automation process. It is indeed a very time-consuming phase which relies on the documentation process study. Deployment of robots in production environment is thus quite risky. It is highly crucial for the staff at the back-office to attain such knowledge and begin with supervising them non-invasively. It is done through storage of image sequencing; mouse actions and key actions and their timestamps are stored along. A log is obtained in this way which is transformed into UI log via image analysis techniques for example fingerprinting. Afterwards it is transformed into process model with the usage of discovery algorithms. Accuracy and speed are achieved after clear evaluation (Jimenez-Ramirez *et al*., 2019).

Mendling (2018) notes that emerging technologies such as RPA are sometimes difficult to understand and require human intervention and expertise even though sometimes humans lack consistent diagnosis. However, technologies like RPA can have a strong impact on business processes and supply chain systems as they make routine tasks much easier, less corrupted, and low risk. RPA contribute to the supply chain systems as manual tasks are replaced by automated solutions and thus it greatly reduces administrative support (Mendling *et al*., 2018).

Cruz (2018) further adds that customer-oriented and expanded food industry requires faster actions to address collaborative and dynamic supply chain systems. Efficient traceability and management are highly essential in food supply chains to make them more effective and efficient. Traceability within FSC's improves the production and distribution of products and their quality. Thus, traceability is a huge concern for food supply chain systems and is a tool which is used to ensure food safety and security. RPA is widely adopted as a new technology for automating food processing and operations, thereby enhancing end-to-end food traceability. Caldwell (2023) emphasises that technological advancements like robotics and automation that have changed the face of the food supply chains by providing automated solutions and ensuring transfer of information in an efficient manner.

Duong et al (2020) explains the importance of food security and resource utilisation as a point of concern for organisations and is a global challenge in present times. The role of innovative and integrated food supply chains operations in carrying out efficient business processes is crucial. Food supply chains constantly strive to be innovative and competitive due to external pressures for instance competitive global market and smooth organisational processes. The need to use technology in a well-organised and systematic way is essential and concerns the FSC's. RPA plays significant role in enhancing the supply chain systems and improve their productivity and operations. The use of RPA is promising to cope with the difficulties of food supply chain systems by enhancing food safety and security. Generally, food safety can be described as maintaining food quality and avoiding food from getting contaminated. It is crucial for the food industry to maintain food quality, safety, and security by using technology like RPA in food supply chain systems. Another attribute of RPA is that it enhances customer satisfaction, ensures food monitoring and safety, alleviates human error, and lowers external and internal risks thus improving risk management. The food industry is also quite labour-intensive making the supply chains quite complex to handle. Labour shortage is considered as a serious issue due to which business processes become difficult. Robotics and autonomous systems thus help in alleviating human workforce and ensure automated tasks to make supply chains less complex (Duong *et al*, 2020). Development and effectiveness of FSC's also increases firm's reputation, adds value to the whole supply chain system and has a positive impact on the business environment. The implementation and adoption of robotics and autonomous systems within FSC's is encouraged and considered to be quite beneficial due to cost efficiency, avoiding employee stress and fatigue and supporting operators in co-working (Bouzembrak *et al*.,2019).

Mohamed et al (2022) claims that the adoption of RPA in general eases burden of organisations due to less dependency on manual labour. David (2015) contradicts and believes that the acceleration of automated tasks that were performed by humans before is also a concern as it enhances risks of making the existing workforce redundant. This is because humans are replaced by software agents or robots that perform automated, repetitive tasks to complete business operations. This causes a concern in developing economies where workforce is in huge numbers, and this might create problems for them in terms of unemployment or job evaporation. However, Zhao et al (2022) argues and sheds light on employee efficiency which enhances through RPA implementation, as employees can focus on skilled-based, creative and managerial roles instead of performing repetitive and boring tasks. Studying this from another perspective is that routine tasks could be better handled by software agents through automated systems since employees would not have to deal with stressful and strenuous work. Employees may lose concentration level and there could be loss of interest due to repetition in tasks which results in fatigue and increases chances of making mistakes. In short, routine tasks if done by humans could increase risk factors thus making the supply chain processes more prone to risk and increase their complexity. Automated tasks ease the supply chain systems, and the tasks could be more scalable. The completion of routine tasks could take longer time if done by humans and automated task are set to be completed in given time frame which creates value-addition in the food supply chains. This has a positive impact in food processing and food production as it could be done more systematically and in a more structured manner. The need for automation is increasing day by day as supply chains prioritise risk-free tasks, sustainability and effective management which could be easily done (Ni and Obashi, 2021).

According to Khandelwal et al (2021), a typical food supply chain system includes many partners such as suppliers, pack-houses, exporters, importers, retailers, and end-consumer. One of the biggest concerns for the FSC are food safety, security, and traceability in this era of modernisation. This makes the SC structure quite complex as it involves numerous interactions. As the number and connection is large and expanded in the FSC's so the shared information is also increased likewise. In addition to that, the food supply chains across the globe are small and medium enterprises which have quite limited and resources and finance. These complexities are a reason why robotic autonomous systems get challenging to be adopted in the food supply chain systems. Moreover, the systems or software agent are required to be monitored and maintained through an information infrastructure. This is considered as a technical barrier in the food industry within food supply chains. RPA within the food supply chains makes whole food supply chain cycle much relaxed and easier. It ensures food quality as tasks are automated and only human monitoring is required for them to be conducted promptly. The popularity of RPA within organisations and food supply chains is well- known and there has been an increase observed within FSC's of its adoption and implementation (Vandeplas *et al*., 2013).

Zouari et al (2020) highlights that continuous digitalisation impacts and influences the automation of business processes and organisations require latest information to remain updated. Digitalisation has spiked interest in RPA technology and organisations are making efforts for successful adoption of RPA to improve their business operations. RPA solutions is use of software agents or bots that perform ruled-based and strenuous tasks and helps organisations to be cost-effective and resilient. However, the key challenge of RPA is to promptly identify tasks and processes that suit the automation process. Process descriptions such as work instructions provide a significant insight regarding this matter. Organisations often try to maintain hundreds or thousands of records or process descriptions, but it becomes quite difficult and unfeasible for larger firms or food supply chain systems. An automatic approach to keep a check on current automation is essential rather than putting manual efforts within supply chain systems making it ineffective. Supervised machine learning is a concept which automatically identifies and recognizes whether the task description is manual, automated or is a human interaction with information systems (Leopold *et al*., 2018).

The fundamental element of RPA is a software bot. RPA is deployed to process tasks through automation in organisations also including shared services. The use of software bot's automation is not that straightforward and requires skill. In most businesses, "back office" processes are usually the ideal candidates for automation where the main aim is to provide customer-oriented services that are faster. The back offices are usually under constant pressure to maintain cost efficiency, scalability, service excellence, security, flexibility, and compliance. The two main attributes of RPA include that it is suitable for non-programmers and is designed in such a way and doesn't disturb or effect existing systems. However, on the contrary, even though RPA is considered an efficient service enabler it has its shortcomings. A false perspective about RPA is that it requires very little input from the IT services to perform automated tasks. The truth is that engagement of IT in term of deployment and design is essential if an organisations requirement is to partner them onto a solution and specially this is needed when mistakes are made. A quick and dirty RPA system is often tempting for businesses to be constructed but it lacks security, sustainability, and scalability. Cost reduction benefits maybe be observed in short-term but the chances to pay for the risks are much higher and likely to be experienced by companies. However, other than these small issues that can be dealt, RPA has great potentials to provide solutions that are cost-effective, affordable, and easy to implement (Suri *et al*. 2017).

One of the main challenges that the food supply chains face is regarding the security of food products or their long-term, quality availability. Production environment associated with health risks, short shelf-life of food products, processing, and distribution requirement with the perspective of customer satisfaction and supply chain complexity are the known facts that make the food supply chain different than other supply chains. Increasing population, increased demand of food, climate change and variety of products also make the FSC's more complex (Rahimifard *et al*., 2017). Therefore, sustainable manufacturing and innovative systems are highly important to be adopted such as RPA technology to make businesses competitive (Smith, 2008). Figure 2.7 outlines the key challenges faced by the food manufacturing supply chains which are: consumer complexity, supply chain difficulties, intelligent factories and their adoption, future food processing planning and implementation, resource efficiency and availability and innovative product development. To create sustainability in food manufacturing all these challenges must be met to gain competitive advantage in a fast-paced market. It is highly important to gain consumer satisfaction and provide quality services to enhance business reputation and gain consumer loyalty and trust. Consumer complexity in food supply chains reflects the diverse and evolving preferences, values, and priorities of modern consumers. Meeting the needs and expectations of consumers requires food producers, retailers, and policymakers to navigate these complexities effectively through innovation, transparency, and responsiveness to consumer demands. Moreover, the other challenge that the food manufacturers face is managing complex supply chain systems; efficient planning, monitoring, and incorporation of technology in an effective manner can enhance supply chain management system and add value. In this modern era of technological advancements, it is vital to implement innovative trends and strategies to compete in the market and ensure innovative product development. Innovative trends are driving transformative improvements in food supply chains and sustainability. By leveraging technology, adopting circular economy principles, and embracing regenerative practices, the food industry is moving towards a more sustainable and resilient future, where food is produced, distributed, and consumed in ways that minimise environmental impact, promote social equity, and ensure food security for future generations. Adopting technology and focusing on innovative product development is important with respect to value addition and this can at times become challenging for organisations. Technological innovations play a crucial role in enhancing supply chain systems by improving visibility, efficiency, agility, and collaboration across the entire value chain. Embracing innovation and leveraging disruptive technologies enable organisations to stay competitive, adapt to market dynamics, and meet evolving customer expectations in an increasingly digital and interconnected world. Furthermore, utilising and allocating resources in an efficient manner is also a big task for food manufacturers. Effective resource utilisation is essential for optimising supply chain systems, reducing costs, enhancing sustainability, and delivering value to customers. By leveraging technology, enhancing collaboration, and empowering employees, organisations can drive continuous improvement and innovation across the entire supply chain, ensuring long-term success and resilience in a dynamic and competitive business environment. Therefore, smart, and successful utilisation of resources and making them available to employees for enhanced delivery creates sustainability within supply chains. It is important to analyse the power of technology to change the face of future food processing and making it more advance. Technological adoptions and efficient long-term planning of organisations for future food processing is important and challenging task for food manufacturers at present times as projected in Figure 2.7.

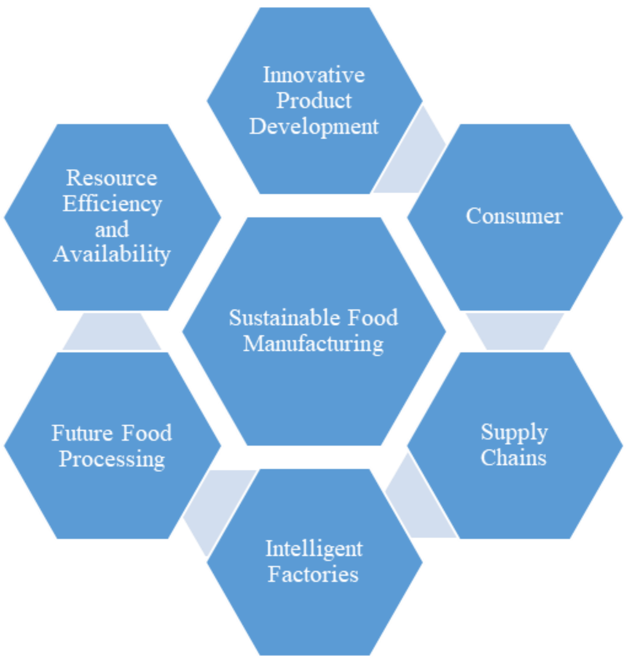


Figure 2.7: Key Challenges in sustainable food manufacturing in FSC's (Adapted from Rahimifard *et al*., 2017; Joshi *et al*., 2023; Oyedijo *et al*., 2024)

The use of RPA helps the FSC's to become more resilient by reducing risks such as alleviating human error as tasks are performed by bots. In a fast-paced market, RPA enhances consumer satisfaction by ensuring quality of food and finishing tasks timely. Also, the use of such innovative technology minimises the chances of delays in food products to the market or end-consumer thus enhancing food safety and avoiding any food waste. Food process is driven and dependent on high quality food, hygiene factors and food security which greatly enhances the FSC's both economically and environmentally (Mahalik, 2009). Another bright side of RPA adoption and implementation is that it allows the food industry to quickly respond to the market in an efficient way as routine tasks are automated. This allows the employees to concentrate on tasks which require more human attention, and their energies are saved for other skilled work. IT skills and active management within FSCs facilitate the adoption of faster technologies like RPA (Gray and Davis, 2013; Schmitz *et al*., 2019).

2.5 Beef Supply Chains

The meat industry is quite large, expanded, and advance and has a complex supply chain system which requires effective management (Karwowska *et al*., 2021). The long forecasts for the red meat industry such as beef, are good and progressive. This is due to the constant growth of population and an increase in demand and supply specifically in developing countries. Developed meat market is doing great business and requires efficiency to manage and control expanded supply chain systems as the customer demand is increasing. Innovation and science play a vital role in the equipment of the meat industry to respond actively to the growing market and meet up their expectations and demands promptly (Zilberman *et al*., 2019).

Sen et al (2022) highlights the developments in meat sector and focuses on its progressive approach and constant efforts to improve red meat quality and nutritious value to gain competitive advantage and add value to business processes. The use of advanced technological systems offers the industry such as beef processing, to adopt automated solutions rather than conventional business procedures to enhance the whole supply chain system. The application and adoption of advanced, innovative methods creates an opportunity to lower risks, satisfy customers, cater scalable red meat market, and improve customer satisfaction. Scientific contributions within the FSC's of meat industry are commendable and offer solutions to compete in globalised meat market and cater the needs of people in a productive manner (Troy and Kerry, 2010).

The main challenge in meat industry is providing quality red meat to the consumers and for that reason buying of healthy and hygienic animals is a skilful task and requires knowledge. The importance of red meat quality is crucial to assess as the meat industry is highly competitive and customer expectations are quite high due to various meat suppliers present in the market. The freshness of the red meat (beef), healthy appearance and visible fat on the meat are the attributes of good meat quality (Font-i-Furnols, 2023). The nutritious quality of red meat is also an important area to highlight as nutritious value should not be compromised as customer satisfaction is directly linked to it. Also, maintaining the nutritious quality of food enhances food safety which makes the red meat tender and fresh and enhances consumer satisfaction (Biesalski *et al*., 2009; Balkir *et al*., 2021).

RPA helps in improving food safety, its hygiene and increases production to cater a large-scale market within the meat sector. Innovation is the key driver to flourish businesses and the meat sector and so senior management tries its level best to incorporate robotics and autonomous systems for efficient production and meat processing and gain productive results. The upper management should have the capabilities to articulate consumer needs and requirements The meat industry is considered to have a complex food supply chain system and it processes various actors. The need to utilise information technology and knowledge on autonomous systems helps in creating value addition to meat supply chains (Henchion and McIntyre, 2010).

According to Fattahi et al (2013), enhanced technology and special skill sets help alleviate risks, speed up the processes and allows faster market access which in turn enhances the meat supply chains and make them well-integrated. Supply chain managers are determined to assess and evaluate performance management to resolve any problems or risks that might occur within wide meat supply chains. Technological renovations have made changes in the overall structure of meat supply chains within the meat industry as the meat processing tasks are done with the use of advance technology like RPA. Modern food supply chains such as the meat supply chains are quite complex as it involves a lot of stakeholders and specific roles are conducted by each of them for food production (Astill *et al*., 2019).

The meat supply chain system is quite challenging in its structure and makes it difficult for the retailers like Tesco in U.K, to set up policies and processes that ensure food safety and security. The complex meat supply chain encourages engagement and partnership of producers (meat suppliers) with retailers to form a collaboration, meet the consumer demands more efficiently and strengthen the SC (Lindgreen and Hingley, 2003). Some of the meat products are purchased by retailers, caterers, secondary processors and are imported. After meat processing, the abattoirs sell the products to butchers, caterers, secondary processors, or retailers.

The Figure 2.8 explores the beef supply chain system and depicts how expanded it is, starting from the breeder to reaching the farm known as farming stage. Then comes the abattoir stage where the carcass transfers from the farm to the abattoir and then carried forward for further processing. The beef manufacturing stage involves the process of slaughtering and cutting or boning stage after which it is delivered to the packaging / storage stage. Then the process is further carried out and beef produced and packed transfers from the manufacturers to the retailers or at distribution centres / food service. The final stage of the beef supply chain is when the processed beef reaches the end consumer for consumption. Lastly, as observed in Figure 2.8, the arrows in between the stages signify the transportation (logistics) from one stage to the next (OpenLearn, 2015; E-Fatima *et al*., 2022).

Figure 2.8: Beef Supply Chain Stages (Adopted from OpenLearn, 2015)

2.5.1 The dynamics and challenges of the UK beef supply chain

Singh et al (2015) describes beef supply chains as a challenging business system involving complex processes and stages. It is imperative to consider the dynamics and features of the beef supply chain system to understand its unique characteristics and procedures that are different from other food supply chains. The dynamics and characteristics of the beef supply chain, which comes in red meat industry, is quite different and has unique or distinctive features. The demand of this sector and its mechanism has experienced increased focus and attention within organisations and its supply chain processes. This requires businesses to enhance their supply chain operations and functionalities to ensure sustainable and efficient SC's. The UK red meat supply chain is facing structural transformations or changes due to reforms such as common agriculture policy. The beef supply chain is crucial to understand due to its complexities and difficulty in management as the overall supply chain phases are complex (Chamanara *et al*., 2023). The consumer demand greatly affects the produce of red meat (beef) consumption due to diseases in cattle's such as foot and mouth disease. To cater these issues a

Food Chain Centre (FCC) is recommended which helps in bringing together different people from all parts of the food supply chain. The FCC facilitates the UK food chain with high efficiency, and it is directed by groups like government-owned bodies and respective agri-food industry (Francis *et al*.,2008).

The Red Meat Industry Forum (RMIF) was initiated in the year 2001 to concentrate on the red meat supply chain. The RMIF enables and provides the opportunity for all the stakeholders within the industry to share their difficulties and concerns to reduce all the risk factors and find solutions to problems for sustainable supply chain processes. The RMIF provides a ten-point plan for improving the profitability and performance of the beef or red-meat stakeholders. The digital development has changed the ways through which the red meat industry operates and functions. Cattles can be tracked by the RMIF forum, red meat markets are more accessible, and trading can be done effectively by lowering costs and increasing profits. It is highly important to observe the needs of people, maintain meat quality and cater the retailers with providing high-quality and nutritious meat (beef) to enhance customer satisfaction and add value to gain competitive advantage (red meat industry forum, 2013).

In developed economies like U.K, the meat market has been involved in following quality and safety regulations as a response.to food crisis and has given much attention to this. The consumer satisfaction and confidence are also linked to schemes related to quality assurance, regulatory bodies, and animal welfare (van Wyngaard *et al*., 2023). These mainly aim to ensure traceability, accountability and transparency within the meat supply chain system and act as catalyst for enhanced collaborative behaviour. However, the critics argue that these schemes and regulatory measures adds up the overall cost that weaken the United Kingdom competition in terms of price, against the imports (Fearne *et al*., 2005).

According to Stewart et al (2023), beef is a famous staple food item, and its demand and consumption has increased considerably in the past years in U.K. In the year 2020 alone, the beef industry generated around 9.6 billion pounds in United Kingdom. The production value of beef experienced high figures in the year 2017 where its value doubled in comparison to last ten years. Then in 2019 the value of beef production decreased, and the graph projects a dip. In the year 2019, the overall cattle and calf's population was about 9.46 million in the U.K. About 300,759 organic cattle were produced in U.K in that year. In recent years, ground beef also known as mincemeat, has been the choice for consumers in the U.K. Younger generations are less likely to opt for meat in comparison to other age groups. However, despite the fact, the beef industry is still flourishing and booming in the United Kingdom and the value of beef production experienced an increase after the pandemic and year 2021 observed a boom and higher value (Statista, 2023). The statistics of beef and veal production in U.K has been observed in Figure 2.8, from year 2003 to 2021. The overall trend of production of beef has been seen increasing since year 2019 and in year 2021, the value of veal and beef production was observed to be 3.27 billion British pounds according to the statistics (Statista, 2023). Hence, the beef market trends have risen in the year 2021 and an increase was observed according to the Figure 2.9.

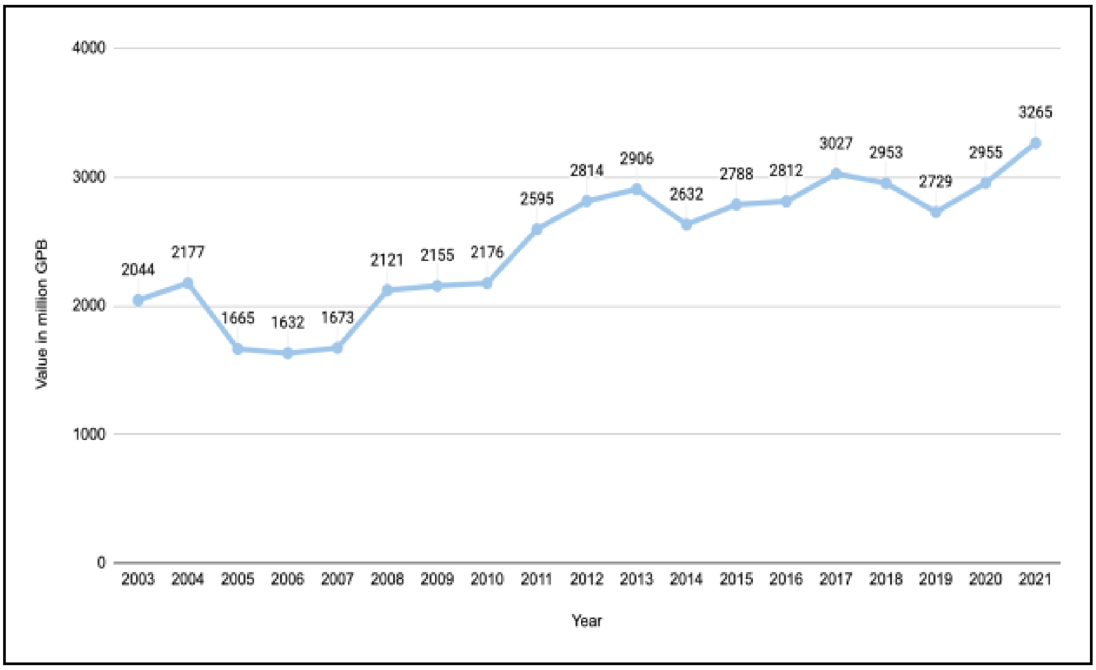


Figure 2.9: Value of beef and veal production in UK from 2003-2021 (Adopted from Statista, 2023)

The important feature of the UK beef supply chain during 1990s was the emergence of coordination and partnerships between abattoirs, producers, and supermarkets. Lately, these alliances and partnerships have broadened the whole supply chain system by including the breeders and compounders of feed (Fearne, 1998). The UK beef sector is highly fragmented and faces powerful and large retailers which increases mistrust and lack of common goals and aims. Consumer confidence in the beef industry has also faced a lot of crises due to its supply chain complexities. However, the government incorporates risk management controls, and the beef industry focuses on initiation of sustainable designs and lean supply chain practices to enhance beef marketing and quality (Jin *et al*., 2023).

Quality can be defined as a degree and characteristic which fulfils the requirements of the beef industry. Requirements can be generally stated as obligatory or compulsory actions that must be successfully completed for enhanced supply chain performance. The quality attributes that are relevant to the beef industry are categorized as safety, service elements, quality food and ethical production (Pogorzelski *et al*., 2022). Another significant category of the beef quality consists of attributes that are directly linked to its nutritional and consumption qualities. This includes the fat content in the beef, fat composition, appearance of the beef, flavour, colour and texture of the beef or meat. All these attributes are dependent on breed of the animal, sex, production system, feeding regime and the age of the animal. Beef carcasses are graded according to their quality as per the Meat and Livestock Commission (MLC Services Ltd) which is responsible for its classification in Britain. This classification is done through a meat grader as per EUROP grading system. EUROP is an abbreviation where all the alphabets refer to the classification such as E refers to excellent, U means Very good, R means good, O refers to fair and P means poor (AHDB, 2022).

Dinnella et al (2023) observes that meat quality is subject to the likings and disliking of the individuals, and the producer pays attention to carcass quality more than the consumer. The service elements are linked with modern foods and can be defined as 'convenience'. Versatility and availability are the examples of quality attribute which includes food packaging which plays an important role in the whole supply chain. Consumer value is also greatly impacted by high yield of cuts that are valuable. Ethical production is another attribute of the beef supply chain system. Meat production generally raises ethical concerns for instance animal welfare and new biotechnologies that applies to farm animals and intensive systems that are impacted by the environment (D'Silva and Webster, 2017).

Beef production has been widely recognised as being quite extensive in comparison to poultry and pig production. Farm assurance schemes that include beef were originated and implemented for reassurance of consumers regarding the high animal standards. The British quality foundation offers a three-pronged direction to quality satisfaction: consumer satisfaction, employee satisfaction and society impact (Hocquette *et al*., 2022).

The classification of beef carcase is observed in the Table 2.6. It is seen in the table that the level of fat has greatest impact on the yield. Less meat is available for selling purpose if the carcase is fat, and more meat is available for consumers if the carcase has less fat. Conformed carcase that are better in classification have a greater yield of meat for premium cuts or higher value. Therefore, there are different classes of the carcase that are graded according to the EUROP grading system in the U.K. There are different fat levels i.e., 2 containing less fat content and 4H containing the highest level of fat, which defines the fat content or fat presence in the meat (AHDB, 2023).

Table 2.6: Percentage yield of meat for carcase classifications (Adopted from AHDB, 2023)

FAT CLASS – INCREASING FATNESS →

Conformation Class	2	3	4L	4H
-U	76.5	73.8	71.7	70.4
R	74.8	72.1	70.0	68.7
O+	73.1	70.4	68.3	67.0
O-	71.7	69.0	66.9	65.6
P	70.8	68.1	66.1	64.7

The EUROP grading system is used to classify the carcase as per the conformation (shape) and the fat content or level and this is done on a scale that is alpha-numerical. The scores are then combined where fat level is determined along with the conformation and then it is decided that which carcase is suitable for the market. Abattoir in U.K that slaughter more than 150 cattle's a week are supposed to classify the beef carcases. Conformation is evaluated on E to P basis, where E is a shapely or convex carcase, R being a straight profile or average shape, and P having concave profile and being plainer in shape. The fat level is assessed on 1-5 basis, where 1 describes leaner meat and 5 shows fat meat. In the U.K, the conformation classes i.e., U, O and P are further divided to give a high or low classification. There are 56 total carcase classifications in the beef sector. E means excellent conformation, U means very good, R denotes good, O represents fair, and P indicates poor carcass conformation. The red shaded area shows the beef with little or no demand with poorest returns and the yellow area indicates medium demand with average returns. The green shaded area shows beef that are high in demand and prices, with good rate of returns as represented in Table 2.7 below (AHDB, 2023).

Table 2.7: The EUROP grid system for carcase classification (Adopted from AHDB, 2023)

Leaner → Fatter

	1	2	3	4	5
E- excellent					
U-very good					
R- good					
O- Fair					
P- Poor					

The production and manufacturing process of beef requires efficient planning, effective utilisation of resources and strategic management given that meat supply chain systems are widespread and large. The meat supply chain includes farmers, butchers, processors, retailers, and wholesalers and all of these play a vital role in efficient beef production (Singh *et al*., 2018). The retail sector is a considered to be a big driver globally in meeting the supply and demand for meat. The butchers play an essential role in choosing the types of animals and advising customers which are considered to have high importance in the chain. However, the requirements of the customers vary according to their gender, country, financial condition, culture, age, likings, habits, and the purpose of meal. In addition to that, the customer demands for less prices can conflict with high-quality products demands. Another major factor for increasing attributes of meat quality is also dependent on the culture of the society or country (Hocquette *et al*., 2012; Liu *et al*., 2022).

The slaughtering of the animal is followed by animal bleeding after which the muscle tissue converts into meat and that process is done in the post-mortem period. During the post-mortem period, complex cascade of biochemical, energetic, and physical transformation takes place in the muscle, and this makes the meat tender, juicy and flavourful. There are considerable efforts done to enhance and increase the beef eating quality. The intrinsic factors that affect the quality of the beef include sex, age, breed, inter-animal variability, muscle properties i.e., contractile, and metabolic. The extrinsic factor affecting the beef quality include feeding, season, hormones, animal handling, transport, and age-conditions to post-slaughter (Hocquette *et al*, 2012; Listrat *et al*., 2016; Nasiri *et al*., 2023). Meat quality is a critical and complex concept and can perceived as the characteristic of meat which has sheer significance in satisfying the meat consumers (Nielsen *et al*., 2021). The main challenge that developed countries generally face is that the livestock sector faces market saturation and an increasing demand in meat. Enhanced meat safety and healthiness because of efficient food production systems with enhanced environments is the prime goal of FSC's. In that respect, providing fresh meat with safety and guarantee of the meat quality is an important aspect for meat producers to gain customers and achieve customer satisfaction (Gagaoua *et al*, 2017).

Healthiness, nutritional value, meat tenderness, juiciness and flavour are all important attributes to judge meat or beef quality and has influence on consumer decision of purchase (Mwashiuya *et al*., 2018). Beef production systems are representation of providing nutritious meat, enhanced meat quality, genotype, and age of the slaughter animal. Efficient management of the beef production system has a great impact on the meat quality and the sustainability of the whole beef supply chain. Carcass management plays an important role in effective functioning of supply chain system. The post-slaughter has a greater impact on the meat tenderness than genotype, feeding systems or genotype. 'Pasture to plate' systems for management are being initiated to ensure that the meat is tender. The chemistry describing the beef flavour is quite complex as there are 140 components that are identified in beef volatiles being cooked. Cattle diet greatly influences the beef flavour, but evaluation of flavour is subject to the preferences and experience of panellists. Modern lean beef consists of about 25-50 grams/kilograms of intramuscular fat content and is known to be a low-fat food. The quality of grass is highly important in the cattle's diet and its increase results in a decline of saturated fatty acids content. This causes an increase in conjugated linoleic acid amount and polyunsaturated fatty acid concentration (Judge *et al*., 2021; Caram *et al*., 2023).

The beef sector faces diverse challenges when it comes to effective management of the beef supply chains, just like other agri-food sectors. This is due to an increase in consumer preferences and likings, the changing perception of society towards food integrity and safety, nutrition, and health concerns. Strong competition within the beef producers is another challenge that the beef industry faces, hence the beef industry focuses more on the beef characteristics to gain enhances efficiency (Feng *et al*., 2019). Consumer acceptability of beef is linked to the healthiness of meat and sensory ratings of beef. In this context, the cattle that consumes grass-based diet tends to be leaner and has a good amount of fatty acid composition. However, giving feed such as grazed grass alone can have a negative impact too as it leads to depletion in intramuscular fat level which affects the flavour desirability. This is because of changes in the fatty acid composition that leads to production of volatile compounds in the beef when it is cooked (Wood *et al*., 2004; Juárez *et al*, 2012). To have enough intramuscular fat, the cattle require to be fed with high energy cereal diets before they are slaughtered. On the contrary, provision of cereal concentrated diets before slaughter could lessen the benefits of grass silage or grazed grass that is consumed earlier by the animals. Hence, the characteristics of beef are dependent on the diet of the cattle. The diet or nutritional value of beef has an in-turn impact on the consumer buying or preference which makes it highly essential to be focused on by the beef industry (Aldai *et al*., 2011; Judge *et al*., 2021).

To further stress on this, the beef manufacturers constantly face sustainability challenges, as the supply chain system is typically complex and difficult to manage. The beef supply chain is sensitive to manage as it involves environment, financial, and food-related concerns, and challenges, which increase its complexity (Silvestre *et al*., 2018). Considerations regarding beef shelf life, quality, human consumption, and financial aspects makes the beef supply chain challenging. Because of the constant social and financial pressure faced by beef manufacturers, they are constantly seeking sustainable strategies that could be implemented to address these concerns. According to Cox et al (2007), the supply and demand of beef is highly uncertain due to the nature and distinctive features of the beef supply chain. Beef manufacturers are seeking sustainable approaches and autonomous production systems to meet the growing demand for beef, achieve customer satisfaction, and maintain a high level of production. Some central problems related to beef production are quality concerns, shelf life, environmental challenges, and high costs. Globalisation and technological advancements have the potential to enhance production systems, cut-down labour costs, and increase operational and employee-level efficiency to achieve sustainability and a competitive advantage (dos Reis and Machado, 2022).

The demand for beef is growing because of the increasing population, which has introduced challenges within the beef sector. The dynamics of the beef supply chain are unique and complex due to the presence of various actors in the stages of the supply chain. These actors involve breeders, butchers, slaughterhouses, producers, manufacturers, retailers, end consumers, etc., which increase its managerial and processing complexities in task delivery. The beef processing sector is competitive and faces issues such as cultural and managerial challenges, economic difficulties, supply chain disruptions, and unprecedented events, which make the processes in the supply chain complicated and risky to handle (Anderson *et al*., 2021). To address these issues and prevent any discrepancies that could cause supply chain disruptions, it is crucial to assess the risks in advance and to develop an efficient management system by adopting systematic, innovative tools and techniques (Tsapi *et al*., 2022).

The beef supply chain systems also entail risks that are emerging from complex production and manufacturing stages involving strenuous processes that could be harmful to the environment and employees working on the processing lines. Wide-spread stages and procedures in the supply chain result in coordination, synchronisation, and managerial issues. The beef industry faces unprecedented events that raise concerns about its manual-centric processes; the adoption of innovative and sustainable strategies that could create supply chain resilience is thus encouraged. Resilience in beef supply chains is important as the consumption of beef is directly related to human health concerns that impact both society and the environment. Sustainable solutions and innovative procedures in the supply chain could help these procedures, thus making the supply chain resilient to any risks or disruptive events such as COVID-19. Other than disruptions caused by the COVID-19 pandemic, other risks such as animal diseases and agricultural disturbances also impact the production and manufacture of beef. The beef industry is focussed on addressing labour shortages, supply and demand uncertainties, high operational costs, and environmental issues; to achieve resilience in these issues, sustainable and long-term strategies should be adopted to avoid any losses or failures in the respective supply chains. As a result of these prevailing sustainability challenges, the beef sector endeavours to adopt efficient techniques and systems to deal with environmental and social concerns, such as labour scarcity and the transmission of diseases, to create financial and operational resilience and enhance management practices (Payne-Gifford *et al*., 2022; Hayes *et al*., 2022).

2.6 Key definitions and perspectives on RPA: An Industry 4.0 revolution

It is critically important to understand the different academic perspectives provided in literature on the revolutionary technology which has changed the face of complex supply chain systems and created sustainable value in business processes through acceleration of tasks using automation. The game changing innovative business solution has transformed business operations and taken a pitch on green production within beef supply chains. Philosophically, there are different key concepts and definitions associated with RPA and its impact on business operations in practical aspects and therefore there are various philosophical perspectives, theoretical underpinnings, and key approaches to RPA and how it can be perceived or defined (Willcocks, 2016; Siderska, 2020; Chugh *et al*., 2022; Moreira *et al*., 2023).

There is insufficient research and lack of knowledge available in literature relating to RPA as a growing and significant field. The academic research crucially lacks a synoptic and theoretical analysis of the respective approach. In different scientific papers, the term 'RPA' has been discussed from various point of views such as its nature and scope, technical understanding, benefits etc (Siderska, 2020). According to Gradim and Teixeira (2022), RPA is considered an emerging technology which uses software bots to perform strenuous, boring, and repetitive tasks and relieve employees who can potentially concentrate on more creative and value-based jobs, making their lives easier. Another theoretical definition to RPA is that the revolutionary technology has brough digital transformation to complex supply chain systems and business processes and has improved operational efficiency dramatically (Syed and Wynn, 2020). As another theoretical viewpoint, Doguc (2022) explained that new technology can also be described as a software technology that mimics human behaviour or actions interacting with software and digital systems where the bots are programmed or instructed to perform repetitive, strenuous tasks in replacement of humans as labour. Mohamed et al (2022) further discusses RPA as a strategic catalyst which accelerates sustainability in business organisations and helps businesses in achieving corporate social responsibility. Achieving CSR and gaining competitive advantage are some of the significant benefits of RPA adoption in organisations as it improves efficiency levels and productivity and reduces costs, energy, and time to create sustainable value. Patricio et al (2023) observes the sustainability aspects through RPA implementation and explains that the promising and game-changing technology helps supply chains to gain socio-economic benefits and enhances financial performance through cost reduction. Other philosophical and theoretical aspects to RPA explain that the advanced technology is trending famously in the fourth industrial revolution in the world of supply chain management and logistics as bots are used with a set of instructions to perform complex, repetitive tasks and replace humans for process execution. Doorsamy (2020) highlight and provides opinion on the revolutionary technology which facilitates complex business processes with automation and free employees working to stressful tasks; RPA automates processes and ensures positive financial impact within the business environment. On the contrary, Ruiz et al (2022) argues that RPA adoption also has some drawbacks and challenges which could also result in negative impact on the business environment. Some of the prominent drawbacks of the technology include the bots being rule-based, automation suitability processes, poor RPA governance and management, low-level RPA acceptance by employees etc. Ruiz et al (2022) further explains that if RPA is not implemented using thorough planning, critical assessment on nature and scope of business processes, then the procedures can adversely become more costly due to mismanagement, lack of critical evaluation and poor leadership. Successful RPA adoption requires change management and effective planning, as employees may resist the adoption of RPA due to fear of job displacement or unfamiliarity with new technologies. Overcoming resistance and promoting a culture of acceptance and collaboration is crucial for successful RPA implementation. Introducing RPA requires training employees to work alongside automation tools effectively which can be observed as another challenge. Ensuring that staff have the necessary skills to operate, manage, and troubleshoot RPA systems is essential for smooth implementation. Moreover, another challenge highlighted by Ruiz et al (2022) in RPA implementation is communication and stakeholder engagement. Effective communication with stakeholders is vital throughout the RPA implementation process. Engaging employees, management, and other stakeholders early on and addressing concerns transparently can help mitigate resistance and facilitate buy-in. Data security and compliance is also considered as significant challenge in RPA deployment. Ensuring data security and compliance with regulatory requirements is essential when implementing RPA. Monitoring RPA bots' access to sensitive data and implementing measures to protect against cyber threats are critical considerations. As RPA initiatives expand, scalability becomes a challenge. Monitoring and managing the scalability of RPA solutions to accommodate growing demands while maintaining performance and efficiency is essential. Furthermore, standardising processes across different departments or business units can be challenging. Variations in workflows and procedures may complicate RPA implementation and require additional effort to streamline processes. Lastly, resource allocation is also considered a potential challenge for organisations in RPA adoption as proper allocation of resources, including budget, personnel, and infrastructure, is crucial for successful RPA implementation. Monitoring resource utilisation and adjusting allocation as needed ensures optimal performance and cost-effectiveness. Addressing these challenges requires a proactive approach, including clear communication, ongoing training and support, robust monitoring and evaluation processes, and a commitment to continuous improvement (Ruiz *et al*., 2022).

Another theoretical perspective to RPA implementation is it's *'sustainability dimension'* which is a significant aspect to consider in both conceptualisation and operationalisation of RPA technology. RPA is considered to enhance supply chain operations through facilitating processes with automation and mimic human actions or tasks; the promising technology contributes to the three facets of sustainability. The revolutionary technology creates sustainability in supply chains through speeding-up and scaling up the processes, accelerates procedures and minimises time and costs reacted to business processes. The trending technology helps organisations adds value to their supply chain processes, boosts productivity, and ensures operational and financial excellence.

2.6.1 The historical development and journey of RPA

There is an important history behind the development and journey of the revolutionary and modern technology termed as RPA. It is crucially significant to study and examine the historical views and development of the promising RPA technology to have a greater and enhanced understanding on how it evolved, emerged, and conceptualised. According to Viswanadham (2002), the 20th century has experienced and observed the development in the domain of supply chain automation from various perspectives procurement of raw-materials, manufacturing, processing, information or material flow, governance and monitoring and logistics. Nof (2023) states that the definition of automation has evolved, progressed, and developed over time with the aspect of its functionality and application across industrial sectors. The historical background of RPA began with the automation of user interface (UI) analysis. It generally means the testing of visual elements to ensure their effective functioning so that users don't face any difficulties with the app. Electroneek (2023) explains the evolution of RPA and states that in the 90's, there were only few computers available in markets, in comparison to the present day where technology has immensely grown and advanced in every aspect and industry. Initially computers were only used by larger organisations but gradually the concept started at homes as well and the usage increased with time. By the end of 90's and in the beginning of 2000's, organisations started valuing and recognising the agile development concept where people were prioritised over tools and processes; the awareness and recognition to staying competitive and speeding up business operations also gained focus. Therefore, numerous quality assurance and UI testing scripts were developed out of sheer necessity of the growing businesses. In the 2000's, insurance companies and banking sector was perceived as amongst the first to embrace automation of data extraction which greatly improved the efficiency and effectiveness of businesses in terms of handling large data. Banking sector and insurance companies were considered as the pioneers to process automation as they had the resources available for the development of the groundbreaking technology. At that time if a company desired process automation, a whole complex IT system and environment had to be built which was quite costly and time-consuming. The innovative technology had its real pivotal point from the year 2012 onwards; this was the year when large supply chains or businesses recognised the power of "automation". The 2020's in scientific research is known as the growing time of RPA technology in all economic segments (ElectroNeek, 2023). The central focus on all industries has been automation in the last decade. To further highlight automation historic background and development, Bellgran (2010) highlights that the early 1900's observed the first assembly-line automation for automobile engines manufacturing, and this was accomplished by Henry Ford. Despite many cultural and economic challenges, the main aim of manufacturing supply chains has been raw materials procurement, smart and autonomous production systems, and efficient deliverance of products to consumers globally. According to Goel and Gupta (2020), the motive behind automating supply chains is to increase production levels and reduce costs, and primarily satisfy customers efficiently and effectively. Scientific research depicts that advancements in technology have paved way towards sustainable supply chain systems and production systems to enable businesses to more competitive; modern production systems are flexible, easier, efficient, and sustainably modern and developed. As described by Xu et al (2021) regarding automation capabilities at present times as a theoretical view, the innovative use of software bots as a business solution has scaled up and accelerated supply chain processes and addressed organisational issues or challenges associated with quality, safety, security, sustainability, costs, and productivity. However, a theoretical argument stated by Ylä-Kujala et al (2023) focuses on the task selection criteria as one of challenges to RPA adoption. To further explain this viewpoint, RPA could also become challenging in terms of its application and thus requires robust planning and evaluation of processes which are suitable for RPA implementation, as otherwise the adoption process could be costly rather than cost-effective.

Karabegović et al (2019) theoretical perspective observes that the incorporation of bots within business systems provides automation to repetitive and tedious tasks thus allowing employees to be more productive and efficient as compared to the past where processing and manufacturing was dominantly manual centric which caused production systems to be slower, riskier, and less-efficient. The author also believes that robotic automation is the foundation and basis of the fourth industrial revolution and automation plays a vital role in modern manufacturing systems. Nagy et al (2018) highlights and emphasises on academic literature related to RPA, providing some deeper insights on the aspects due to which businesses gained greater attention towards process automation and these are some of the following aspects:

1. Financial issues or crisis and the need to improve productivity at lower operational costs to gain socio-economic benefits

2. The need for digital transformation to enhance efficiency levels and satisfy growing demand due to growing population and globalisation
3. RPA was considered as a less expensive and easier business solution to achieve sustainability in business organisations
4. The need for manufacturing and production systems to be more advanced, integrated, fast-paced, resilient, viable and sustainable
5. Digitisation of processes through process automation to reduce supply chain complexities and challenges and to add value to business processes so that competitive advantage can be achieved

Some of the prominent factors which made RPA gain popularity and attraction amongst business users who constantly strive to gain sustainable value in supply chain systems were discussed above. Therefore, more businesses started using and adopting the pioneering technology to ensure long-term organisational benefits through automation. Ng *et al* (2021) states that RPA has gained valuable consideration in the past decade because of the promising benefits automation brings, however, its potential still requires more study and analysis in terms of its adoption and implementation especially in dynamic, complex business environments to enable business users to enjoy its maximised benefits.

2.7 The adoption of RPA as a sustainability-oriented technology in UK beef supply chains

The main reason for companies to use technology is to improve their operational and financial efficiency and ensure faster and sustainable business processes. The red meat industry (beef sector) has been a late adopter to modern technology; however, organisations are looking to digitalize their processes and control their machinery. The beef supply chains are large and complex and require tasks that are routine-based or regular, to be operated using automation to make the SCs easier to handle and increase meat production. The red meat industry, pertaining to beef processing and beef production, is challenging and difficult given its complex supply chain system. The use of technology such as RPA enables to enhance the business processes within the beef supply chain and lowers the risk factors in beef production, safety, and traceability. The use of robots in beef processing instead of human operatives has a lot of potential benefits including socio-economic gains, tangible and intangible advantages (Bader and Rahimifard, 2020). The safety risks and hygiene along with social and labour costs makes the human workers not that useful with the food sector. The food safety regulations are quite stringent these days, so meat supply chains are vigilant than ever and prioritise this matter for beneficial and economical results. The employers face difficulty while recruiting and training skilful butchery employees which becomes too costly and so meat supply chains always face this pressure. Robotic automation is more consistent in performing tasks and much more reliable than humans. The positioning of robots is much more accurate than humans when done for the first time. The ability to get things done right in the first attempt not just saves time but also reduces error and costs thus making the whole meat supply chain more systematic and structured. The use of automation also reduces production costs, and the hourly costs of robots are much lower than manual workers (Purnell, 1998). After the industrial revolution, automation and mechanisation has increased tremendously and the meat industry has also adopted this to reduce potential risks and timely, speedy red meat production and processing such as beef. The red meat industry was lagging in the adoption of robotic technology but now it increasingly implements automated processes for greater efficiency. Consumer interest has substantially grown within the red meat industry (beef) and this urges the meat supply chains to invest in low-cost sensors and software systems or bots for performing automated, rule-based tasks (Barbut, 2014).

Autonomous beef production and manufacturing is a technological development and advancement which makes beef supply chains less complex, systematic, resilient, efficient, and sustainable. In the past, the beef supply chain was mainly manual centric, however, technological advancement and adoption like process automation, innovative software systems or robots enhance tasks completion and delivery. RPA is a sustainability-oriented innovation where software agents or robots operate and automate strenuous tasks (Wewerka and Reichert, 2023). Processes like slaughtering and manufacturing in beef supply chains, have become much easier and less complicated through task automation and robotic intervention and this allows production of high quality, safe and hygienic beef. The cattle are slaughtered at speed that is low line. Mostly the plants operate in single shifts to slaughter cattle at a line speed of 30-75 per hour and the specialisation of the plant is to slaughter all sorts of cattle, be it of any weight or type. This enhances the work environment, reduces human error and other risk elements (Madsen *et al*., 2006). The biggest challenge for the beef industry is to achieve sustainability within supply chains due to its work-flow management system complexity and high fragmentation. Demand for high-quality red meat is growing day by day and requires the meat sector to process fresh and high-quality meat. Meat consumption is set to increase about 14% by the year 2030 as meat is an important source of protein for humans and its demand continues to increase (The Scottish Farmer, 2023). The prices of beef have increased around

68.2% in the last ten years. From the year 1961 to 2018, the meat production globally has quadrupled due to increasing population and demand (Piña *et al*., 2023). A production line that is automated is highly suitable for the meat supply chains. However, the running costs of highly robotized or automated line may be a problem for small-scale meat supply chains and they might hinder from accessing the technology. A slaughter-line that is traditionally automated can produce ten times higher than an average slaughter line. It is quite feasible for large producers to automate their processes than small producers as the costs are calculated according to scalability or number of cattle (Kristensen *et al*., 2014). The adoption of RPA is a value addition to UK beef supply chains as it contributes to enhancement of operational and employee-level efficiency whilst providing the opportunity of cutting costs. Increase in work and task efficiency and production of quality beef also makes the beef supply chains more sustainable in long-term perspective.

Food safety and quality in beef has encouraged decision-makers to pursue and implement sustainable technological solutions to enhance the performance, maximise financial benefits by lowering the associated operational costs, and meet health and safety requirements (Chen *et al*., 2012; Overbosch and Blanchard, 2023). Achieving sustainability has created awareness within business setups, encouraging the adoption of sustainable business approaches so that long-term advantages can be achieved. The awareness and recognition of sustainable supply chains incorporating modern technology such as RPA has attracted many businesses (Kedziora *et al*., 2021). The different approaches and perspectives of sustainable supply chains are explained in Table 2.8.

Table 2.8: Definitions of sustainable supply chains (Source: Author)

References	**Definitions of Sustainable Supply Chains**
Saini et al (2023)	Sustainable supply chains strive for operational excellence, innovative approaches, and increased business efficiency, all while minimising adverse effects on the environment and society.
Zimon et al (2019)	A sustainable supply chain is a business model that prioritises competitive advantage, societal benefits, and environmentally friendly production methods.

Vargas et al (2018)	Sustainable supply chains aim to create value and gain competitive advantage through their commitment to sustainable business practices.
Ahi and Searcy (2013)	Sustainable supply chains integrate green production methods and operations management techniques to achieve social, environmental, and economic benefits.
Mefford (2011)	The concept of a sustainable supply chain revolves around the adoption and execution of sustainable business concepts, innovations, and strategies to achieve lasting benefits.
Seuring and Müller (2008)	A sustainable supply chain entails the management of business processes that encompass social, environmental, and financial dimensions.

Sustainability has gained a lot of attention and has become a primary goal of beef supply chains to add value and achieve corporate social responsibility (Sulfiar *et al*., 2022). Sustainable beef processing and manufacturing brings considerable benefits to organisations as they could achieve long-term viability, profit, and cost reduction. Sustainable business strategies and procedures such as the use of technology could prevent risks and hazards and achieve a positive social, economic, and environmental impact. The use of RPA tools can maximise profits and enhance task efficiency in processes such as beef cutting, deboning, and packaging. The implementation of RPA can also reduce environmental or social hazards such as accidents on the processing line or the transmission of diseases by re-placing humans with software bots to complete tasks. The bots are also able to work 24/7 and do not require any breaks, which increases beef production levels; this also ensures the quality of beef produced as the chances of meat contamination are reduced. RPA not only provides technological support to beef supply chains, but also enables decision-makers and managers to achieve sustainability criteria in the fast-paced market. RPA is a valuable addition to beef supply chains as it assists and improves system pro-cesses and allows firms to achieve sustainable value and achieve a competitive advantage (Mohapatra *et al*., 2023).

Modern technological advancements in simulation and process automation have been widely adapted for use within businesses and industry. Incorporating sustainable technologies in organisations has gained value as automation can relieve employees who perform strenuous, repetitive tasks, as well as provide sustainable solutions to complex and disruptive business environments. RPA is a leading and widely adopted technology that has the potential to improve business process management through task automation and it is considered a sustainable practice to enhance supply chain operations. RPA technology facilitates, improves, and optimizes business processes considering the addition of value and sustainability criteria. For instance, RPA acts as a helpful sustainability tool to enhance workforce efficiency by replacing tough and repetitive tasks with automation, allowing humans to use their potential and expertise in judgement-based tasks or managerial areas. Moreover, RPA also simulates different process systems and analyses the data to develop a more cost-effective and sustainable method of organising. It is crucial for business users to decide which processes would be most suitable for automation for successful adoption of the process. Digital transformation, such as RPA, continuously improves supply chain operations and process efficiency, and helps organisations meet their sustainability agendas and goals (Moreira *et al*., 2023).

RPA serves as a process efficiency tool to create sustainable value in beef supply chains. Automation solutions such as RPA accelerate production processes by speeding up the processing line and reducing errors by replacing the human workforce with software bots. New sustainability demands are linked to beef quality, safety, and cost and are associated with supply chain processes in the beef industry. The integration and adoption of RPA assists by adding value to supply chain processes and producing high quality beef that is safe for human consumption. RPA also allows for an eco-friendly beef production environment as tasks are automated, resulting is less human error; reduced chances of accidents on the processing line; lower transmission of diseases; and less time, cost, and energy consumed when conducting strenuous tasks. It also improves supply chain synchronisation and coordination through the removal or reduction of human error and through efficient process delivery at different stages of the beef supply chain (Hernández *et al*., 2023). RPA is now perceived as an asset as it eases employee-level pressure by improving processes, thus allowing the human workforce to concentrate on meaningful and skilled-based activities. RPA provides business organisations with various advantages for achieving effectiveness and competitiveness. RPA increases productivity levels, im-proves the quality of production, and ensures enhanced consumer satisfaction. The value provided by RPA technology improves accuracy levels, increases profitability margins, and boosts the financial conditions of the business organisation (Madakam *et al*., 2019). Referring to the concept map in Figure 2.1, the RPA adoption has three main themes as being discussed in the literature review, followed by sub-themes or ideas which are further discussed in more detail.

2.7.1 Simulation-based approach to assist RPA adoption in Beef Supply Chains

Magalhães et al (2020) pointed out that the beef supply chain has highly fragmented, broad, and unique characteristics. The beef sector faces constant pressure and challenges when attempting to achieve sustainability and gain added value. As the beef supply chain has complex procedures and activities, increasing production levels and enhancing operational efficiency is complicated. Emerging technological solutions such as RPA help improve business process delivery and reduce task complexity. Value-based beef supply chains help the beef sector to maintain quality and safety standards in production, while allowing for higher levels of output. Value-based supply chain systems are prioritised nowadays due to the awareness and need to build sustainable business systems. To enhance consumer satisfaction and maintain high food quality standards, innovative strategies are implemented within organisational structures to serve business purposes and gain sustainable value. Organisations in beef supply chains are responsible for the health and safety concerns of humans; hence, producing high-quality, nutritious beef is one of the main aims. To satisfy the demand for beef and ensure the production and processing of healthy, safe beef, valuable additions such as RPA could reduce human error and minimise the cost to perform these processes (Pullman *et al*., 2010; Rutaganda *et al*., 2017).

The simulation and optimisation of food supply chains help to identify risks to enhance business operations and prevent any risk factors present (Tsiamas and Rahimifard, 2021). It is imperative that comprehensive and precise sustainable evaluation and assessment of business processes are conducted within the food industry. This is because the food industry, comprising of meat supply chains, includes the production and manufacture of perishable food items and thus it is essential that organisations meet the quality and safety standards. As the demand for beef has grown within recent years, it has become important for the beef sector to adopt and implement technological innovations such as RPA that could potentially help save money, time, and energy, as well as the lower cost of manufacturing beef (Marciniak and Stanisławski, 2021). Simulation-based approaches help business organisations to improve efficiency, lower waste due to processing, and increase business productivity and viability. Simulations also aid in identifying risk factors that are present in the business environment and help supply chains achieve sustainable value by ensuring social, economic, and environmental gains. Simulation-based approaches guide organisations in calculating and assessing the best approach for adopting technological and innovative strategies. Supply chains can gain long-term success through simulation and optimisation, as risk events can be pre-determined in a virtual environment and the best approach for conducting processes or business activities can be discovered and then implemented (Talley and Davis, 2020).

Nimmy et al (2022) asserts that it is difficult to eliminate or prevent risks and assess supply chain performance in real-world processes; therefore, simulation-based approaches could be used to determine and investigate supply chain risks using a virtual environment, and thus be used to plan accordingly for the future. The beef industry is highly seasonable due to the cycle of calving, which raises issues regarding the supply and demand of beef, making supply chain processes inconsistent. Issues such as seasonality increase the risks of fulfilling the demands of consumers and manufacturers. Implementing innovative machinery and equipment, as well as employees working on the processing lines could be costly due to tension between the producers and manufacturers. Another concerning challenge is that supply chain procedures are cost-intensive, making the profit margins narrow (Ali *et al*., 2021; Jouzdani and Govindan, 2021). This is because supply chain processes are intensive due to the large supply chain system. The beef supply chain strives to achieve sustainable business development strategies that could facilitate supply chain processes, reduce operational costs, and improve production levels. A simulation-based approach could help address such concerns as it has the potential to provide a well-coordinated supply chain system with the integration of technology such as RPA, which could minimise costs and enhance financial and functional efficiency to create sustainable value at different stages of the supply chain. According to Kamble et al (2022), simulation approach could potentially help evaluate supply chain activities and observe behaviour at various stages, thus identifying any inconsistencies or risks during task delivery. Process simulation and optimisation allows beef supply chains to mitigate slaughtering, processing, and manufacturing bottlenecks while reducing operational costs, time, and energy. Simulation-based techniques use a virtual environment to develop models that accelerate supply chain performance and determine any handling issues to ensure smooth and systematic beef processing and distribution. The simulation and optimisation of the beef supply chain also allows for the smooth adoption of technology such as RPA, allowing for automating labour-intensive tasks and replacing human workers with robots for process excellence. Simulation allows for minimization of the total production or system costs and enables business organisations to enjoy socio-economic benefits and create sustainable value within beef supply chains (Ge *et al*., 2022).

Sustainability is the main goal and challenge for beef supply chains due to its complicated business structure and fragmentation; the simulation-based approach in beef supply chains can facilitate decision-makers or stakeholders to follow the best approach for technological adoption and remove or prevent any risk events in real-life scenarios and create supply chain resilience (Tordecilla *et al*., 2021). Robust and successful adoption of RPA creates sustainable value within supply chain systems and enhance business profitability and sustainability.

2.8 RPA adoption as a value addition in beef supply chains – The key themes

RPA's full utilisation allows organisational growth and enables food manufacturing supply chains to gain competitive advantages and create sustainable value. In supply chain management, achieving sustainability remains as key challenge for stakeholders due to increased competition, technological advancements, higher customer expectations and maintenance of quality standards (Okoye *et al*., 2024). The Triple Bottom Line (TBL) framework is a foundational sustainability concept within supply chain management that emphasises the importance of considering environmental, social, and economic factors in decision-making processes. The TBL framework encourages organisations to evaluate their performance and impact across three dimensions: people, planet, and profit (Huma *et al*., 2024). The social dimension of the TBL framework focuses on the well-being of people within and affected by the supply chain. This includes employees, workers in the supply chain, local communities, and other stakeholders. The environmental dimension of the TBL framework pertains to the impact of supply chain activities on the natural environment. Organisations aim to minimise their ecological footprint, conserve natural resources, and mitigate environmental degradation throughout the supply chain. This involves reducing greenhouse gas emissions, minimising waste generation, optimising energy, and water usage, and promoting sustainable sourcing and production practices. Strategies such as green procurement, eco-friendly packaging, carbon footprint reduction, and sustainable transportation contribute to environmental sustainability within supply chains. The economic dimension of the TBL framework focuses on generating financial value and ensuring long-term profitability while also considering social and environmental impacts (Wamalwa and Nang'ole Meyer, 2024). In supply chain management, organisations seek to optimise economic performance by maximising efficiency, reducing costs, and enhancing profitability. This may involve implementing lean practices, improving supply chain visibility and coordination, optimising inventory management, and leveraging technology to drive operational excellence (Sun *et al*., 2024). By aligning economic objectives with social and environmental goals, organisations can create shared value for stakeholders and achieve sustainable growth. By adopting the Triple Bottom Line framework, food supply chains can integrate sustainability principles into their supply chain strategies and operations, balancing the needs of people, the planet, and profit. This holistic approach enables the food sector to address complex sustainability challenges, enhance stakeholder value, and contribute to a more resilient, equitable, and environmentally sustainable global supply chain (Oyedijo *et al*., 2024). Therefore, the triple bottom line allows decision-makers to address sustainability issues and mitigate risks in food supply chains (Eyo-Udo *et al*., 2024; Mohaghegh and Größler, 2024).

The link between the Triple Bottom Line (TBL) framework and the adoption of RPA lies in their shared goal of promoting sustainability and driving value across economic, social, and environmental dimensions. RPA adoption can positively impact the social dimension of the TBL framework by improving working conditions and enhancing job satisfaction for employees. By automating repetitive and mundane tasks, RPA allows employees to focus on higher-value activities that require creativity, critical thinking, and interpersonal skills (Palaniappan, 2024). RPA adoption can support environmental sustainability by reducing the ecological footprint of supply chain operations. By automating processes, organisations can optimise resource utilisation, minimise energy consumption, and decrease waste generation. From an economic perspective, RPA adoption offers opportunities for cost savings, efficiency gains, and revenue growth. By automating repetitive tasks, organisations can lower labour costs, reduce errors, and increase productivity (Farinha *et al*., 2024; Franceschetto *et al*., 2024). In summary, the adoption of RPA aligns with the principles of the Triple Bottom Line framework by promoting social well-being, environmental stewardship, and economic prosperity. By integrating RPA into their operations, stakeholders can achieve sustainability objectives while driving value across multiple dimensions of their business. Given that this research examines the role and influence of RPA through a sustainability lens and identifies potential implementation risks, the Triple Bottom Line theory has been emphasised and discussed to provide a deeper and more comprehensive understanding within the context of food supply chains. The food supply chains are committed to achieving social and environmental objectives alongside profitability.

Thematic reviews can be well-explained in-depth and critical analysis of themes can provide insights and greater understanding on a specific topic. Thematic reviews are used to assess and evaluate the risks or problems related to an issue in a sector or market. They can be used to find out the happenings of a market and provide suggestions to tackle problems (Behl and

Dutta, 2019). In a thematic review, policies, procedures, or processes of a specific area of the supply chain or market are examined so that problems can be resolved or eliminated. Thematic reviews are done on a particular topic and are based on reviewing themes or sub-themes or ideas on the topic. To summarise, the thematic literature review focuses on analysis, discussion and literature content in a thematic style or manner. To have a better understanding on the topic, the literature or information is based on the three themes of the subject. The research question is the most important part of thematic reviews as themes are dependent on that (Findlay *et al*., 2017). Thematic review enables to summarise the sources and discuss the themes for research purpose. Data and information are gathered to identify the themes which brings a focus to the research.

The thematic review evaluates the overall research structure and focuses on solving the research problem and filling the research gap. Finding way to solve issues on a topic or subject area is prioritises in thematic review. In this research, thematic review enables to give the study an appropriate research structure where the impact of RPA is critically analysed in the UK beef supply chain and its opportunities and challenges in implementation are discussed. The concept map in Figure 2.1, illustrated initially in the chapter, projects the key themes and the underlying concepts which are relevant and based on the research topic with regards to their importance and significance to the research aims and objectives.

2.8.1 Theme 1: Organisational perspective in RPA adoption

RPA has established affordable and solid solution for the organisations to tackle rule-based, repetitive tasks. This has not only resolved the issue of higher turnover but only ensured and paved way for opportunities that increase the moral in organisations. Humans working alongside software robots is reality and many organisations are following it worldwide (Anagnoste, 2018; E-Fatima *et al*., 2022). Use of RPA in organisations empowers and encourages people to do rewarding and interesting tasks that are not mundane and repetitive. Automation of processes relieves the workers in an organisation and provides facilitation in performing rule-based tasks. Bots don’t require complex and difficult coding mechanisms; however, they do require human expertise in terms of knowledge transfer and processing to simplify the instructions. RPA in SME’s opens new opportunities and gateways for an organisation and its people as more time could be spent on tasks which require human judgement and intervention for instance management and administrative work. In areas where humans face difficulty and struggle, software bots could ease up the overall supply chain process make it more efficient and reduce human error. RPA is codeless and so it can be accessed by users easily as it doesn't require any coding experience. However, some sort of knowledge or information and involvement at every level by the organisations ensures RPA performs tasks with best practice. RPA is based on sets of instructions that can be maintained well by the SMEs once they are developed with appropriate understanding of process and targets. It is crucial for the people with top positions or roles at an organisation to get involved in approving tasks that require automation (Golizadeh *et al*., 2019).

For RPA to work best, it is essential for the SMEs and small businesses to map down their tasks and identify which ones are suitable for automation (Jeeva Padmini *et al*., 2021). Small businesses are short in terms of budget, resources, and information and so it is essential for them to pre-assess automation tasks at initial stages to avoid any RPA operational failures. This will help save time as proper planning by the senior management will ensure in prioritizing tasks that require automation and thus benefit best from RPA. From the SMEs perspective, presence of an RPA team at organisational level helps the adoption of RPA in a step-by-step journey. Their input helps identify which tasks require automation and establish an order in which those processes take place within the beef supply chain (Phillips and Collins, 2019).

2.8.1.1 Employee-level capabilities

RPA technology has become popular and its usage within small and medium enterprises has also significantly increased over time, however, they still struggle with its adoption process. SMEs could advantage using RPA technology as it helps in performing mundane tasks and the employees can focus on managerial or decision-making aspects which are more interesting and require human judgement. SMEs face challenges and difficulty in operations when they scale, and so adoption of RPA can make the supply chains easier to manage and perform. It is relatively easier for the SMEs to implement RPA as mostly very less or no infrastructure is required in its adoption. Szelągowski and Berniak-Woźny (2023) emphasise that the deployment of RPA in the SMEs is affordable and supply chain operations are completed with higher efficiency, productivity, and accuracy. Organisations are eager to use RPA technology across the UK beef supply chains as the technology promises lower-costs and reduced human errors. SMEs require greater understanding of analytical capabilities in managing 'bots' as they have smaller budgets and usually have lesser resources. This makes it essential for the employees to have analytical capabilities for decision making and management regarding tasks that require automation and the order in which they will be automated. RPA implementation within a business environment changes the overall nature of the work as the rule-based tasks are performed by 'software bots' and employees can concentrate on work of higher-value. It opens more jobs related to RPA monitoring and management. Activities that require human judgement and decision making are done by the employees and repetitive tasks are performed by RPA. Other jobs such as data analysis, robot management and consulting are also examples of higher-value work that employees can do once RPA is implemented (Syed *et al*., 2020). It is highly significant that employees have technological readiness and are skilled to understand the process and technological aspects of RPA implementation. Communication is another important aspect of successful RPA implementation and adoption in organisations or SMEs. Efficient communication, understanding and knowledge of use of digital innovations like RPA helps in its successful adoption in SMEs. Mostly SMEs face such employee level capabilities and so the successful adoption of RPA becomes a challenge for them, and they struggle to enjoy its benefits. Hence, correct knowledge and analytical capabilities of the employees is significant in RPA adoption in beef supply chains (Flechsig *et al*., 2021). Employee capability to understand and co-work with the advanced technology is another skill required for full implementation of RPA. The comfort level of the employees and fair understanding that the software bots will contribute to their tedious tasks will help them focus on roles where human intervention is required more in the business process. RPA adoption allows employees to focus on skilled roles such as RPA developer, RPA tester, Bot Orchestrator, business analyst, project manager etc (Sisodiya *et al*., 2024).

2.8.1.2 Process and organisational level capabilities

Organisations should possess certain capabilities that are crucial from the aspect of achieving benefits of RPA and adopting it fully. Standardisation and flexibility are two of the capabilities which are widely spoken about and relate to the implementation of RPA in all organisations (Hofmann *et al*., 2020). Other capabilities at an organisational level are specific such as the capability to automate the IT processes or business processes automation. According to studies, there is an increase in standardisation as RPA automates the business processes in the same way. Robot's actions are logged at every step which improves it transparency. Thus, this helps in handling and identification of process deviations. Increase in transparency and standardisation helps in improving compliance and audibility. Moreover, capabilities in relation to scalability, control and flexibility also play role in an organisation for implementation of RPA. Firstly, humans are not that flexible and cannot work 24 hours round the clock whereas RPA has flexibility with regards to working hours. Thus, RPA eliminates tasks that are manual and tedious, and those which employees don't enjoy. It allows organisations to automate processes making employees focus on purpose-based, critical, and value-added jobs (Papageorgiou, 2018).

RPA also doesn't require IT systems to be altered or integrated with it. It is easy for SMEs or other large organisations to implement RPA and make their supply chains structured, stress-free, risk-free whilst enhancing operational efficiency. Hence, this makes it easier for processes to controlled by the business owners as they must monitor RPA (Rajagopal and Ramamoorthy, 2023). In addition to this, capability of effective monitoring and controlling by the top management or RPA managers is essential to adopt RPA fully. Process management capability is another aspect which holds significance whilst adopting RPA in SMEs or larger organisations. It is important to understand the policies, procedures, and guidelines to adopt RPA. Also, since automated processes leave human workers on tasks which are more strategic and require judgement or analysis, management and decision-making so roles should be pre-defined for humans so that they can work efficiently as well. The top management including RPA designers should possess the capability of critical decision-making skills to prioritise and select which processes to automate (Agaton and Swedberg, 2018). Process improvement and enhanced workflow should also be monitored by the humans and capability of efficient decision-making allows successful adoption of RPA. Process level capabilities add value to the overall supply chain and help achieve competitive advantage in SMEs when working alongside software agents. Organisational acceptance and trust towards the RPA technology and using bots for operational efficiency, less cycle time, cost saving and low risk, is another capability which is significant to adopt RPA fully and enjoy its benefits. RPA trust helps organisations in building and incorporating strategies to introduce RPA successfully and sustain the technology to perform daily tasks and operations. Appropriate management of process complexity, process prioritization by the business analysts and RPA designers allows to effectively understand the scope, cross-functions and steps or procedures involved in a process (Syed and Wynn, 2020).

2.8.2 Theme 2: Technological Perspective in RPA adoption

It is essential to discuss RPA from the point of view of technology and what role it plays in its successful adoption. RPA is not just replacing people or human force from companies to perform tedious, repetitive tasks; it is certainly much more than that looking at the bigger picture. The application of RPA from a technological perspective is important to analyse and understand. RPA automates processes where a range of different technologies of process automation are used. Each of them serves a purpose and suit various objectives and processes. There are pre-defined guidelines or set rules which the software bots follow to perform their tasks. However, task selection and which processes require automation is based on human-judgement and so that must be well-decided before time (Van der Aalst *et al*., 2018). It is important to characterize RPA in a structured manner and highlight its major and significant traits from a technological perspective as shown in Figure 2.10. To elaborate this, RPA is explained as the use or application of preconfigured software which uses pre-defined rules and set activity choreography to execute autonomous activities, tasks, processes, and transactions that deliver service or result in an efficient manner. The deliverance of result or successful completion of tasks are with the help of human exception management to benefit most from RPA adoption. Figure 2.10 elaborates on the major traits of RPA and depicts the nature of RPA. The software bots follow choreography of control flow operators and technological modules. The user designs software robots by arranging control flow operators and configurable modules in a sequential manner thus creating a choreography as per the business rules. It is also important to highlight that RPA uses applications that are established and operates in IT ecosystems. To gain full benefit of RPA, effective front-end automation and underlying systems infrastructure must be capable of operating the software bots. It is not necessary to gain specialized knowledge for developing the software robots, however, it is vital to have a basic understanding of the IS functionalities for instance, the overall structure of rule-based systems (e.g., parameters, loops, conditions), data usage and application interfaces. RPA technology is not complex and is easy-to-use within companies and add value to the supply chain systems or projects as depicted in Figure 2.10 (Hofmann *et al*., 2020). These characterises define the nature of RPA and how it functions improve business processes and reduce supply chain complexity. To summarise the fundamental nature of RPA, the projects or organisations implement the software bots and automate the process and operate within the IS ecosystem. The choreographies of the software bots are controlled and are in accordance with pre-defined, set rules for deliverance of tasks. Moreover, the choreographies consist of modules and control flow operators. The projects implement software bots which use applications for task delivery in a business environment. The Figure 2.10 depicts the cycle and nature of RPA and how it functions for process delivery.

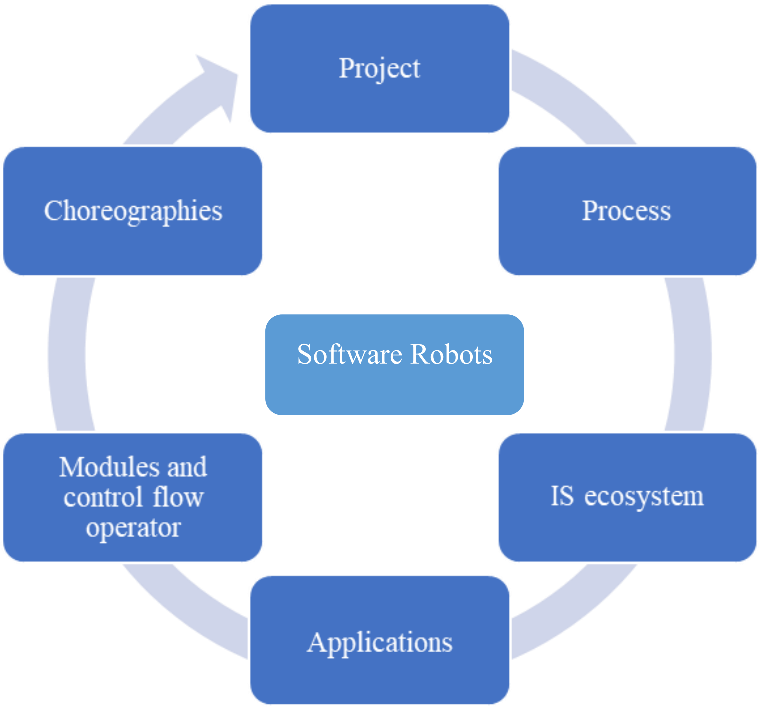


Figure 2.10: Nature of RPA (Adapted from Hofmann *et al*., 2020)

2.8.2.1 Task Selection

The process owners in an organisation or SMEs evaluate specific process needs according to which they automate their processes or activities in a supply chain system. In an RPA environment, employees need to develop flexibility, acceptance, and trust for successful RPA adoption. This approach enables organisations to enhance their agility and ensure quick adaptation or response to progressing market conditions and changing environments where humans work alongside software bots. Emergence and use of technological innovation enable users to simplify tasks and speed-up processes in a supply chain (Bygstad and Iden, 2017). Task selection is an important aspect in RPA adoption and enjoying the benefits it provides to automate processes. It is significant to analyse the nature of RPA and then select or prioritise tasks that will be completed by the software agents. The beef supply chain is complex in terms of its management due to the technical and difficult procedures in its manufacturing process. This makes the supply chain decisions complex and require effective decision making and judgement in prioritising processes for automation. In the past several tasks were manual; however, the adoption of RPA has now automated them. Understanding the selection of tasks which require automation is significant specially in beef supply chains. The beef supply chains are not fully automated and require human intervention in some processes due to its complexity. The RPA can perform tasks such as scanning of the carcasses, weighing them, measurements of its length and intelligent cutting of the carcasses using guillotine-style blades. Automated cutting machines perform the task of cutting the carcasses into two and split it up. However, tasks are not performed well by the RPA and require refinement where there are variable sizes of the carcasses. Other tasks in the beef supply chain such as shackling and stunned animal sticking is also not fully automated. Inaccuracy in task selection can lead to damaging the carcasses with regards to variety in carcasses size and intelligent cutting or shaping of beef. Hence the business owners in the beef supply chain require firm understanding on what tasks can be performed by the RPA according to its capabilities and functionalities (Wanner *et al*., 2019).

2.8.2.2 Pre-implementation guidelines

The key to the success of RPA adoption in a supply chain is the pre-assessment and evaluation of the business processes. This is the first and essential step which leads to RPA success or failure. Organisations should understand that RPA implementation is for long-term business outputs as automating tasks ensures less complex and well-structured supply chain systems. According to Syed *et al* (2020), it is important to optimise processes first and then automate them. Business owners in supply chains should analyse criteria upon which processes should be automated or not. Supply chain processes that are complex in nature face difficulty in automating tasks. Automation of complex processes result in exerting more effort, time, and money for performing tasks. This results in low RPA performance and less financial gains as more money is spent on task automation. On that contrary, if organisations evaluate and plan tasks and set criteria for automating processes which suit best with RPA capabilities, more benefits can be achieved (Ibrahim, 2018). RPA is best suitable for performing tasks that are higher in frequency i.e., repetitive. For instance, in the beef manufacturing tasks of splitting the carcasses into two are performed repeatedly and frequently making RPA suitable for the respective job. Moreover, it is important for the task to be stable and consistent and should not include any changes while performing it. Consistency and stability of the task that require automation is essential for RPA effective performance. RPA works with pre-defined rules and performs tasks accordingly. If RPA finds that the process doesn't match the predefined guidelines, then it will not be able to work best and will result in a failure to produce expected output. For example, if there are variations in the sizes of the carcasses RPA will not be able to perform the task. It is not instructed to handle variable sizes and is not intelligent enough to complete the task which could result in damaging the carcass in the beef supply chain. Hence, the business process should be analysed first and should be done according to the RPA guidelines and set rules. Processes should be assessed and redesigned to remove any risks in automation whilst improving their efficiency and time. Redesigning processes means eliminating any unnecessary steps and make supply chain simpler and structured to maximise benefits from the RPA technology (Santos *et al*., 2019). With the help of the employees, it is possible to redesign the processes for effective RPA adoption. Employees know best about the supply chain procedures due to their experience and knowledge of what will work best in practice. However, redesigning with the help of employees will not always be easy as RPA is seen as their main competitor. Therefore, process mining tools and programme mining can help and enhance task performance and increase RPA efficiency. The identification and design of processes that can be automated is one of the primary problems in implementing RPA (Pramod, 2021).

2.8.3 Theme 3: Management and Governance in RPA adoption

Businesses are eager and motivated to adopt RPA as it promises to provide benefits to the supply chain systems such as time and cost savings along with enhanced production (Nayak *et al*., 2023). However, governance and management of RPA requires attention in the beef supply chains. When a supply chain grows its efforts related to RPA, the maintenance also increases. Effective governance and management are required to prevent hight maintenance costs and efforts (Orynbayeva, 2019). A very common mistake that organisations make is that they treat RPA like any other software programme. This leads to lesser efforts in its management and governance arrangements. Moreover, little IT arrangement and standard project management methods also lead to ineffective management of RPA. Effective and timely decision-making, knowledge of RPA roles and responsibilities, process pre-assessment and enhanced IT engagement leads to efficient governance of RPA (Lam *et al*., 2024). It is important to understand and vision RPA not as a 'tool' but a platform for process automation. Whilst, RPA has been largely adopted within supply chain systems, challenges such as change management have also been encountered by organisations. Organisations are too consumed with adopting and implementing RPA but forget the change implications for people, technology, organisational structure, and processes (Salih Aydıner *et al*., 2023). The purpose of RPA should be well-explained to the staff so that employees are able to build trust and acceptance towards the technology. RPA should be aligned with human workforce in an effective manner and work environment with new job roles for employees should be created and understood for RPA to perform well. Therefore, management and governance play crucial roles in the adoption of

RPA within supply chain systems. Effective management ensures that the implementation of RPA aligns with organisational objectives, addresses operational challenges, and maximises the technology's potential benefits (Palaniappan, 2024). It involves strategic planning, resource allocation, and coordination among various stakeholders to ensure smooth integration of RPA into existing processes. Governance, on the other hand, focuses on establishing policies, procedures, and controls to govern the use of RPA within the supply chain. This includes defining roles and responsibilities, establishing performance metrics, and ensuring compliance with regulatory requirements. Effective governance helps mitigate risks, ensures accountability, and promotes transparency throughout the RPA adoption process. Management and governance provide the framework for successful RPA adoption in supply chain systems, enabling organisations to leverage automation effectively, optimise processes, and drive sustainable growth (Davlatov, 2023).

2.8.3.1 Quality and Hygiene

According to Casagranda et al (2023), the beef supply chain contains complex processes and activities during beef production and manufacturing. The foremost priority for all organisations in the beef sector is to produce beef which is of high quality and nutritious. It is important to pay attention to the quality standards and other health-based aspects while producing beef. Health concerns, nutrition and well-being are very important elements when manufacturing beef for the customers. Beef contamination and less-shelf life of beef has been an issue in the beef supply chain. This is because bacteria or germs can be transferred due to human touch and may result in beef contamination. However, the adoption of RPA has enabled tasks to become automated and so there are lesser chances of contamination to beef products. RPA has lowered risk-factors regarding producing unhygienic and low-quality beef as the process time is less to perform tasks; the innovation also facilitates and controls wastage along the processing line through efficient process delivery (E-Fatima *et al*., 2023; Leffler *et al*., 2023). Due to short processing time span, there are low chances of contamination and since most of the tasks are automated, so it also lessens human intervention. Hence, the biggest advantage of RPA adoption is that it lowers production time span and lowers risk percentage for the beef to get contaminated. However, poor monitoring or governance can lead to beef contamination and result in animal wastage. There are many factors that combine to produce quality beef and if they are not administered properly that may cause a problem in RPA successful adoption. The factors include monitoring RPA, controlling temperature where beef is being cut and manufactured and preventing unnecessary human touch to the beef. Thus, maximised RPA performance is essential to produce hygienic beef that is of high-quality. RPA role in maintaining beef quality and hygienic production is significant as the technology allows business processes to scale-up (Nicoletti, 2023).

2.8.3.2 Process Knowledge

RPA is an emerging technology which become increasingly and widely adopted by supply chain systems and facilitates in terms of providing automation solutions to complex business processes and ease employee burdens in organisations. It helps solve problems related to human error, supply chain complexities and instability and catering risk factors. RPA adoption also help businesses to tackle process challenges in complex supply chain systems (Costa *et al*., 2022). RPA has gained significant value in terms of adoption for making business processes easier, flexible, and less-complex; however, the process knowledge, criteria's, suitability, and standards of adoption requires more focus and critical examination. Organisations have widely adopted RPA, however, its full utilisation and attaining its maximum benefits is still challenging for business environments or supply chain systems. Process knowledge to RPA technology adoption is an important factor to consider as it contributes to appropriate RPA adoption. It is crucial to analyse the knowledge, requirements and suitability of RPA when deciding of its adoption. This is because RPA is only suitable for business processes where tasks are repetitive, strenuous, mundane and rule based. Acquiring this sort of process knowledge where suitability criteria and measures are considered for RPA adoption is highly important for organisations to gain full advantages of this technology. Evaluation of the business process, requirements of the processes and their work nature are important aspects to analyse in decision-making of RPA adoption within supply chain systems (Siderska, 2021).

The process knowledge of RPA adoption directly relates to the nature of the business processes, work environment, work behaviour, employee-acceptance to the technology and settings of work. Time constraints, manpower requirements for RPA monitoring and implementation, cost occurring in adoption process, business system structure are all other process knowledge criterions or parameters to consider in the adoption process of RPA. The process knowledge of RPA implementation and adoption may vary from business to business and each other organisation may have their own expectations from RPA technology (Wanner *et al*., 2019; Syed and Wynn, 2020). Therefore, analysing and assessing the process knowledge and the parameters to RPA adoption is important from the perspective of a decision-maker.

2.9 Research Problem evident from Literature Review

This study aims to support the beef industry by providing a generic process model for the effective adoption of RPA in beef supply chains. The beef supply chain faces numerous challenges and disruptions, including environmental impact, labour conditions, economic viability, social responsibility, food security and other supply chain risks (Arabsheybani, 2024). To address these challenges and meet sustainability goals, there is a need for innovative technologies. While there has been increasing interest in RPA adoption in recent years, previous research has not thoroughly examined the potential risks to its implementation within beef supply chains (Payal, 2024; Raffik *et al*., 2023). This study focuses on identifying main bottlenecks in RPA implementation and assessing its sustainability impact. By examining the role and impact of RPA from a sustainability perspective, the study aims to provide valuable insights for academia and practitioners. The findings contribute to addressing risks in RPA adoption in the beef supply chain and enable managers to utilize the process model effectively to meet sustainability criteria. Overall, RPA successful adoption and maximised potential can positively impact beef supply chain management by increasing efficiency, accuracy, visibility, cost-effectiveness, responsiveness, and compliance. By addressing the gap identified, beef supply chain stakeholders can optimise their operations, improve customer satisfaction, and achieve sustainability through adopting RPA strategically and systematically.

The thematic narrative literature review conducted in this chapter focused on the key themes that were derived from existing literature and information related to RPA adoption in beef supply chains. The key themes and the underlying concepts were discussed in detail in the thematic narrative literature review. The themes play a significant role in assessing the adoption of RPA in beef supply chains and provide an enhanced understanding on its application and implementation. To summarise, this chapter discussed three key themes: management and governance, technological perspective, and organisational perspective. It is evident from the literature review that RPA has gained considerable popularity and is an emerging technology that facilitates business operations and allows efficient task delivery through process automation. The thematic narrative literature review also discussed beef supply chain dynamics and challenges and RPA nature and characteristics. The literature review stresses and points that RPA provides potential benefits to business organisations and enhances supply chain performance and managerial decision-making to achieve sustainability and gain competitive advantage. However, its full adoption remains a challenge in beef supply chains as apparent from the thematic narrative literature review. The discussion in this chapter revealed that there are potential risks to the adoption of RPA within beef supply chains due to which beef manufacturers are unable to utilise its maximised advantages and full potential. The literature review also highlights that attention is required to overcome the potential risks or hinderances in RPA adoption in beef sector. Smooth RPA adoption and accuracy automates tasks and allows beef supply chains to gain operational and financial efficiency, as pointed out in the thematic narrative literature review.

The forthcoming chapter explores the theoretical framework utilised in this research to examine the adoption process of RPA technology within beef supply chains. This framework offers a deeper understanding of the theoretical perspectives and foundational knowledge essential for addressing the research problem at hand. By focusing on RPA technology adoption within beef supply chains, the theoretical framework fills existing research gaps and aligns with the study's aims and objectives. It also plays a crucial role in guiding the implementation of cutting-edge RPA technology within the beef supply chain, considering key parameters pertinent to this context. Moreover, the theoretical framework establishes a systematic approach for assessing factors influencing RPA adoption and serves as a foundation for scenario development and analysis in subsequent chapters. The study aims to solve the research problem, explore RPA's role from a sustainability perspective, and identify potential adoption risks by testing 'what-if' scenarios based on significant parameters. The chapter provides an in-depth overview of the theoretical framework employed in this research, facilitating the achievement of study objectives, and offering solutions to the research problem.

CHAPTER THREE: THEORETICAL FRAMEWORK FOCUSING ON RPA ADOPTION IN BEEF SUPPLY CHAINS

3.1 Introduction

This chapter provides an overview, analysis, and evaluation of the extant literature on the influence and adoption of RPA within beef supply chains to address the research gap and meet the research objectives of this respective study. The chapter comprises of six sections which are significant in terms of their discussion with respect to the theoretical framework of study to explain the adoption process of RPA and highlight the significant parameters which influence its implementation process in beef supply chains. Initially after the introduction to chapter, RPA conceptualisation has been explained followed by discussion on the theoretical framework undertaken in this simulation study to address the research problem and fill the research gap. Afterwards, RPA operationalisation has been discussed, and the theoretical propositions have also been highlighted which are then followed by the chapter summary. The Figure 3.1 provides an overview of the chapter three for enhanced understanding.

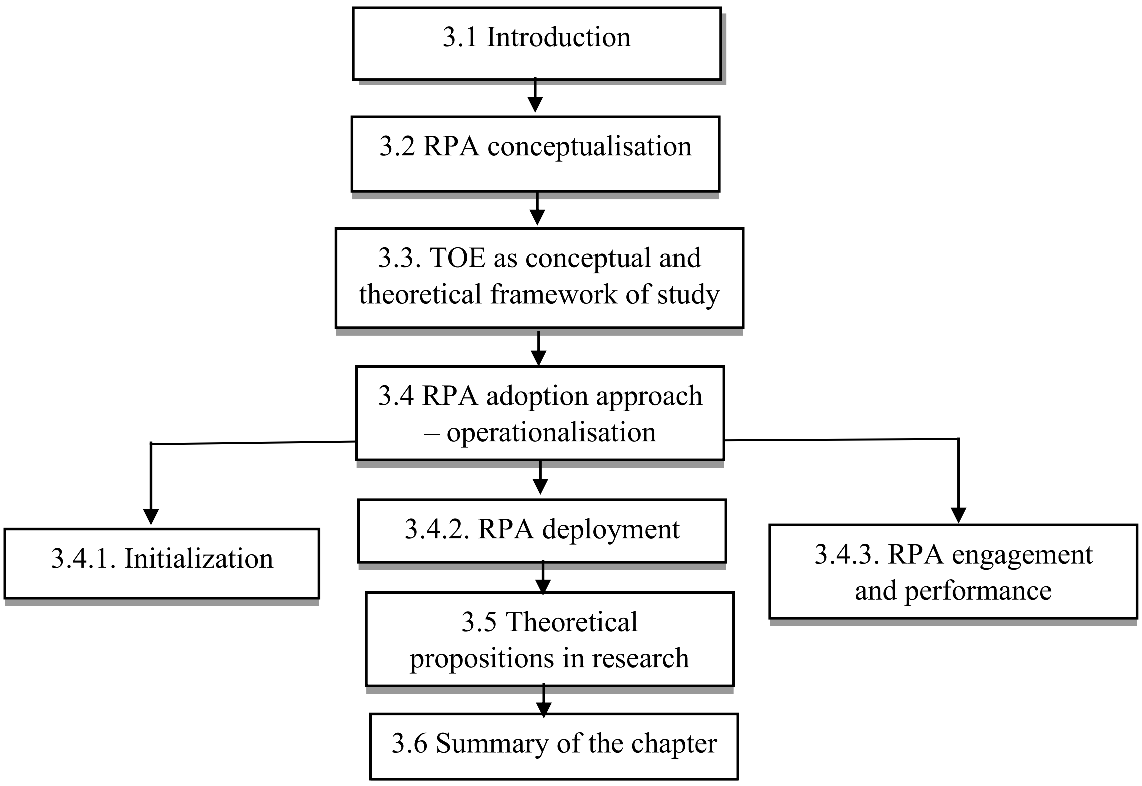


Figure 3.1: Research outlined based on theoretical framework undertaken (Source: Author)

3.1.1 RPA – concepts and theoretical views

This section explores and discusses the different approaches to RPA. In 2012 the term was first used by the Blue Prism's Marketing Director Patrick Geary and was coined by Phil Fersht who was the lead analyst and founder at HFS Research (Hindle *et al*., 2017). Machine Learning is one of the famous technologies that helped businesses to improve their processes and is considered a prominent innovation, and this finally led to the creation and development of RPA. Although, the European Patent Office (EPO) acknowledges Adrien Jacquot and Cyrille Bataller as the inventor the promising RPA technology (Rajagopal and Ramamoorthy, 2023). There are many definitions in academic theory of RPA and so no one philosophical approach can explain the term RPA in literature due to lack of scientific research in the specified domain. All definitions mainly have an emphasis on the automation of repetitive tasks through adoption of software bots to perform rule-based processes (Osman, 2019). Therefore, the research evaluates and assesses the essence of RPA and its role in beef supply chains as a sustainability tool and driver; the study also focuses on the identification of potential risks in its adoption process within beef supply chains for a robust adoption approach and alleviation of risks. The technology is one of the major inventions in Industry 4.0 revolution and has reformed business processes and allowed business enterprises to achieve sustainable value.

In historical and theoretical perspective, Jordan (2019) shed light on the term 'robot' which developed in the 1920's by a Czech writer and was used in a play named as R.U.R. "Robota" is a Slavic word from where the term robot has been derived and it means hard work and effort. 'Robot' and 'RPA' are the two terminologies which are interconnected in academic literature. The concept RPA is directly associated with 'software robot' that use predefined algorithms to imitate human tasks and actions. RPA has grown both industrially and in research and linked to sustainability in business processing. The overall concept of RPA in viewed from a broad and narrow approach in the literature. As informed by Sobczak (2021), the narrow aspect to the technology refers to information technology tools that are utilised for business process automation with the use of software bots that are computer programmed. In academic theory, the broader view of the term states that the technology can be potentially recognised as a technological and organisational change which deploys software bots leading to creation of a hybrid labour.

RPA is a widely used term in academic literature and scientific research as it is one of the prominent technologies developed and emerged in the industrial revolution. According to Gradim and Teixeira (2022) RPA is a significantly trending technology in Industry 4.0 and adopted across many sectors such as accounting, finance, manufacturing, logistics, banking etc. As bots replaced humans to perform tasks earlier, now the software bots also known as RPA automates business processes to perform repetitive, time-consuming, and non-value-added tasks. RPA is much easier, user friendly, less expensive, and faster in terms of implementation as no programming skills are required for the promising technology. Bots' implementation can save numerous manual hours and enhance efficiency, productivity, and organisational competitiveness to meet sustainability goals. There are many views and interpretations associated with the term though it is broadly used as technological advancement which support business processes. Many believe that the term RPA emerged and developed in the early 2000's; however, its initial working and development process started in the early 1990's. Even though, RPA has attracted many business users who strive to enhance efficiency levels, the terminology is still confusing to many and has certain misconceptions related to its concept and functioning. Therefore, Ghouse and Sipos (2022) stated that '…. RPA excludes the involvement of physical robots to perform automation but software, which is used to imitate human actions and that software, is developed to perform certain actions in accordance with the developer's instructions.' Thus, following the significant theoretical analysis on RPA terminology, the concept of the technology could be understood with its actual and authentic meaning which depicts that the innovative technology uses software bots for process delivery and generally physical robots is a misconception associated with the respective terminology.

3.2 RPA conceptualisation

It is crucial and important to understand and determine the theoretical concepts and perspectives related to how RPA, considered as a strategic catalyst in business development, has evolved and conceptualised in academic literature. This study endorses an organisational level approach, focusing on the beef supply chain, to analyse RPA adoption process with the aim to identify the potential risks in the implementation process. The promising technology is popularly considered and widely adopted by manufacturing supply chains to automate processes, enhance business operations and productivity, and achieve sustainable value, though it has its challenges in terms of the adoption processes. Successful and robust RPA adoption remains a challenge, especially in the beef sector, and thus it is important to identify and analyse the risks at an organisational level so that these could be potentially alleviated or eliminated in real-life scenarios within the beef sector. Hofmann et al (2020) conceptualises and defines RPA as *"preconfigured software instance that uses business rules and predefined activity choreography to complete the autonomous execution of a combination of processes, activities,* *transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management."* In another theoretical viewpoint, RPA can also be characterised and described as improving key performance indicators using automation and execution of tasks through pre-defined rules or instructions (Fung, 2014).

To further highlight, RPA involves the use of software robots or "bots" to automate routine and repetitive tasks, improving efficiency and accuracy. In the context of beef supply chains, RPA can streamline various processes, from production to distribution. RPA leverages software to mimic human interactions with digital systems, executing tasks such as data entry, processing transactions, and responding to simple inquiries (Mohamed and Frank, 2024). The core components of RPA include bots, automation software and machine learning. RPA can be applied across several stages of the beef supply chain such as production, processing, distribution, and retail. The promising technology reduces costs and improves efficiency, accuracy, and scalability. In summary, RPA offers significant advantages for beef supply chains, enhancing efficiency, accuracy, and cost-effectiveness. However, successful implementation requires careful planning and addressing potential challenges (Eulerich *et al*., 2023).

3.2.1 The age of automation: RPA as a groundbreaking innovation

Process Automation in Beef Supply Chains and its adoption challenges

As a facilitator to complex business systems, RPA is considered an emerging and innovative technology in the domain of Business Process Management (BPM), as it provides benefits such as automating rule-based processes. Agrosinelli et al (2022) note that in recent years many industrial deployments for business-oriented services and facilitations have resulted from scientific research, knowledge, and practical aspects on RPA. RPA have attracted meat processing supply chains that constantly strive for quality, safety, efficiency, capacity, and cost sustainability. For the food supply chains, especially in the meat manufacturing and processing, COVID-19 has brough considerable challenges with respect to labour shortages and shutting of meat processing plants. Over the past 25 years, automation has significantly impacted beef manufacturing and processing, aiming to streamline business processes and simplify supply chains. While full automation remains debated—small organisations still rely on manual labour—larger businesses are adopting digital technologies like RPA. Historically, industrial revolutions have transitioned from steam-powered mechanization to mass production with electricity, then to computer and electronic automation, and now to AI, machine learning, and RPA in the fourth revolution. Today, the beef sector quickly adopts technological innovations due to high demand, sustainability, quality, safety requirements, and high operational costs. Many tasks once manually performed are now efficiently handled by RPA, where software bots automate complex, rule-based tasks.

The beef supply chain is complex, necessitating careful evaluation for adopting RPA. Historically, the beef industry has been slow to embrace such innovations due to its operational challenges. The first automation in meat production began with pork. Traditionally reliant on human labour, the beef sector is now turning to RPA due to technological advancements, high operational costs, labour shortages, increased demand, and productivity issues. According to de Medeiros Esper (2021), meat demand grew by 20% over the past decade and is expected to rise by another 15% in the next ten years. Harsh working conditions, such as cold operating rooms and rigorous processing tasks, have also deterred labour, driving the push for RPA in beef supply chains. Kerry et al. (2006) emphasises the importance of shelf-life, beef quality, and nutritional value in sustainable beef production. In the past, meat processing plants and production systems were manually operated due to their complexity, leading to higher contamination risks and shorter shelf-life. Echegaray et al. (2022) highlight modern autonomous systems, such as software bots, enhance production efficiency, profitability, and beef quality. Barbut (2014) adds that significant changes in the beef sector over the past fifty years, including the advent of electricity, computers, and scientific advancements, have transformed meat processing. Automation and mechanisation have notably increased since the industrial revolution. Santos et al. (2020) note that while RPA is popular in today's digital business environments, much of the scientific literature focuses on theoretical aspects, with less attention to practical implementation gaps.

3.2.2 Theoretical views on driving sustainability through RPA in beef production

Sustainability and sustainability-oriented innovations have gained significant value in business processing and supply chain management. Qureshi et al (2020) highlights that the increasing demand and awareness in businesses towards sustainable practices in production and manufacturing have become the centre of focus for organisations in the past decade such as in the manufacturing supply chains. Sustainable practices and innovative business strategies have transformed business processes and enabled organisations to be more productive, long-term viable, profitable, and systematic. Over the past years, organisations have become significantly aware of socio-economic pressures and strive to adopt sustainable technologies that could improve efficiency levels and create sustainable value. Many consultants and scholars argue that such pressures offer excellent benefits and opportunities for businesses, and further explain that innovation is the key to achieve sustainable growth. Achieving such socio-economic goals requires investment and focus from business organisations in innovative technologies such as RPA. Therefore, in recent years, sustainable supply chain management and sustainable development in businesses has grabbed attention of many academics and practitioners. In academic research and existing literature, Seuring and Müller (2008) define sustainable development as *"a development that meets the needs of the present without compromising the ability of future generation to meet their own needs"*. Grimm et al (2014) theoretical approach in literature depicts that the food industry has considerable sustainability challenges and therefore, food manufacturers focus on adoption of sustainable business strategies, technologies and models that could potentially enhance quality and safety standards in food production whilst reducing risks and costs.

The industry dynamics have been continuously progressed during the past years due to digital transformations and technological advancements such as RPA in business processes. Habib and Chimsom (2019) highlight that industry 4.0 and its technologies are the key forces behind digitalisation and sustainable value creation in business processes. Technology such as RPA are the industry 4.0 revolutionary innovations which has provided promising benefits to businesses in terms of social welfare, quality deliverance, improving operational and financial efficiency levels and majorly contributing to the three dimensions of sustainability i.e., social, environmental, and economic. In argument to that notion related to RPA benefits, Syed et al (2020) analyses that despite current advancements such as process automation, there are still several challenges to its full implementation and adoption such as in the beef supply chains due to potential risks to its adoption process. Figueiredo and Pinto (2021) conducts further research investigation in the RPA domain and adds that RPA might have come across as a powerful business tool to automate processes, but its full potential and adoption still requires focus and attention for its full utilisation of services to achieve sustainable value.

Zoubek et al (2021) assesses the benefits of RPA stating that the state-of-the-art technology is an industrial revolution innovation which contributes to green production, socio-environmental advantages, and sustainable development in manufacturing supply chains such as the beef processing and production. Sustainability is gaining importance in manufacturing supply chains and businesses are readily attracted towards sustainable choices Javaid et al (2022) notes that technological breakthroughs such as RPA lower production costs, improve market competitiveness, ensure higher profits and productivity, and enable businesses to have a high sustainability effect. Sustainability 4.0 considers social, economic, and environmental dimensions to transform manufacturing processes, employ socio-economic stability and accelerate value addition in supply chain systems (Grzybowska *et al*., 2020). Storer et al (2014) researched and analysed that quality, efficiency, and competence of beef supply chains are important factors for consideration and explains that these aspects are vital and contribute to sustainable beef production and value creation. According to recent academic research and existing literature, beef supply chains are described as being highly risky, challenging, and vulnerable to threats due to a complex supply chain system and thus beef manufactures are now seeking smart, advanced technologies, simulation approaches, and sustainable business tools such as the RPA which automates rule-based tasks and ensures process excellence to gain financial and operational efficiency (E-Fatima *et al*., 2023). Azizsafaei et al (2021) argues and theoretically evaluates that systematic risk assessment in advance is required for challenging food supply chains such as the beef sector for full implementation and adoption of innovative technologies like RPA.

3.3 Conceptual and theoretical framework

This research examines and identifies the potential risks in the adoption of RPA in beef supply chains. The study also investigates the role and impact of RPA in beef supply chains from sustainability lenses. According to Li et al (2023) organisations are feeling a desperate need and requirement to adopt and implement advanced digitalised technologies as they face numerous entangled challenges due to globalisation, increased competition, and fast-paced markets. Due to this necessity to remain competitive in the market and gain sustainability, there has been a shift in the production and manufacturing systems and how they function. In the industry 4.0 paradigm, experts suggest that socio-environmental developments along with technological advancements could pave the way for green production and manufacturing in industrial aspects (Reischauer, 2018; Frank *et al*., 2019; Klingenberg *et al*., 2021). Beef supply chain is highly fragmented, complex, and challenging and therefore the adoption process of RPA is difficult due to hinderances and risks in the supply chain process. The stakeholder theory and institutional theory are important framework employed in supply chain management. These theories play crucial role in shaping and guiding supply chain management practices. According to Wang et al (2024), stakeholder theory in supply chain systems focuses on understanding and managing the relationships between various stakeholders involved in the supply chain. This theory emphasises that organisations should consider the interests and expectations of all stakeholders, including customers, suppliers, employees, investors, communities, and regulatory bodies, when making decisions and formulating strategies. Key aspects of stakeholder theory in supply chain systems include identifying stakeholders, understanding stakeholder interests, balancing stakeholder's interests, managing stakeholder's relationships, accountability and responsibility and creating shared value. The respective theory highlights the importance of identifying opportunities to align business objectives with societal needs and environmental concerns, thereby generating shared value for all parties involved (Mahajan *et al*., 2023). Overall, stakeholder theory in supply chain systems emphasises the importance of taking a holistic and inclusive approach to supply chain management, where the interests of all stakeholders are considered and integrated into decision-making processes to create sustainable and mutually beneficial outcomes (Yawar and Seuring, 2024). On the other hand, the significance of institutional theory in supply chain systems lies in its ability to provide a framework for understanding and navigating the complex external environment within which supply chains operate (Lopez-Morales *et al*., 2023). Institutional theory helps supply chain managers comprehend the external pressures, norms, and regulations that influence supply chain operations. This understanding allows organisations to adapt their strategies and practices to align with institutional expectations. Institutional theory guides organisational behaviour by shaping the norms, values, and practices that are considered legitimate and appropriate within the industry. This influences decision-making processes and the adoption of certain supply chain practices. Institutional pressures can stimulate innovation and change within supply chains. Organisations may adopt new technologies, processes, or sustainability initiatives in response to evolving institutional expectations and market trends (Hatamlah *et al*., 2023). To summarise, the institutional theory provides valuable insights into the external forces and institutional pressures that shape supply chain systems. By understanding and responding to these influences, organisations can effectively manage their supply chains, enhance their legitimacy, and drive sustainable business success (Arranz, and Arroyabe, 2023).

The simulation study utilised the TOE framework to examine the role and impact of RPA technology in beef supply chains, as well as to identify potential implementation risks. The framework proved highly suitable in filling the research gap, providing a robust theoretical foundation for addressing the research problem and questions effectively. Additionally, the TOE framework was chosen for its holistic approach to RPA adoption, enabling the identification of key factors influencing both supply chain operations and RPA implementation. It encompassed not only technological and organisational aspects but also internal and external factors pivotal to the adoption process. Moreover, the research employed

TOE theoretical framework as it aligned with the research aim and objectives and aided in providing a conceptual overview and understanding from organisational context with respect to the RPA adoption process in the beef sector. The TOE framework allowed a comprehensive view, systematic understanding and strategic approach towards the adoption and implementation of the sustainability-oriented technology termed as "RPA" in beef supply chains. The TOE framework, an acronym for Technological, Organisational, and Environmental, serves as a comprehensive framework for analysing the adoption of new technologies within organisational contexts. This study aimed to achieve sustainable adoption of RPA within beef supply chains by mitigating implementation risks. The study also focused on RPA impact on beef supply chains and evaluated RPA capabilities from sustainability dimensions that are social, economic, and environmental. The TOE framework aligns with the study's primary focus, as it comprises three key constructs: technological, organisational, and environmental. The utilisation of the TOE framework was particularly pertinent, aligning well with the research objectives and aiding future decision-makers in effectively adopting and leveraging the RPA technology.

Baker (2012) provides insights on the TOE framework and highlight that the theoretical framework was created and developed by Tornatzky and Fleischer in 1990. The TOE theoretical framework focuses on the three aspects from an organisational context which influence and impact the adoption and implementation process of a technological innovation. Agrawal et al (2022) sheds light on the three key determinants to the TOE framework which are technology, organisation, and environment respectively. To further explain, the TOE framework was purposely developed in the domain of information systems to explain and examine the adoption process of new technologies and the factors that influence the adoption process. This includes the characteristics or attributes of the technology itself, the organisational context in which the technology is adopted and the external environment in which the business operates. Technology refers to the nature of the technology itself, its attributes, complexity, suitability, and functionality with existing business systems. Organisation comprises of the internal context in which technology is to be adopted, including other organisational aspects such as culture, size, structure, management, and resources. Environment in the TOE term refers to external factors such as social and cultural norms, regulatory requirements, market conditions etc (Chatterjee *et al*., 2021). The framework is widely used and adopted for an enhanced understanding on the technology adoption within supply chains or organisations; the TOE framework has proven to be very useful and a powerful tool for understanding the strong connection between technology, organisation, and the wider environment. Hence, the TOE framework includes the technological, organisational, and environmental constructs that were the centre of focus in this research for a deeper understanding on the adoption process and the factors that influence its implementation in the beef supply chains. The Figure 3.2 provides a TOE framework and its three contexts (Morawiec and Sołtysik-Piorunkiewicz, 2023).

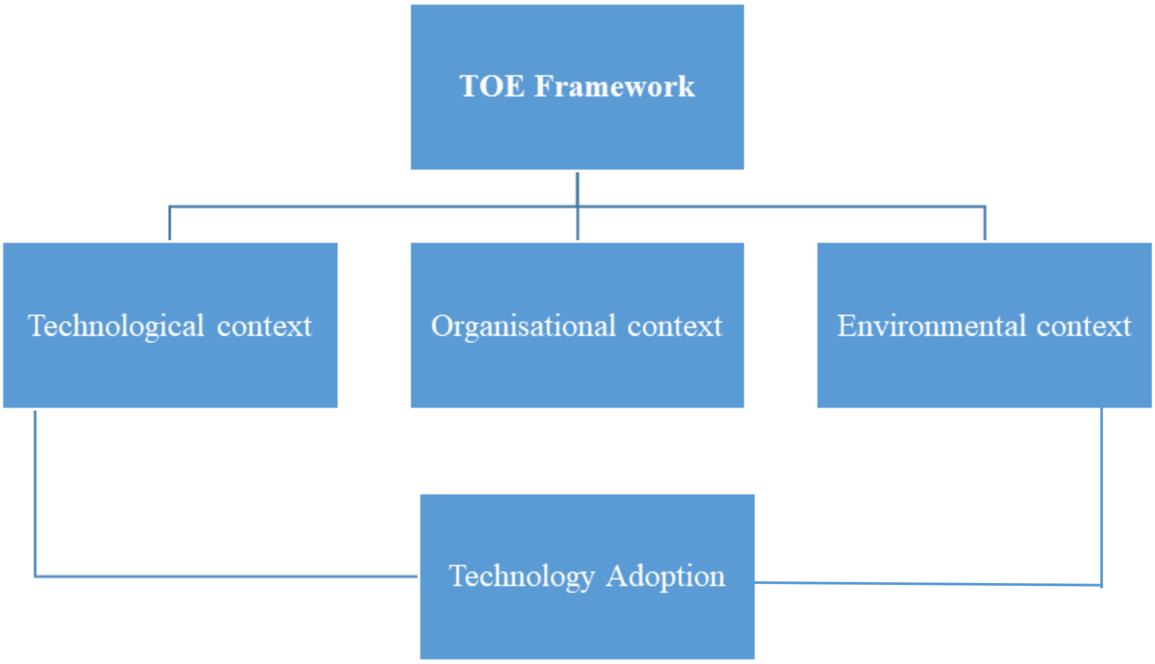


Figure 3.2: The three contextual aspects in TOE Framework (Adapted from Morawiec and Sołtysik-Piorunkiewicz, 2023)

This research used the TOE framework as the study investigates the role and impact of RPA technology in beef supply chains and identifies the potential risks to its implementation process. This framework was a perfect fit and helped the researcher to build a robust theoretical ground which aided in solving the research problem and answer the research questions adequately. There were also other reasons due to which the TOE framework was selected and suitable for the respective research. The TOE framework provided a holistic approach to RPA adoption process and helped in identifying the key parameters or factors that influence supply chain operations and RPA adoption process. The framework not only focused on the technological or organisational aspect, but also considered the internal and external factors or parameters that play a significant role in the RPA adoption process. Oliveira and Martins (2011) observes that the TOE framework provides a finely nuanced approach to the researcher in understanding the complex interplay of parameters that impact the technology adoption decision. Another important reason behind the TOE framework utilisation in this research was its flexibility, relevance and application to simulation-based approaches and range of technologies within organisations. The TOE framework includes the organisational and technological aspects along with focusing on the external parameters which include social and environmental dimensions, and this helped in accomplishing the aim and objectives of this simulation study. Consideration of the socio-environmental aspects along with organisational and technological factors also helped to examine and analyse RPA technology from a sustainability perspective in beef supply chains. RPA facilitates business processes through process automation and is also considered to be sustainability booster and accelerator due to process excellence; the multi-dimensional approach of the TOE framework not only supported with the knowledge and understanding on the key factors or parameters important for consideration in the adoption process but also facilitated the study by evaluating the impact of RPA technology from the three facets of sustainability in the beef supply chains. Hence, TOE theoretical framework undertaken and chosen in the study aligned with the research problem and helped to meet the aim of research that identifies the potential risks in the implementation process of RPA and investigates RPA's impact and influence from sustainability perspective in beef supply chains.

3.3.1 TOE as the theoretical framework in the adoption of RPA in beef supply chains – consideration of the three constructs

The TOE theoretical framework, encompassing technological, organisational, and environmental contexts (Stjepić et al., 2021), underpins research on implementing and adopting innovative technologies. This study focuses on the organisational context within the beef supply chain, where modern economies drive the need for flexibility and new business strategies due to rapid innovation, globalisation, and competitiveness. The research examines the role and impact of RPA technology in beef supply chains, identifying potential adoption risks. It employs a simulation-based approach to evaluate 'what-if' scenarios, using a business process model of significant beef supply chain stages. The TOE framework facilitated an in-depth exploration of factors influencing RPA adoption, guiding scenario development and analysis. By applying the TOE framework, the study gained a deeper understanding of RPA's impact on beef supply chains and identified crucial adoption risks. This framework provided comprehensive insights into RPA as a sustainability booster and its potential in the beef industry. The findings help fill research gaps and offer practical solutions for future beef industry practitioners to adopt RPA efficiently and robustly.

RPA adoption from organisational perspective and TOE framework chosen for this research

According to Bwalya (2020) the revolutionary and state-of-the-art RPA innovation which is a prominent technology in the fourth industrial revolution has marked a significant change in process delivery philosophy and the technology infrastructure. Robust RPA adoption enables beef manufacturers to meet sustainability goals, enhance operational and financial efficiency, and meet growing demand at lower costs. Pramod (2021) notes that while organisations are eager to adopt RPA to streamline business processes, they face challenges in complex environments. A thorough analysis of the nature and scope of RPA and the business environment is essential for successful implementation. Given the complexity of beef supply chains, it is crucial to adopt the best RPA approach to maximise the benefits of this advanced technology (Kirchmer and Franz, 2019).

RPA adoption in beef supply chains requires thorough development, assessment, and theoretical analysis. Research on the philosophical and theoretical approaches for RPA in this context is limited (Baby and Kannammal, 2020). While models like TAM, UTAUT, and the IS success model are commonly used for technological adoption (Mardiana *et al*., 2015), they often focus on technical aspects and overlook organisational and supply chain perspectives. The Diffusion of Innovations Theory and Swanson's typology suggest that external and technological factors are as influential as organisational ones in technological adoption. Institutional theory (Rogers, 2003; Yang *et al*., 2021) emphasises the role of external business challenges in innovation adoption. Cagliano et al. (2019) note that technology-specific traits are crucial in the adoption process. This research chose the TOE framework for its flexibility and ability to incorporate various factors influencing RPA adoption in beef supply chains (Li *et al*., 2023). Figure 3.3 in the study provides a comprehensive overview of the TOE framework, highlighting the significant parameters affecting RPA adoption in beef supply chains.

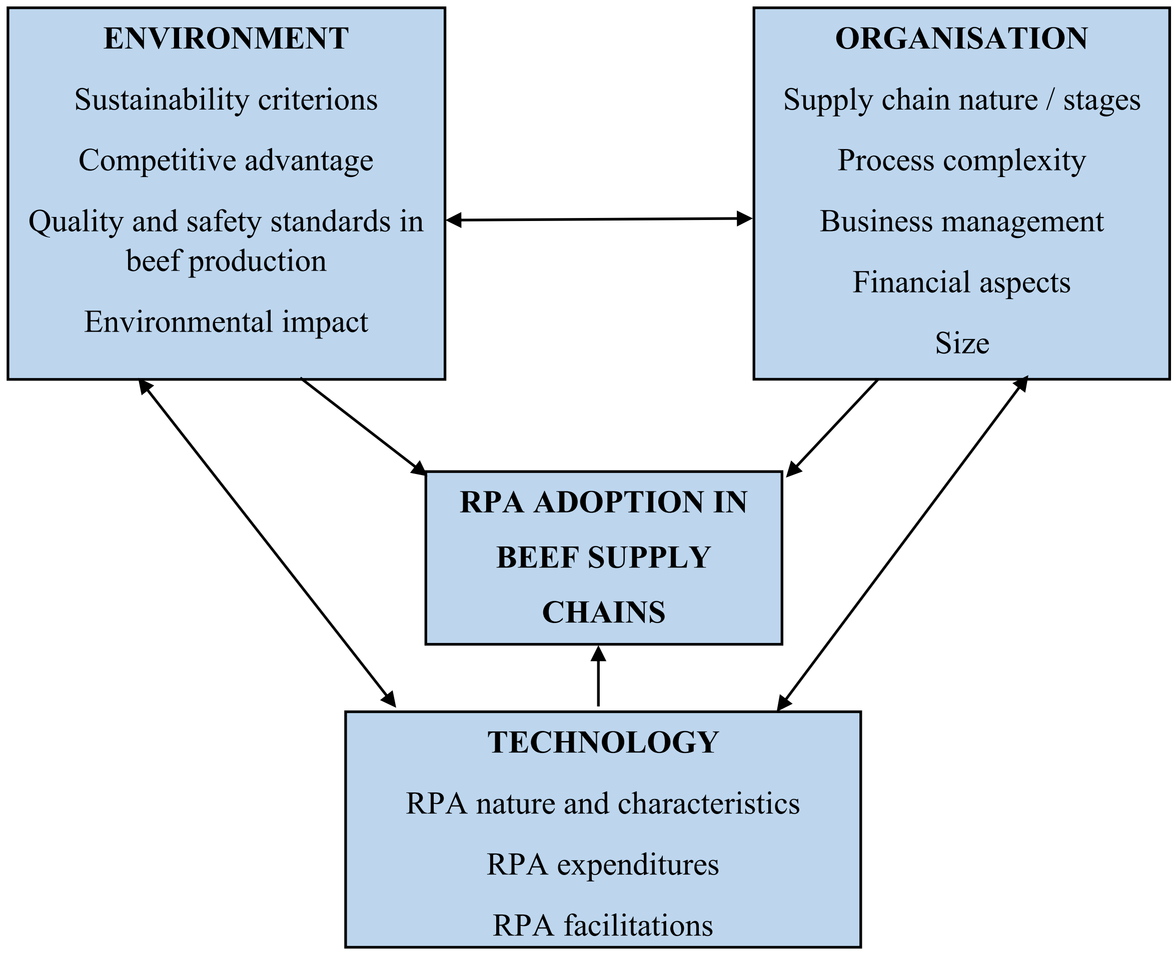


Figure 3.3: The Context of RPA technology: TOE framework outlook (Source: Author)

As illustrated in Figure 3.3, our simulation-based study utilised the TOE framework, focusing on its three key constructs: technological, organisational, and environmental. These constructs were crucial in evaluating the robust adoption of RPA in real-world scenarios within beef supply chains. While Industry 4.0 technologies like RPA offer significant improvements to manufacturing supply chains, the approach to its adoption for sustainable beef production remains unclear and requires careful analysis (E-Fatima *et al*., 2023; Kim, 2023). The following discussion highlights the roles of these TOE framework constructs in the RPA adoption process.

Technological context in RPA adoption in beef supply chains

Aboelmaged (2014) emphasises the importance of the technological perspective in understanding technology adoption processes. Technological considerations provide insights into the nature, characteristics, and sustainability implications of technologies in business environments (Dadhich and Hiran, 2022). The technological context, covering RPA nature, costs, and facilitations, is crucial for theoretical analysis. Understanding RPA's nature helps assess its suitability for automation within the beef supply chain. Financial assessment is essential for RPA integration, considering its costs. RPA is seen as a sustainability booster, necessitating evaluation of its role in accelerating processes from a sustainability standpoint. Theoretical exploration of RPA provides insights into its benefits across social, economic, and environmental dimensions. A thorough analysis of the technological context is vital for the robust adoption of RPA in beef supply chains.

Organisational context in RPA adoption

Based on the theoretical knowledge and understanding, the TOE framework explored the organisational context from different perspectives such as the beef supply chain nature and stages, process complexity, financial aspects or parameters and organisational structure. Analysing beef supply chain characteristics and identifying suitable stages for RPA adoption is essential. Understanding supply chain nature provides insights into beef manufacturing processes. Evaluating process complexity helps determine which operations are ripe for automation. Assessing business management within the organisational context is crucial for understanding RPA's impact on sustainability and managerial decision-making. Robust RPA adoption enhances beef supply chain quality, safety, and shelf-life. Hildebrandt et al. (2019) emphasise the role and importance of organisational size and structure in RPA adoption. Stakeholders and managers must evaluate RPA process suitability based on the size, assembly, and stages of the beef supply chain to address challenges effectively.

Environmental context in RPA adoption

The TOE framework, encompassing various contextual aspects, including the environmental context, evaluates the adoption process of RPA in beef supply chains and its environmental impact through process automation. Given the sustainability challenges faced by beef supply chains, thorough assessment of RPA adoption is necessary to ensure successful implementation. Environmental considerations include sustainability criteria, competitive advantage, quality and safety standards, and environmental impact. Assessing RPA's impact on social, economic, and environmental dimensions is crucial. Evaluating how beef supply chains can achieve green and sustainable production systems through RPA adoption is essential. Given the ongoing environmental challenges in beef supply chains, it is essential to assess how RPA improves process delivery and creates sustainable value in beef manufacturing. Enhancing competitive advantage in dynamic work environments also enhances employee efficiency, leading to significant socio-environmental impact through autonomous business processes (Sheth et al., 2020). It was crucial to evaluate RPA adoption's impact on beef quality and safety standards, essential for ensuring optimal production practices. Furthermore, studying RPA's broader environmental impact and potential socio-economic benefits in beef supply chains was highly critical. Gerber et al. (2015) stressed the importance of assessing external environmental factors in beef production's environmental impact. Awa et al. (2017) utilised the TOE framework to analyse the significant role of technology, organisation, and environment in meeting quality and safety standards, enhancing customer satisfaction, and increasing business efficiency. RPA adoption has greatly improved manufacturing systems by developing smart, automated, flexible, and eco-friendly production systems. It not only boosts business competitiveness but also improves complex process management and resource utilisation (Liu and Zhang, 2020). Robust RPA adoption in both large organisations and SMEs aids in achieving sustainability goals and overcoming potential risks in beef supply chains.

3.4 RPA adoption approach – operationalisation

Shidaganti et al (2023) observes that industrial revolution and digital transformations such as the RPA has brough considerable changes to business processing and added value to supply chain processes. The cutting-edge and pioneering technological solution has automated repetitive tasks making supply chain processes less complex due to reduced risk and human error. Although the revolutionary technology is employed and implemented for financial and operational excellence, it is significantly applicable among various sector and dynamic business environment. Nahak et al (2023) advocates RPA as a global topic which has gained considerable value in the business world as it improves customer satisfaction and allows organisations to gain competitive advantage and sustainable value; however, there is still a pressing need for additional study and research on practical and theoretical ramifications of the innovative technology. Robotics and automation have promising benefits related to sustainable value, corporate social responsibility, and competitive advantage within businesses. To choose and adopt the best approach for RPA application in beef supply chains, it is necessary to engage and evaluate relevant knowledge and literature related to key parameters which play an important role in RPA adoption process (Nielsen *et al*., 2023). RPA operationalisation involves key steps and phases which are shown in Figure 3.4 for a firmer understanding on RPA adoption process in the beef sector. The lifecycle adoption stages include process initialisation, RPA deployment, RPA engagement and performance and the analysation of overall process in organisations (König *et al*., 2020).

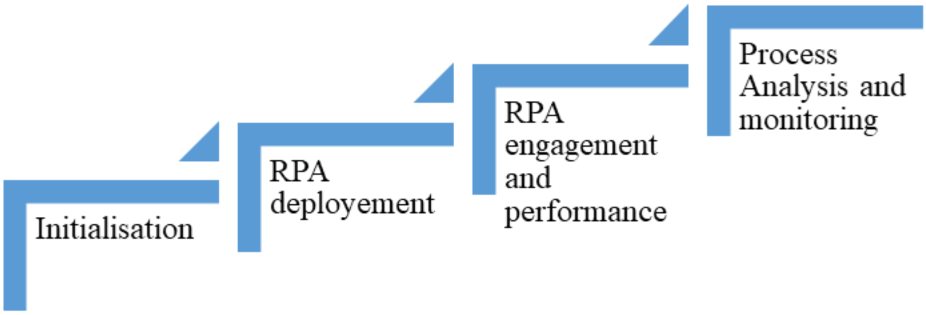


Figure 3.4: RPA lifecycle for adoption (Adapted from König *et al*., 2020)

3.4.1 Initialisation

As discussed above, it was crucial to assess and study the various stages of the RPA lifecycle to have an enhanced understanding on its operationalisation from theoretical lens in this research. This provided further insights and enhanced understanding on the key parameters that impact and influence RPA adoption process. For this purpose, RPA lifecycle stages were assessed and examined. Jimenez-Ramirez et al (2019) points out and explains the RPA initialisation stage which involves the RPA analysis and alignment or suitability with the business processes in dynamic working environments. The RPA design stage models or defines the actual process or task that requires automation and involves any dependencies that need mapping in automation, for instance like the systems it usually interacts with. Moreover, once RPA design has been done then it requires construction or development before moving on to the next stage of deployment. In the development phase of the RPA, the developer builds the bot in accordance with the design stage after which the quality assurance team or RPA developer tests the automated process to observe whether it serves the purpose or not and executes the task as per expectations. These all stages are included within the RPA initialisation after which it reaches the deployment phase for adoption and implementation to run the business process or task (Plattfaut *et al*., 2022).

3.4.2 RPA deployment

Ylä-Kujala et al (2023) focuses on the deployment phase which is considered a significant stage in the RPA lifecycle and is crucial within the adoption process. Before the deployment phase, as discussed and explained in detail before, the RPA is tested and run to see the execution of the process as per the expectations. Once the testing for the RPA is complete, the next stage is its deployment in the business environment. In this stage, the bot is thoroughly and carefully deployed in the production, and it runs as designed and organised in RPA tool's orchestration. The RPA deployment is the stage where the bot is run and performs the task in the business set up and automates processes to create value and meet sustainability standards in processing and manufacturing.

3.4.3 RPA engagement and performance

Once RPA has been deployed for task automation and process excellence in the business processes then it reaches to its final stage of lifecycle. The bot in this stage is continuously monitored with respect to its engagement levels and performance or efficiency to depict how it impacts the supply chain processes. In the RPA performance and process monitoring stage, it is observed and assessed whether the bot works smoothly without any errors or risks in task execution. Bots have various dependencies, and they interact with different systems, therefore they are impacted if any change occurs to those systems. Kirchmer and Franz (2019) believe that change management is a key element in RPA lifecycle; effective change management can prevent the bots from making any errors and ensures smooth and systematic process excellence and delivery. Efficient change management can also enhance RPA adoption process and increase the ROI thus improving supply chain resilience and cost-effectiveness.

To summarise on the above RPA operationalisation stages and lifecycle, it was important to understand the key stages in RPA adoption process to gain enhanced accuracy and potential. RPA is considered as a powerful sustainability tool which automates rule-based, repetitive, and strenuous tasks in dynamic and complex business environments. Lievano-Martínez et al (2022) indicate that RPA is purpose-build to allow stakeholders to add value to their supply chain processes and improve production levels whilst increasing quality, safety, and traceability. However, Rechberger and Oppl (2021) argues that the full adoption of RPA is still challenging in organisations and therefore, it is highly crucial to select the right process for automation to add value to the overall business system. The innovative technological advancement also allows business users to better plan, evaluate, and manage business systems and improve operational and financial performance levels. Therefore, robust, and successful adoption of RPA allows business users to enjoy its maximised accuracy and potential.

3.4.4 Process Analysis and monitoring

The significance of RPA process analysis and monitoring lies in its ability to ensure the effectiveness, efficiency, and reliability of automated processes. By continuously analysing and monitoring RPA processes, organisations can identify optimisation opportunities (Mahala *et al*., 2024). Through process analysis, organisations can identify areas where RPA can be further optimised for improved efficiency and performance. RPA monitoring also allows stakeholders to detect anomalies and errors in real-time, enabling timely intervention to prevent disruptions or errors in process execution. Moreover, analysis and monitoring help ensure that RPA processes adhere to regulatory requirements and internal policies, reducing the risk of non-compliance and associated penalties thus ensuring compliance. Also, by analysing key performance indicators (KPIs) and monitoring process execution, organisations can identify opportunities to enhance performance and achieve better outcomes. Regular analysis and monitoring of RPA processes enable organisations to drive continuous improvement, iteratively refining processes to achieve greater efficiency and effectiveness over time (Kurowski *et al*., 2024). Monitoring RPA processes helps ensure the integrity and security of data being processed, minimising the risk of data breaches or unauthorised access. RPA process analysis and monitoring contribute to sustainability by optimising resource usage, reducing environmental impact, ensuring regulatory compliance, and encouraging a culture of continuous improvement towards sustainable practices (Ling *et al*., 2024). Demonstrating a commitment to sustainability through RPA process analysis and monitoring enhances stakeholder engagement and transparency. By sharing progress and achievements related to sustainability, organisations can build trust with stakeholders and enhance their reputation as socially responsible entities. RPA process analysis provides valuable insights into resource utilisation and environmental impact, enabling data-driven decision-making to enhance sustainability practices. Monitoring enables organisations to track progress towards sustainability goals and make timely adjustments as needed (Rane *et al*., 2024). Overall, RPA process analysis and monitoring are essential steps for maximising the benefits of automation while mitigating risks and ensuring compliance with regulatory requirements and organisational standards.

3.5 Theoretical propositions in research

In this simulation-based research, TOE theoretical framework was employed which comprised of the three contextual aspects or constructs including technological context, organisational context, and environmental context as explained above in ***section 3.3***. The utilisation of TOE framework significantly allowed the researcher to investigate and identify the important key factors or parameters which play an important role in the adoption of RPA in the beef supply chains. The TOE framework outlined the three components from an organisational or beef supply chain context. As this study investigates the potential risks in the adoption process of RPA within beef supply chains and evaluates the role and impact of RPA in beef sector, hence it was crucially important to investigate the key parameters or factors which serve as a basis for scenario development and analysis in this simulation study. The TOE framework was utilised in this research as explained in-depth above and the significant parameters were obtained from technological, organisational, and environmental aspects. A thorough analysis and evaluation was done through critical assessment of different theoretical perspectives, and information related to RPA adoption and deployment in beef sector.

The overall insights of the TOE framework utilised and adopted in this simulation study indicated some prominent parameters from technological, organisational, and environmental perspective that play a significant role in the application and implementation of RPA in beef supply chains. Considering how these parameters influence the effectiveness of beef supply chains and RPA adoption for the automation of strenuous tasks, they were highly important in this simulation research and therefore used as a basis for the 'what-if' scenario analysis. To further shed light on the theoretical proposition and significant parameters, these were also well-reflected in the TOE framework provided in Figure 3.3. As this research investigates RPA adoption impact on beef supply chains from a sustainability perspective, the application and use of the TOE framework immensely helped to consider all three important constructs from an organisational perspective to evaluate the socioeconomic benefits of the groundbreaking technology in beef supply chains.

Quality is an important parameter to consider in the adoption and implementation of RPA technology as it associated with customer and retail satisfaction; also, given this era of digitalisation and sustainability awareness maintenance of quality standards is highly important in beef processing and manufacturing (Tsapi *et al.*, 2022). As quality beef production and maintaining quality standards is a global demand due to human health concerns related to this parameter, it was crucially important to consider this factor from an environmental context as depicted in the TOE theoretical framework. Moreover, Han et al (2022) highlights that beef safety is another important factor or parameter which is important from retailer and consumer perspective. Since this aspect is related to safety and quality standards, health concerns and nutritional value hence, beef safety was considered as a vital parameter in this study. RPA brings a lot of opportunities and services to beef supply chains and one of the prominent parameters for consideration is beef safety. Beef contamination is a common issue and challenge faced by beef manufacturing supply chains and hence, beef manufacturers are constantly seeking sustainable ways and application of innovative technologies that ensures safe beef production. Therefore, beef safety was considered as a parameter from a socio-environmental context in RPA adoption process. In addition to above, Nethra et al (2023) points out that shelf-life is also a significant parameter or factor in beef production and manufacturing which requires attention and focus for robust RPA adoption process in beef supply chains. Beef supply chains strive to achieve higher beef shelf-life and thus struggle to implement sustainable business strategies such as the RPA which ensures less queuing time and energy and accelerated supply chain processes that are fast-paced and less-time consuming. Fast-paced supply chain system allows greater and improved shelf-life thus reducing beef waste and improving customer satisfaction (Rudra *et al*., 2022). Hence, this was another essential parameter considered and included in this research for evaluation of RPA adoption process in beef supply chains. Beef shelf-life was also seen from a technological and environmental context as outlined and highlighted in the TOE framework in this chapter. Through utilisation of the TOE framework the study also focused on another crucial parameter from organisational and technological context which was financial, or cost-related aspects (RPA expenditures and supply chain costs). According to E-Fatima et al (2023) consideration of financial aspects is highly important for efficient and smooth RPA adoption process in beef supply chains. The consideration of financial aspects and RPA expenditures improves the adoption process of RPA in beef supply chains and provides a greater understanding of the cost-related factors. In this simulation-based research, 'what-if' scenarios were assessed and examined based on these four parameters. Therefore, the researcher thoroughly assessed and scrutinised the underpinning knowledge and information relevant to the domain to address the research questions promptly.

3.6 Summary of the chapter

Digital transformations such as RPA have paved way for digital workforce and replaced humans with software bots to execute repetitive, boring tasks (Marciniak *et al*., 2019). This research employed the TOE framework for the adoption of RPA in beef supply chains. The TOE framework provided a deeper and in-depth theoretical understanding on the different concepts, perspectives, and viewpoints on the adoption of RPA technology which has gained considerable value in business organisations due to process excellence and acceleration, value addition, and helping businesses to gain sustainable value. Organisations struggle to fully adopt the innovative RPA technology in beef supply chains; therefore, this study identifies the potential risks to accelerate the adoption process and adopt a strategic approach for its implementation. The TOE framework provided the opportunity to study and examine the three important constructs (technology, organisation, and environment) which were crucially included and considered in this research to obtain the key parameters. The framework also allowed a more systematic and thorough approach to identify and select the key parameters or factors that influence the adoption process of RPA in beef supply chains. The TOE theoretical framework connects and links the researcher to existing knowledge and information related to RPA adoption, conceptualisation, operationalisation, and implementation within beef supply chains and allowed to observe and investigate RPA from sustainability perspective. Guided by the TOE theory, the key factors or parameters were highlighted and proposed in this chapter, and this also helped to conduct the research methodology in a systematic and organised manner. The articulation of theoretical ideas and propositions aided in addressing the research questions and achieving the goals and objectives of the study. Through utilisation of the TOE framework, the researcher was also able to consider the limitations of the study.

The next section explains the research methodology along with the research design and approach undertaken in this research in detail. The research methodology also explains the data collection method and analysation process along with details on the use of simulation software utilised to conduct scenario analysis in this study and answer the research questions to solve the research problem. The research methodology also discusses the development of business process model and the formation of 'what-if' scenarios for process simulation based on the significant parameters that influence functioning and operations of beef supply chains and RPA adoption process.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

Gupta and Gupta (2022) define research as scientific and systematic research to search for information on a specific topic. It can also be described as an art to search for knowledge and investigate scientifically. Research is perceived as a critical evaluation and inquiry on a subject and can be done in any branch of knowledge. The aim of conducting research on a specific topic is to discover answers to specific questions and find solutions to problems. Every research has its own essence and research problem to analyse and solve, thus adding further to the knowledge. Different scientific procedures are followed to conduct research on a specific topic. The purpose to conduct research is to add advanced knowledge to existing material and find answers to problems in a structured and systematic manner (Kothari, 2004).

According to Kumar (2018), the word ‘research’ has multiple definitions that vary from discipline to discipline and specialist to specialist. It also provides future improvements to study, advancements to knowledge and critical analysis of existing literature. Research allows to critically examine and analyse a topic and hence provide answers to unsolved problems. Research also helps the researcher develop logical, critical, and analytical thinking and examine different aspects of the research topic for enhanced review (Kumar, 2018). The benefit of research is that it develops new ways and strategies to investigate and identify the possibilities and give recommendations for refinement.

Saunders et al (2007) highlights the well-designed research onion where the first layer depicts the research philosophies. The research philosophy is the most crucial and integral part of the research onion. A research philosophy is well explained as an idea or belief related to collection, interpretation and analysis of the data collected (Melnikos, 2018). The research onion shown in Figure 4.1 below explains various research philosophies; the major and visible standpoints associate to epistemology, ontology, and axiology. The research onion shows different research paradigms i.e., pragmatism, positivism, interpretation, and realism. The philosophical approach helps the researcher in adopting the right strategy to conduct the research work in an appropriate manner. Philosophical perspectives hold significance as the researcher’s assumptions about their research work are revealed. It also aids in determining the methods of research and research strategy to fulfil research objectives. The research paradigms influence the overall research process and how the researcher thinks. All research paradigms were reviewed as part of the initial phase of research design. The most suitable paradigm would be opted so that the researcher is able to answer the research questions and fill the research gap. The following research onion is followed to consider various philosophical perspectives and choose the suitable one for this research. This also helped in determining the research approach and strategy for data collection and analysis.

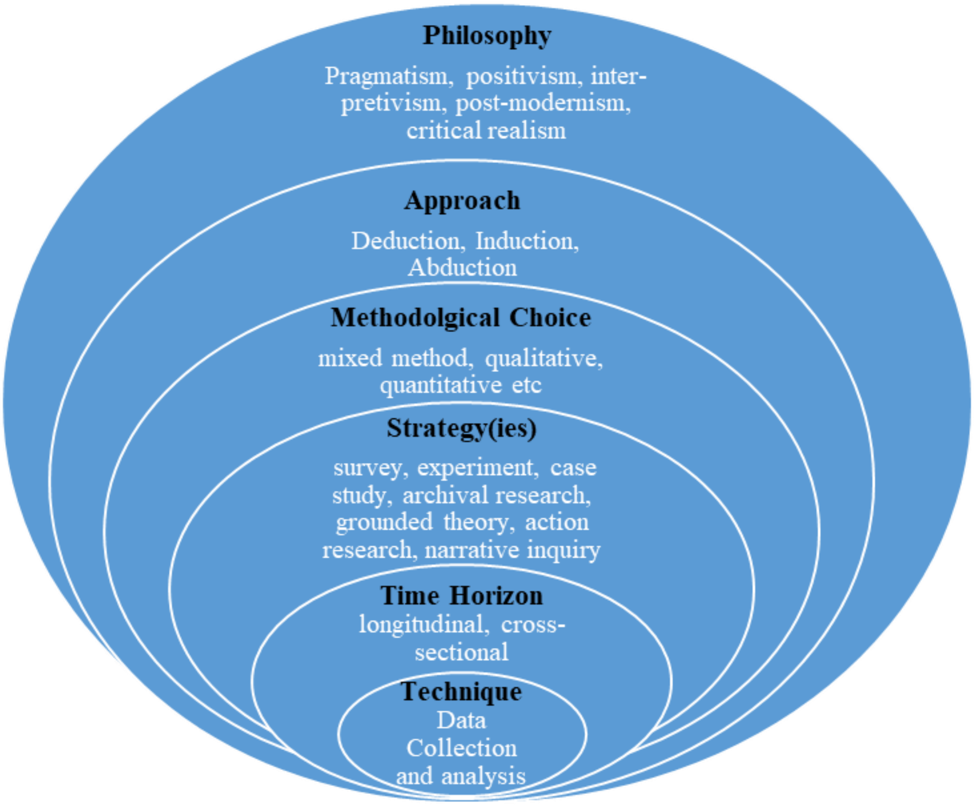


Figure 4.1: The Research Onion (Adapted from Saunders *et al*., 2007)

It is essential that the research is conducted with carefulness so that philosophical assumptions and methodological choices are defined before data collection and analysis (Brown and Sice, 2003). Hence, it is of sheer importance for researchers to plan their research projects and evaluate the strengths and weaknesses of the various research methodologies along with assessing the project limitations. All types of research require appropriate and authentic research methodology so that objectives could be achieved thus ensuring that the findings are credible. Different research cases follow different methodologies hence there is no standard research methodology followed by researchers. The rule of choosing the right methodology for research is to analyse the scope and nature of the study and the type of data or information available (Bell and Waters, 2018). The justification of type of methodology should be dependent upon the nature of topic, subject matter, and research endeavour (Kelemen and Rumens, 2008).

This chapter has in-depth and detailed focus on the research planning and research strategy that primarily concentrates to fulfil the aims and objectives. It also covers and evaluate the research method options that were available and why the methodology chosen was best suitable for this research. The respective chapter enables the reader to understand the research plan and provides insights regarding the steps that were taken to answer the research questions via applying appropriate methodology. The research process implemented will also guide and clarify the readers perspective about the topic and how the methodology chosen provided a robust conclusion or outcome. According to Žukauskas *et al* (2018), the explanation of research philosophy is of sheer importance as the research method and approach is dependent on that. The following section discusses the considerable research philosophies, ontology, epistemology, and axiology of this research.

4.2 The philosophical underpinnings of research

The research philosophy is defined as the assumptions and beliefs about the development or progress of knowledge (Saunders *et al*., 2007). It is important to follow a research philosophy as it a steppingstone towards further investigation and is also considered as a belief system with which the research is designed. It is also crucial to have assumptions that are paradigm-based because the quality of findings in scientific studies and filling the literature gap, are both dependent on it. Therefore, this research followed a pragmatic approach to address the research problem in an effective manner. In a pragmatic approach the research question is the most essential determinant. The approach focused on practical solutions to problems and the researcher thought in a practical manner. Madden (2020) defines pragmatism as one where researchers adopt methods and approach which is need-based and decides accordingly to solve the research problem. Bouwman et al (2020) further explains that a pragmatic approach to business models improves business processes and creates value for the organisation. According to pragmatic philosophy it is sensible to find solutions of the problems according to the circumstances rather than following fixed ideas or theories. In this way, value can be added to the business processes and a pragmatic approach could identify and solve problems. As the focus is on the research problem in pragmatism so the researcher aims at value-driven approach and contribution to the UK beef industry in both practical and academic aspect. The research investigated the role and impact of RPA within beef supply chains. The study also evaluated and identified the potential risks and main bottlenecks in RPA adoption within beef supply chains, using a simulation-based approach. Simulation to different scenarios allowed identification of potential risks and enables business users to adopt RPA with enhanced accuracy and improve supply chain performance. RPA smooth and systematic implementation also provides the beef sector with the opportunity to produce sustainable beef at low operational costs and improve productivity levels. Detection of risks through 'what-if' scenario analysis also improves RPA adoption process and allows the beef sector to adopt the technology with higher potential and greater ease, in true sense. The chapter looks at the research paradigm which comprises of several components namely, Ontology, epistemology, methodology and the methods (Alharahsheh and Pius, 2020). All these components are thoroughly discussed in the following sections.

4.2.1 Ontology

There are two different perspectives of viewing the research philosophy i.e., ontology and epistemology. Ontology is defined as the study of being and it focuses on nature of reality. It further reflects an individual's interpretation about what represents fact. Objective and subjective are the two ways of perceiving social entities, which is the central question in ontology (Al-Ababneh, 2020). According to the nature of this research, it was multiple i.e., subjective or objective, as the main concern was to answer the research question in the best possible way. The data was gathered using existing or current information and the research philosophy followed a pragmatic approach. The ontology was external, rich as the emphasis was to gain practical benefits out of ideas, as an outcome and streamline the RPA adoption process in UK beef supply chain. The most important factor in the research design research strategy was to address the problem i.e., identification and elimination of risks in RPA adoption to ensure efficient, improved, and well-organised beef supply chain process. As a pragmatist, there were different ways of interpretation and multiple realities to the research. This did not mean that multiple methods were used, in fact the method which enabled credible, reliable, and well-founded information and quality results was followed. Ontologically, the emphasis was to achieve practical advantages (reality) by solving the research problem, which was the key factor in the research design. Pragmatic approach is flexible, and it helped in identifying the risks associated with RPA adoption in UK beef supply chain. The research followed all the step-by-step procedures of the research design to avoid any mistakes that could affect the results. The researcher ensured that each stage of the project is being reviewed before moving to the next stage. The research design and research strategy were planned and followed in a structured manner to provide robust and efficient results or conclusion.

4.2.2 Epistemology

Epistemology is a branch of research philosophy, and it focuses on sources of knowledge. It is concerned with the nature, limitations, possibilities, and nature of knowledge (Martinich and Stroll, 2021). According to this research, logical knowledge was utilised with the use of logical reasoning and a new knowledge was created as a result. As the research philosophy was pragmatic, subjective meanings and observable phenomenon provided acceptable knowledge according to the research question and solutions to problem were provided. Research question is the most important aspect of the epistemology so that research objectives are met promptly. True knowledge and theories lead to successful action which helps to achieve research objectives. The focus in this research was on the identification, evaluation, and alleviation of the potential risks in RPA adoption within UK beef supply chain. This study provides solutions to help beef supply chains achieve operational and strategic goals while mitigating risks associated with beef production. By identifying these risks, the research supports successful RPA adoption in the UK beef supply chain, enhancing organizational efficiency. The findings offer informed practices and problem-solving strategies for the UK beef industry, concluding with practical recommendations for robust RPA implementation. The simulation of the process model in various scenarios identifies risks and bottlenecks early, allowing the beef sector to address potential issues and implement RPA efficiently. Thus, this research contributes both practically and academically, solving key problems in the beef supply chain.

4.2.3 Axiology

According to Patel (2012), axiology can be described as the role of ethics and values in research. It is important to acknowledge and consider the ethical aspect when conducting a study. The researcher tried its best to have a positive impact of own beliefs and values on the research work. Gitundu et al (2016) argues, that one's ethical values and beliefs provide guidance to humans on which their actions are dependent. Hence, it is highly important to explicitly reflect and recognise them while conducting and writing the research work. The research philosophy and data collection techniques reflect one's beliefs and values. The researcher was morally neutral in the research conducted and did not let own ethical values or belief shape the research work. This research did not involve any human participation or intervention in the data collection process. This is because the research conducted was based on secondary data collection and all the data or information were collected virtually or online, meaning by, that there was no human involvement. The researcher followed a proper data management plan to store and secure the secondary data and it can only be accessed by the researcher. The researcher followed ethical values to ensure that the secondary data is not shared or accessed by anyone. As the researcher followed a pragmatic approach so this research was value-driven and supported the UK beef industry by providing solutions to adopt RPA successfully and effectively. The research was sustained and initiated by the researcher's beliefs and doubt. The researcher emphasised on answering the research questions and focused on the research problem. The researcher stressed on providing practical solutions to the research problem that was alleviation of risks in RPA adoption within UK beef industry. As a pragmatist, the ethical values or beliefs related to the concept of beef supply chain process in UK and RPA adoption, were tested and then made acceptable for all. As the UK beef supply chain are large and complex, consisting of various phases and stages, hence the adoption of RPA is challenging and requires efforts and evaluation. This is because of potential risk elements present in the beef supply chain process or circumstantial changes during the process thus causing hinderances in RPA adoption. Therefore, new values were created because of dealing with existent problems.

4.2.4 The research assumptions

This research investigated the role and impact of RPA in UK beef supply chain. It further inspected the associated risks to the adoption of RPA in beef industry of United Kingdom. The features and characteristics of beef supply chain are analysed critically to understand the overall business process for successful RPA adoption in it. It further explores the UK beef forecasts and market trends, statistics related to beef consumption in UK and beef supply and demand in Britain. This data and information associates with the beef supply chain management and practices related to RPA adoption in the supply chain system. This section reviews the research aim that was to critically analyse the potential risks pertaining to RPA adoption in UK beef supply chain. Also, this section reviews the research objectives i.e., evaluation and investigation of role and impact of RPA in UK beef supply chain; thorough study on how RPA can be adopted fully in UK beef supply chain and effect its functioning; critical analysis of the potential risks in RPA adoption within UK beef supply chain; identification of potential risks and providing solutions for elimination of risk factors for successful RPA adoption in UK beef supply chain. It was essential to review the research aims and objectives so that an appropriate research design and strategy was followed for sound results. Pragmatic approach allowed the researcher to be flexible and embrace the extremes i.e., inductive, or deductive, to offer a reflexive approach to the research design (Biesta and Burbules, 2003; Alturki, 2021). The use of secondary data collection as methodology allowed a deductive approach. A deductive approach enabled thorough examination of the risk indicators in the adoption of RPA within UK beef supply chain. A deductive orientation aimed at testing existing beef supply chain steps to adopt RPA successfully. It highlighted or indicated the risks in an efficient manner and allowed a smooth adoption process by avoiding the issues pertaining to it. Deductive approach also enabled to explain the relationship between the UK beef supply chain and implementation of RPA. It also signified the impact of RPA in beef supply chains and how it affects its business operations. The characteristics of beef supply chain were also discussed, and a business solution was provided to avoid the potential risks for successful RPA adoption. The research assumptions discussed above aided the researcher in following an appropriate research strategy and design.

4.3 The research strategy

The research strategy can be well described as the research process that enables to answer the research questions systematically (Lyon *et al*., 2015). The research strategy is a step-by-step procedure that gives direction to the efforts and thoughts of the researcher. This enables to conduct research in a systematic way and provide quality results. The process followed a specific research design for achieving an appropriate research strategy. The research design followed a structured and systematic approach to plan and execute the project. There are various research strategies which include survey, experimental, archival, case study, action research, grounded theory, and narrative inquiry. However, the selection of research strategy was dependent on which best serves the research goal and agenda. The archival strategy allows to gather data from historical records, documents, organisational statistics, data repositories or online and this creates a rich understanding and exploration of specific research process (Bearman, 1995). The research project used a simulation method and a simulation-based approach as the research design and followed an archival research strategy. Utilisation of secondary data and information allowed to evaluate the scope and nature and impact of RPA adoption in UK beef supply chain. Statistical data and information relevant to UK beef supply chain and adoption of RPA, was collected using secondary sources and utilised to answer the research questions. The research focused on solving the research problem and filling the gap thus following a specific research design. The use of secondary data along with archival strategy further allowed to evaluate the opportunities and challenges of RPA implementation and the risks in its adoption. The existence of statistical information and data helped to critically examine the changes in the business processes and environment due to the adoption of RPA. The statistical data were used to test 'what-if' scenarios for identification of the main bottlenecks at different supply chain stages. Different research methods were present; however, availability of sufficient data and information allowed secondary research and data collection for the simulation study. This methodological choice helped to serve the research purpose, fulfil research gaps, and solve research problem in an effective way.

4.3.1 Methodological choice

The understanding of the nature and essence of research questions is essential as it allows to follow the appropriate and most suited research strategy. There are many types of research questions for example why, how, where, and how many etc and they are answerable by application of different research strategies. This research used secondary data collection as methodology to answer the research questions and collect evidence to solve the research problem in the best possible manner. Fleming and Kowalsky (2021) believes that the role of research questions is significant in research projects as they narrow down the research problem and help achieve research goals in a formulated way. They are foundation of the research and define the main purpose of the research. Three types of research questions to carry out the research i.e., qualitative questions, quantitative questions, and mixed method research questions.

In quantitative research questions, there are descriptive, comparative, and relationship-based questions. Words like influence, impact, affect, relate are used when stating quantitative questions in a research project. It includes identifying independent variables that impact dependent variables or results in research. It also consists of identification of relationship and influence between dependent and independent variables (Chandola, 2022). Hence, due to such reasoning, the research questions were described as quantitative because this research aimed to evaluate and investigate the potential risks in the adoption of RPA in UK beef supply chains. The study findings provided practical, real-life solution to the research problem through provision of a business process model and contributed to academic knowledge by identification of potential risks in RPA adoption. Also, the study analysed the relationship and influence that RPA adoption had on the business processes in the beef supply chain and assessed simulation results from the three dimensions of sustainability. The aim of this research was originated and derived from the following research questions:

1. What is the role and impact of RPA adoption in UK beef supply chains from sustainability aspect?

2. What are the potential risks in the adoption of RPA and how can they be avoided within the UK beef supply chains to create sustainable value?

The first research question was designed to investigate and examine the role of RPA application in the UK beef supply chain from a sustainability perspective. It also assessed the impact of RPA on the operations of the beef supply chain, discussing its ability to reduce human error, maximise outputs and production, and simplify business processes. This information was gathered using secondary data sources, including journal articles, government websites, official websites, and statistical databases. The second research question aimed to analyse the potential risks within the beef supply chain that could hinder efficient RPA implementation. According to the research design, statistical data and information related to beef supply chain processes and activities with the implementation of RPA technology were gathered. This data, collected from secondary sources, helped to identify which processes should be prioritised for automation, understand RPA's capabilities to transform the business environment and enhance sustainability, and recognise potential risks or bottlenecks to its adoption. In this study, secondary data collection was performed using existing statistical information and data. This data was instrumental in investigating tasks suitable for automation, based on the nature and capabilities of RPA and in identifying the main bottlenecks through process simulation. To ensure the effectiveness and accuracy of task selection, business process modelling, and simulation technique was employed, leveraging statistical datasets. This approach allowed to identify potential risk elements, inaccuracies in decision-making regarding task selection, and any organisational-level mismanagement. By utilising statistical data for simulation modelling and scenario testing, a thorough analysis was conducted, ensuring that the chosen tasks for RPA were optimal and aligned with organisational goals.

This research focused on the full adoption and successful implementation of RPA in beef supply chains by eliminating potential risks or bottlenecks for sustainable beef production. The simulation study evaluated RPA's potential from a sustainability perspective, analysing how this innovative technology adds value and helps beef supply chains meet sustainability goals. By employing simulation technique through business process modelling and using various assumed scenarios, the study identified risks at different stages of the beef supply chain. As previously mentioned, the research utilised statistical data and information for process simulation to test various scenarios based on significant research parameters. Statistical data ensures that the models reflect real-world conditions, playing a crucial role in business process modelling and simulation by providing a foundation for accurate, realistic, and reliable representations of business processes. In this research, statistical data enabled detailed cost-benefit analyses of potential changes to business processes, helping future businesses make financially sound decisions. Additionally, the use of existing statistical data and information from secondary sources for process simulation allowed for further analysis of process variability. This enables potential decision-makers to implement changes that reduce variability and improve consistency in process outputs. Moreover, statistical data facilitated performance analysis and process optimisation through simulation of 'what-if' scenarios, aiding in the identification of inefficiencies and evaluation of performance gaps in the beef supply chain. Existing statistical data allowed for the correct specification of input distributions, which are essential for realistic simulations. Therefore, the methodological approach in this simulation study aligned with the research objectives and goals, aiming to accelerate RPA adoption in beef supply chains and mitigate potential risks through scenario analysis. The full utilisation of RPA enables beef supply chains to create sustainable value, gain a competitive advantage, ensure sustainable beef production, and achieve high consumer satisfaction.

This research proposed a standard business process model as a solution, utilising statistical data and information relevant to UK beef supply chains and RPA adoption. This standard process model was used to analyse and test various 'what-if' scenarios based on different parameters. Simulation to the process model, using Simul8 software, enabled identification of the potential risks or bottlenecks in RPA adoption and provided insights on the inefficiencies in beef processing and manufacturing. Simulation method further allowed to assess the business process performance at different stages of the supply chain and ensure robust RPA adoption to create sustainable value. Simul8 software was used for simulation and optimisation of beef supply chain to analyse the performance of business processes and identify the main bottlenecks within the business system. Identification of risks using a virtual simulation environment helps in better planning and avoidance of risk events in real-life scenarios; this also improves the decision-making of business users and enables them to adopt a systematic and better approach in RPA implementation. Simulation to the process model enabled analysation of 'what-if' scenarios in the supply chain process and provide the best approach or steps for successful RPA adoption. Robust and effective adoption of RPA in practical business environments enables beef manufacturers to utilise its maximised potential, add value to the supply chain and achieve sustainable beef production.

4.4 Data Collection

Secondary data collection for simulation-based research

Different research methods were present; however, availability of sufficient data or information allowed secondary data collection. Stewart and Kamins (1993) explain secondary research as data collected from existing information or literature. The information can be collected from sources such as industry studies, newspapers, scientific journal, government reports, archived data sets, official websites, traditional journals, and books. Hartig (2011) adds that secondary data is dependent upon three criteria's i.e., accessibility, quality, and availability. The existence of statistical data and information relevant to UK beef supply chain and accessibility of relevant information contributes to secondary data collection. Vartanian (2010) explains that there is increased usage and reliance on secondary data due to easy accessibility and credibility. This chapter focuses on the design aspect of the research. The research process follows secondary data collection which particularly helps in providing support for the information that already exists. It also enhances research through perspectives and proposed research questions. Additional perspectives, growing literature with current data creates both trust and credibility of the research carried out (Cowton, 1998).

The research focused on assessing the role and impact of RPA adoption within UK beef supply chains and analysed the relevant information thoroughly. The statistical data and data repositories provide quantitative data in terms of variables or values drawn from dominant virtual sources related to the UK beef industry. The statistical data, policy and regulations about the UK beef supply chain provided an insight about the market progression and development over time. It also explained UK beef trends, beef processing forecasts and beef supplies in the United Kingdom. Availability of secondary data contributes to provide robust results using simulation-based approach, give recommendations, and fill the literature gap. The information was gathered from existing or current literature from various online resources pertaining to UK beef supply chain, influence, and adoption of RPA in UK beef industry. This helped in the evaluation and identification of the potential risks associated with RPA adoption within UK beef supply chain.

As discussed above, secondary data collection was employed in this research in which current or existing literature was used. This study gathered information and statistical data relevant to UK beef sector, beef statistics, policy, and regulations. This was available online at well-known and prominent sources such as Statista, British Meat Industry (BMPA), Department for

Environment, Food, and Rural Affairs (DEFRA) and Agriculture and Horticulture Development Board (AHDB). Utilisation of these prominent data sources enabled a more comprehensive understanding of the UK beef supply chain and its evolution over time. Additionally, these sources also provided insights regarding UK beef trends, statistics, beef processing forecasts and beef supplies in the UK. Similarly, Savills UK, another important source which provided latest information and data about UK beef consumption, trends, and statistics, was used to extract data. Moreover, journal articles, industry studies and other sources were also used for secondary data collection relevant to the domain. Multiple sources available online were used for data collection relevant to UK beef supply chains and RPA adoption. The research focused on assessing and evaluating 'what-if' scenarios through process simulation by considering significant parameters crucial for the effective functioning of beef supply chains and the adoption of RPA to improve efficiency levels. Key parameters used in this simulation included quality, safety, shelf-life, and costs. These were essential for identifying performance gaps, risks, and bottlenecks in the beef supply chain, and for evaluating system performance both with and without RPA. The study employed various variables for a comprehensive assessment and testing of the business process model using simulation technique. These variables included: mortality rate (in beef stores and finishing), beef and veal production, average carcass weight of slaughtered cattle, average meat consumption in the UK, fat inefficiency (quality), red meat shelf-life, and economic cost of production. The economic costs were further detailed into components such as £ per head output, variable costs (livestock expenses, home-grown feed, purchased forage, bedding, etc.), fixed costs (machinery, labour, fuel, electricity, overheads, RPA deployment costs), labour hours – paid hours per head, and labour hours – unpaid hours per head. These variables were selected because they were crucial for investigating the efficiency, productivity, costs, and cycle time of the beef supply chain. They served as key performance indicators to assess RPA's capabilities in reducing time cycles, accelerating efficiency and productivity levels, and minimising costs and the environmental impact of beef production and manufacturing. Statistical data for the simulation study were collected from reliable and published sources, providing comprehensive statistical and descriptive analysis of the UK red meat sector. The primary sources for data collection included DEFRA (Department for Environment, Food & Rural Affairs), AHDB (Agriculture and Horticulture Development Board), Statista, Savills UK, and the British Meat Processors Association (BMPA). The simulation study utilised these critical parameters and variables to observe performance levels, analyse time and effort in beef manufacturing, and evaluate costs and quality. The results of the simulation were aimed at supporting improved decision-making and enabling potential stakeholders to fully utilise RPA. By providing insights into the impact of RPA on the beef supply chain, the research helps stakeholders understand how to enhance efficiency, productivity, and sustainability while reducing operational costs and environmental impacts. The essence of variables in the simulation study lies in their ability to represent key aspects of the system being modelled, allowing for detailed analysis and evaluation of different scenarios. In the context of this research on beef supply chains and RPA adoption, the variables played a critical role in assessing and improving efficiency, productivity, and sustainability. By simulating various 'what-if' scenarios, these variables allowed for the testing of different strategies and interventions. This helped in understanding how changes in one aspect of the system can impact overall performance, such as efficiency, quality, shelf-life, and cost-effectiveness. The variables helped in the identification of potential bottlenecks and risks within the supply chain system. For instance, by analysing the impact of mortality rates, potential stakeholders can pinpoint critical areas that require improvement or more efficient management to improve quality and shelf-life. Variables like production levels and carcass weight are directly linked to the efficiency and productivity of the beef supply chain. The simulation helped to evaluate how RPA can optimise these variables, leading to better resource utilisation and higher output. Moreover, the economic cost of production was also essential for assessing the sustainability of the beef supply chain. The simulation analysis provided a platform to evaluate how different practices, including the adoption of RPA, can reduce environmental impact and improve economic viability. In summary, consideration of these variables in this simulation study provided a comprehensive, quantitative basis for analysing and improving the system in question. For the beef supply chain, these variables help evaluate the impact of RPA, identify key areas for improvement, support decision-making, and contribute to achieving sustainability goals.

As highlighted before, a generic business process model was formed in this study that used values or variables from existing statistical data and information associated with UK beef supply chain and RPA adoption to assess supply chain performance. The process model comprises of a standard and simple structure which makes its adaptability and utilisation easier for practitioners in beef business. The standardised process model offered the opportunity to analyse 'what-if' scenarios for identification of main bottlenecks or risks in RPA adoption. Moreover, the business process model provided insights about the beef supply chain stages and the adoption of RPA as a resource to observe supply chain efficiency. Simul8 software has been used for business process modelling and scenario analysis to generate simulation results. Simulation to business process model further demonstrated its validity and authenticity as it investigated 'what-if' scenarios from sustainability perspective and identified the potential risks in RPA adoption. Scenario analysis was conducted using simulation which provided the opportunity to enhance beef supply chain system, tackle all potential issues timely and save costs for successful adoption of RPA. This research used discrete-event simulation, also known as 'workflow-based', for process modelling. The business process model maps various beef supply chain stages and makes the RPA adoption process easier for the beef manufacturers. It is a standard business model generalised for use in real-life scenarios and can be tailored or modified to meet the requirements of UK beef supply chains based on individual business needs. The secondary data were collected virtually using online relevant sources; hence the overall research process and strategy did not involve any human participation or intervention. Quantitative data, statistical in nature, was used for process simulation to analyse different scenarios with respect to supply chain operational and financial efficiency, beef capacity, quality, and shelf-life. The following section provides further explanation to the data analysis process and simulation method used in this research.

4.5 Data Analysis

The data analysis is an important part of the research process as it helps in analysing and depicting results and findings (Treiman, 2014). The data analysis helps the researcher to make recommendations for future works and helps to solve the research problem by providing solutions (Van de Vijver and Leung, 2021). This research used secondary data collection for data analysis using secondary sources relevant to beef supply chains and the impact and influence of RPA technology in beef production. This study investigated the potential risks of RPA adoption in beef supply chains. The research also evaluated the role and impact of RPA technology in beef supply chain system. The researcher collected the secondary data to analyse and solve the research problem. The aim of the researcher was to answer the research questions by examination of the data. To serve the purpose and solve the research problem this study used simulation-based approach which tested the business process model and evaluated different scenarios to identify the main bottlenecks. The simulation of 'what-if' scenarios investigated and evaluated the operational efficiency and beef capacity at different stages of the supply chain. The researcher aimed to provide solutions to the practitioners and academia by carrying out simulation to the process model. Simulation approach helped in identification of risks or errors to RPA adoption in beef supply chain. A business process model has been proposed in this research and different scenarios were tested using the process model for 'what-if' analysis. The process model used variables or values drawn from existing statistical data and information related to the beef supply chain. The data analysis was done using the Simul8 software where the proposed process model was simulated and analysed for detecting bottlenecks at different stages of the supply chain system. The data analysis was done to measure and evaluate the time taken for task completion and observe the efficiency and production levels at different stages of the beef supply chain.

4.5.1 Simulation Approach for Process Model Development and analysis

In this study, secondary data was sufficient and available and extracted using existing literature, online-published journals, government websites, organisational records, historical data etc. This data was considered according to its relevance to beef supply chain systems, beef supply chain management and impacts of RPA adoption in beef processing and manufacturing. The data and information collected relevant to RPA adoption in beef supply chains, was then used to form a process model using Simul8 software enterprise/research (2019 version) for simulation and analysation. The process model was simulated and 'what-if' scenarios were analysed to choose the best approach for RPA adoption and elimination of potential risks. The simulation approach tested the process model in a virtual environment to evaluate the 'what-if' scenarios and identify potential risks in RPA adoption. The process model was tested, and the software generated simulation results. The simulation results generated via Simul8 depicted the supply chain performance and efficiency levels. The simulation results were in the form of KPI values, Measure of Risk and Error Plots, income statement reports and carbon emission reports. The Measure of Risk and Error Plot highlighted the likely risks or errors in the production of beef. These simulation results are significantly important in the domain of beef supply hain automation as this information can be useful for managers and stakeholders and support their decision-making skills to adopt RPA more efficiently. The simulation findings help practitioners by providing them with the knowledge to plan effectively for the future and adopt strategies to avoid or eliminate the risks in RPA implementation.

Simulation and optimisation help organisations to map the beef supply chain processes and avoid potential risks beforehand virtually. Simulation improves the adoption process of technologies like RPA by allowing organisational leaders to utilise its full potential (Mourtzis, 2020). Different software are used for simulation of business processes; however, this study used Simul8 for the simulation of business process model and for 'what-if' scenario analysis.

There were steps taken to form the process model for simulation which started from defining the main problem. Once the problem was figured out then the next step was the conceptualisation of model. Following the model conceptualisation is the data collection step (Zabidi *et al.*, 2020). Secondary data was collected from existing information or literature, government and organisational websites, online published journals, historical data etc. relevant to beef supply chains and RPA. Model development was done after the data collection step. The process model was then simulated to analyse 'what-if' scenarios and identify the potential risks in the adoption of RPA. Several simulation results were generated by Simul8 software for each tested scenario. MORE Plots in scenarios depicted the risk or errors that may occur in beef supply chain. The identification of errors or risks at early stages in a virtual environment supports stakeholders or decision-makers to plan accordingly and avoid potential risks in real-world situations.

The Figure 4.2, describes and illustrates steps for model development for the purpose of simulation and analysis of results. The first step considered while developing the process model was the identification of the problem after which planning was done according to the goals and objectives. In the next phase, the model was conceptualised followed by data collection stage. The data collected for the model conceptualisation was secondary data that was statistical in nature and used values or variables for simulation process in this research. The business process model included and mapped the significant stages of the beef supply chain for an enhanced understanding and insights on the business processes involved in beef processing. The process model represented important beef supply chain stages so that the model can be easily used or modified in practical aspects. Once the process model was conceptualised and formed, the information was validated for enhanced accuracy. Then the simulation analysis was done after which followed the experimental design stage. The final simulation step in the development and analysation of the business process model was reporting and final documentation based on the simulation results as projected below in the Figure 4.2.

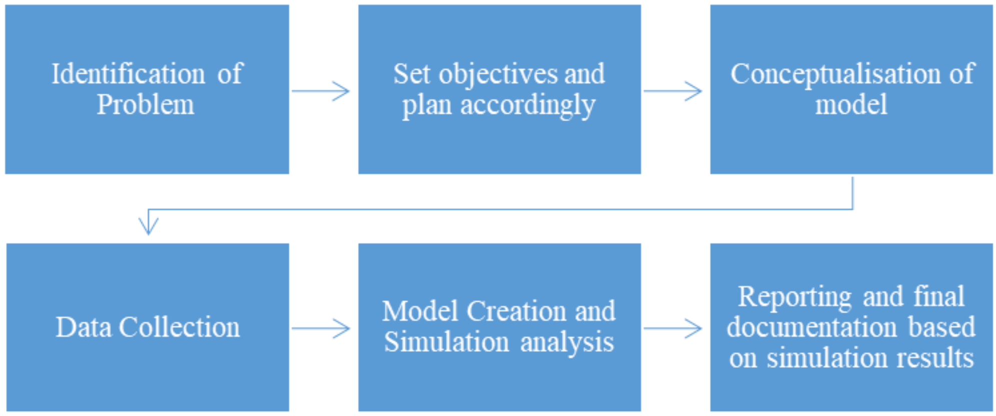


Figure 4.2: Steps involved in the development and analysation of process model in the simulation study (Adopted from Zabidi *et al.*, 2020)

The simulation approach is widely used in food manufacturing supply chains like the beef supply chain as it helps to evaluate the business processes in a virtual environment and gives the opportunity to tackle any risks or hinderances beforehand (Binsfeld and Gerlach, 2022). The simulation approach further helps to optimise and analyse the business processes and help improve the performance of supply chains from different aspects of sustainability, accuracy, and performance. Moreover, simulation to manufacturing beef supply chains also help in improving the operational efficiency by detecting any bottlenecks in different stages or business activities (Desa *et al.*, 2013; Zabidi *et al.*, 2020; E-Fatima *et al.*, 2022). Simulation approach in innovative networks such as RPA adoption in beef supply chains helps reduce human errors and enhance the adoption process of the respective technology by identifying risks and bottlenecks at different stages and making the supply chain more sustainable. The simulation process identifies risks and errors beforehand and accelerates the process of RPA implementation. RPA successful adoption allows supply chains to achieve sustainable value in business processes and gain competitive advantage. (Ivanov, 2018).

4.5.2 Discrete-Event Simulation (DES) modelling technique for scenario analysis– Use of Simul8 software

This research used the Simul8 software for simulation and optimisation of the business process model. Different scenarios were tested and run in the software Simul8. The business process model was analysed and investigated to evaluate supply chain operational and financial efficiency with and without the RPA adoption. Various software's are available for simulation and optimisation of the beef supply chain process model; however, this research used Simul8 software for investigation of 'what-if' scenarios to alleviate potential risks and adopt best approach for RPA implementation in beef supply chains. Other simulation software that are famously used are AnyLogic, MATLAB, SimScale, Arena, Simulink etc. The software Simul8 has been used in this study and it facilitates the user with flexibility to build up visual mock-up of process using different modelling tools and techniques. Simul8 provides opportunity to create a virtual system by adding rules and timings around the resources, tasks, and constraints and simulation to the process can precisely represent real-life scenarios (E-Fatima *et al*., 2022). Simul8 is a tool for planning, designing, optimisation and simulation of manufacturing, production, logistics and service provision processes. It further enables flexible and fast simulation modelling and is user friendly. The reason for choosing this software for this specific study is that it was easier to use, grasp and understand and the licensing has been provided by the university thus making it accessible for this research. For several years, Simul8 software has been widely used by leading businesses to adopt different technologies within their processes, enhance business efficiency and product delivery and reduce operational costs, time, and efforts by identifying risk factors in supply chains (Wiggin *et al*., 2019).

There are different types of simulation models or techniques used by business users to replicate real-world events or processes in a virtual environment. The various types of simulation approaches include discrete-event simulations (DES), system dynamics simulation (SD), Agent-Based modelling and simulation, and Monte Carlo or risk analysis simulation (Brailsford *et al*., 2019). Discrete-event simulation was used in this study to form and test the business process model which maps the beef supply chain stages. The DES is one of the popular and desired modelling methods used to model real-world systems in supply chain systems. The DES maps the processes or events separately that progress with time. The DES simulation model has many benefits including a variable and flexible level of detail along with the possibility to model dynamic behaviour and uncertainties of a real system (Babulak and Wang, 2010; E-Fatima *et al*., 2022). It is advantageous to use such a model in manufacturing supply chains to map and integrate individual stages of a supply chain. The DES model also supports the supply chain network design and evaluates it analytically. However, it is said that DES tools focus on logistical trends in a supply chain more than sustainability or quality. The key capabilities of the DES modelling involve pointing out supply chain uncertainties related to product quality and logistics, along with their interaction. DES tool is used extensively in food supply chains to improve food supply chain design in terms of speed and quality production. The DES simulation model also helps in effective decision-making and help save operational costs whilst speeding up the process by identifying any supply chain risks (Van Der Vorst *et al*., 2009; E-Fatima *et al*., 2022)

The discrete event simulation model also provides key benefits related to the operational efficiency of the meat processing supply chains. Operational efficiency remains one of the biggest concerns for the meat processing industry and organisations constantly strive to enhance it. The DES simulation tool analyses the current operational efficiency and tests it by providing variations in the parameters to give results. This further allows to evaluate the efficiency of the meat supply chain at different stages and identify any uncertainties or risks associated with it. The DES tool allows stakeholders and managers to improve the meat supply chain efficiency in real-life environment and enhance meat quality, safety, and security. It also further enables them to better understand the factors that increase operational efficiency and production levels and allows them to improve managerial practices for productive supply chain system. The DES simulation used in the meat processing supply chains allows managers and strategic decision-makers to test the supply chain stages in a virtual environment and educate themselves of the factors that can lower production costs and enhance operational efficiency in real-life scenarios (Manikas *et al*., 2017).

This study used the DES modelling method to map the beef supply chain stages in a well-integrated manner. The business process model was formed based on the research parameters and scenarios were analysed using the Simul8 software. Simulation approach to the process model and analysis of 'what-if' scenarios allow identification of risks in RPA adoption within beef supply chain, in a virtual environment. Scenario analysis can potentially help managers or stakeholders to eliminate risks in real-life scenarios and enhance beef supply chains by maximising the benefits that RPA can provide and lead to an effective adoption process. Also, the DES modelling tool helps the organisations to utilise their resources effectively and improves decision-making of the managers and stakeholders. Effective decision-making impacts the supply chain performance and enhances the productivity levels and increases employee capabilities which adds value to the supply chain system. Simulation and optimisation of beef supply chains helps to identify opportunities for improving the business processes so that the supply chain can prove to be more competitive and challenging in a fast-paced market. With regards to this context and eye for detail, the DES modelling technique helps and support the decision-making of stakeholders and offers opportunity to analyse and investigate different scenarios based on various parameters and meet the new market conditions. Hence, the DES tool enhances supply chain sustainability and increases productivity and efficiency (E-Fatima *et al*., 2022; Guzman-Moratto *et al*., 2022; E-Fatima *et al*., 2023).

4.5.3 Business Process Model

The business process model provides the opportunity to visualise business or supply chain processes of organisations so that the internal procedures can be better understood. Moreover, the process model allows to enhance the planning, evaluation, and management of business processes. The formation of a process model usually is an exercise for supply chain improvements and to analyse the risk factors that might potentially hinder the processes (Haaker *et al*., 2021; Micheler *et al*., 2021). The visualisation of the processes allows organisations to be more efficient, sustainable, and well-coordinated. Developing business process model helps business leaders and decision-makers to construct sustainable and proficient strategies to streamline system, information, and people in organisations. It gives an insight of how processes are conducted, which resources are important with respect to the business environment and determines how outcomes can be more successful in terms of their delivery. The process model also provides the opportunity to develop the strategies in line with what is favourable for the business environment by focusing on maximised financial and social outputs. It simplifies the understanding of the business processes for users or decision-makers by optimising workflows. This is done via data-driven visual or graphical representations of the key business processes. The opportunity to analyse the process, the right resources needed for providing maximised outputs and the identification of risks or hindrances in the business system are benefits of formation and use of the business process model (Haas, 2019).

This research study designed and offered a standard and simple business process model to the UK beef supply chains making its adaptability easy, and the model can be utilised according to individual organisational circumstances and requirements. The process model was formed to investigate the role and impact of RPA in beef supply chains. The process model used different 'what-if' scenarios for simulation analysis. Simulation to the process model facilitated the study by identification of potential risk associated with RPA implementation in beef supply chains. This in turn improves the RPA adoption process and enables business users to implement it with greater ease. It was crucial to examine the beef supply chain system in-depth for the development of the process model. The process model was used for scenario analysis and identification of risks in RPA adoption. Therefore, this study used secondary data to analyse and evaluate the role and impact of RPA technology in beef supply chains. Moreover, the literature related to beef supply chains, its different stages, and procedures, has been promptly investigated. In the formation of the business process model, several important aspects were considered, including understanding how beef supply chain functions, what resources are required for efficient beef manufacturing and processing, and how business processes can be efficiently managed. Simul8 was used to develop the business process model.

The features and characteristics of beef supply chain were analysed and assessed to understand the overall business process for successful and robust RPA adoption. Therefore, the business process model was formed using the important beef supply chain stages so that the processes were examined in-depth and efficiently. As discussed above in the previous section, discrete-event simulation technique was used in the formation and development of the business process model. The discrete-event modelling tool provides the opportunity to map all the significant beef supply chain stages. Also, the DES modelling technique aids in testing new strategies and procedures and helps to understand the supply chain performance and efficiency with the adoption of RPA. As a result of simulation and optimisation of the process model, the time taken for the process to be completed and the main bottlenecks at various stages of the beef supply chain were identified. By examining different scenarios, the simulation to process model also examined operational efficiency and financial performance in the supply chain, as well as shelf life, capacity, and quality of the beef.

Figure 4.3 demonstrates a business process model which was formed in the Simul8 software for simulation purpose. The process model used values or variables from existing statistical data and information relevant to beef supply chains and RPA adoption. The process model depicted the important and valuable beef supply chain stages as projected in Figure 4.3, which were: farm feeding stage, slaughtering stage, cutting, and boning stage, packaging and storage stage, retailer or distribution stage and reaching the end-consumer. All these stages or processes were mapped and combined to form the business process model using discrete-event modelling tool. To evaluate the time taken for each activity, along with the operational costs, different scenarios were tested and run using the business process model. Process simulation allowed investigation of scenarios to assess operational efficiency, shelf-life, quality, capacity, and costs. Scenario analysis allowed evaluation and impact of RPA in beef supply chain and provided the opportunity to test operational and financial efficiency of supply chain to analyse RPA's potential in saving time, efforts, and energy. Scenario testing also examined RPA promising benefits in sustainable beef production. The proposed process model has been designed in a standard manner and generalised for use in real-life scenarios and this can be adopted or altered according to individual needs of business owners (E-Fatima *et al*., 2022). Figure 4.3 depicts the business process model formed for 'what-if' scenario analysis using the software Simul8 for simulation and analysation of beef supply chain processes.

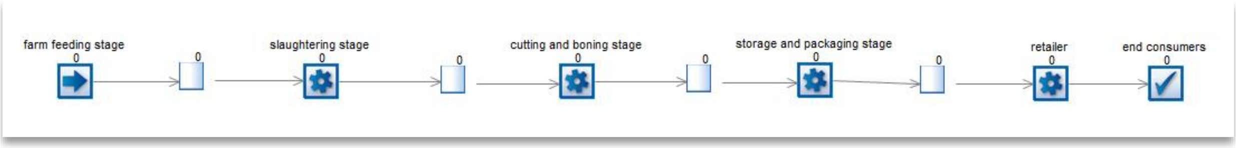


Figure 4.3: The Business Process Model formed in Simul8 for process simulation (Source: Author)

The application or use of process model supports decision-makers in improving beef quality standards and shelf-life which remains a prevailing concern for retailers and consumers in the beef sector. It further facilitates RPA maximised adoption and work accuracy and allows business owners to enjoy its full benefits by alleviating any potential risks to its adoption process beforehand. The business process model provided insights about the beef supply chain and automation processes using RPA. It also provided a systematic approach to tackle with prevalent issues in RPA adoption. To summarise, advantages of business process modelling include:

1. Easing out the process of RPA adoption in beef supply chains.

2. Firm understanding and knowledge of the potential risks in RPA adoption in theory and professional practice with respect to the beef sector.

3. Elimination of potential risks in RPA adoption thus ensuring sustainable business processes.

It is important and crucial to map the beef supply chain processes using business process model, to ensure that everyone within the supply chain is at the same level. In this research, business process model greatly helped in detecting risks in RPA adoption thus accelerating its work potential. Simulation method allows beef supply chains to observe the bottlenecks and error at early stages of the business process and provides the opportunity to adopt RPA with enhanced accuracy thus improving beef quality, safety, and security.

4.5.4 Research Parameters as basis for scenarios

The business process model mapped the important stages of the beef supply chain to better understand the supply chain activities and processes. The discrete-event modelling technique was used to project the activities or stages of the beef supply chain. The process model was simulated and analysed in the software Simul8 where it was tested and run to identify the potential risks for successful RPA adoption. The simulations were also run to observe the operational efficiency, capacity, shelf-life, and financial aspects of beef processing with respect to changing resource inputs. The changing resource inputs help in investigating the efficiency at different stages of the process model and detect the risks or main bottlenecks in beef production. The identification of the bottlenecks at different stages of the supply chains allows the decision-maker to plan and alleviate the potential risks in real-life events. The process model was developed and simulated from the perspective of testing different scenarios. Simulation of the process model using 'what-if' scenarios was key to understanding the most effective approach for RPA adoption and improving beef quality, safety, and shelf-life, thereby making the supply chain more sustainable and competitive.

The research parameters were important in terms of their consideration as these were the basis for scenario development. It was crucial to determine the research parameters or factors as they improve and aid the research direction in terms of analysing data. Determining and considering research parameters is highly important as it allows the researcher to evaluate and understand the behaviour of data in different circumstances and how it can be utilised in real-world scenarios (Shapiro and Mandelman, 2021). Clarity in research aim and objectives influence the research parameters that were important for scenario development and analysis in this simulation study. Therefore, before developing different scenarios it was highly important to determine the research parameters that significantly impact the beef supply chain processes and activities and the efficiency of beef processing.

Based on the availability of secondary data, research parameters or factors were derived using the TOE framework undertaken in previous chapter. The parameters were important for scenario analysis as they influence the adoption of RPA in beef supply chains. Moreover, these parameters impact beef supply chain functioning through the integration of RPA in beef supply chains. The assumed scenarios were developed based on various parameters. The relationship and influence of the parameters was understood in-depth with respect to supply chain performance and efficiency levels. This understanding was important to develop the scenarios for simulation and 'what-if' analysis. The literature discussed various parameters or factors that directly influence the operational efficiency and capacity in beef supply chains with the adoption of RPA technology. Through examining the beef supply chain processes in detail, the parameters used for scenario development were beef quality, safety, shelf-life and financial or cost-related aspects. All these parameters significantly impact the operations and functions of the beef supply chain system and contribute towards healthy, safe, and nutritious beef consumption through adoption of RPA. From the point of view of retailers and end consumers, it is essentially important to produce sustainable beef for human consumption. For beef supply chains to meet high beef demand, it is also essential to produce sustainable beef at low operating costs and energy consumption. Successful adoption of RPA helps in improving supply chain productivity, efficiency and coordination and allows organisations to meet sustainability criterions. The research parameters served as a basis for scenario development and analysis. These parameters are discussed in detail below.

Beef Quality

One of the promising benefits of RPA adoption in business environments is that it enhances quality beef production. The biggest challenge that the beef supply chains face these days is to produce high-quality, nutritious, and healthy beef for wider consumption. This is primarily because of human health concerns involved with the consumption of beef (E-Fatima *et al*., 2022; Hötzel and Vandresen, 2022). High-quality of beef production is characterised by less fat content / lean, more protein levels, red coloured, juicy and tender, clean cut, no smell, firm, and fine-grained lean. RPA increases the operational efficiency of the supply chain processes in beef manufacturing and enhances employee-efficiency as it facilitates by performing mundane and repetitive tasks. RPA reduces human error, touch and involvement in the business process thus enhancing quality beef production. The operational efficiency is also improved by implementation of RPA thus ensuring a fast-paced beef production system maintaining the quality standards of producing nutritious and healthy beef due to less human error. RPA can also perform better in the slaughtering and cutting and boning stage and can effectively work without exhaustion which also enhances the quality of beef produced. To achieve quality and sustainable beef production, it is crucial for RPA to perform with enhanced accuracy. Beef quality was one of the factors or parameters that impacts the efficiency of the beef supply chains and therefore considered in this research. RPA increased performance and accuracy can improve the operational efficiency, profitability, business viability and enable organisations to meet sustainability goals (Pareek and Tailor, 2023). Beef quality profoundly influences every aspect of the beef supply chain, from consumer satisfaction and reputation to operational efficiency and compliance with regulations. By prioritising quality, supply chain participants can enhance their competitiveness, profitability, and sustainability. Beef quality was therefore used as a significant parameter in simulation modelling to assess various processes within the beef supply chain. The respective parameter was used to analyse the outcome of the simulation with respect to production levels, consumer satisfaction, efficiency of supply chain, beef capacity, and time consumed in beef processing. Incorporating beef quality as a significant parameter in simulation modelling enables a comprehensive analysis of the beef supply chain. It helps in identifying key factors affecting quality, assessing the impact of different practices, and optimising the entire supply chain for better quality outcomes. The simulation approach mimics real-life events and allows future beef producers to maintain high standards, meet regulatory requirements, and satisfy consumer expectations while enhancing overall efficiency, and sustainability. Integrating and leveraging beef quality in simulation modelling to test beef supply chain also allowed detection of inefficiencies or bottlenecks at different supply chain stages with respect to processing times, product yield and operational efficiency. Therefore, beef quality was considered as a critical parameter to test and evaluate the beef supply chain system. Simulation modelling aided in investigating the impact of RPA on beef supply chain and how it affected beef quality. In simulation analysis, cycle time remains a crucial factor which affects beef quality, and this was assessed through scenario testing in this research. Process simulation allowed to evaluate the cycle time to observe the efficiency level of the beef supply chain with and without the adoption of RPA. Through simulation analysis and integration of RPA, the cycle time affecting beef quality was measured as it impacts various beef supply chain aspects such as consumer satisfaction, profitability, resource utilisation and sustainability. Scenario analysis using simulation technique provided insights into beef productivity, capacity, and processing times which affects quality. Therefore, this simulation approach supports future beef manufacturers who aim to identify and eliminate non-value-adding activities and minimise cycle time thus improving supply chain cash flow and profitability margins. Hence, the cycle time, which significantly impacts the quality of beef produced, was assessed using scenario analysis. In this study, it was also evaluated how RPA, as a sustainability-oriented technology, enables cycle time reduction and ensures higher consumer satisfaction, efficient resource utilisation, and increased productivity levels.

Beef Safety

Beef safety was another parameter to consider from the aspect of contamination or other diseases due to human involvement in beef handling processes. It was crucial to consider this parameter or factor for producing safer and healthier beef for human consumption. The adoption of RPA technology fastens the production line as bots can work 24/7 with greater efficiency and less chances of errors aids the production of safer beef that is not contaminated. This is another challenge that the beef supply chains face at present times as human intervention makes the beef supply chain risky (Antic *et al*., 2021). The implementation of RPA as a resource input helps safer beef production according to quality standards. Beef supply chains have been manual centric since many years and have been a late adopter of technology due to various complexities within the supply chain system. The beef supply chain is challenging in terms of technology adoption due to suitability of RPA in various supply chain stages. The variability in carcass size, shape and colour makes the supply chain processes difficult and complex. However, the adoption of RPA can improve task completion and reduce human error, involvement, and efforts (Micle *et al*., 2021). Reduction in human touch related to beef handling during processing stage also lowers chances of contamination or transfer of any disease; integration of bots reduces human workforce efforts and allows safer beef production for consumption. Ensuring beef safety has significant implications for public health, regulatory compliance, operational efficiency, and market dynamics. By prioritising safety, the beef industry can ensure a reliable supply of high-quality products, maintain consumer trust, and achieve long-term sustainability. Therefore, beef safety was another parameter or factor considered in this simulation study. By focusing on safety, the simulation model helps in identifying critical control points, evaluate the effectiveness of various safety measures, and optimise the entire supply chain for better safety outcomes. This approach ensures that future beef producers can consistently deliver safe products, reduce the risk of contamination, and enhance overall supply chain efficiency and sustainability. Supply chain simulation considering beef safety as a parameter allowed to assess cycle time in beef processing, productivity/ capacity levels, risks or inefficiencies at different stages and operational efficiency. Incorporating beef safety as a significant parameter in simulation modelling was essential for protecting consumer health, ensuring regulatory compliance, and maintaining the integrity of the beef supply chain. By focusing on safety, the simulation model can help identify critical control points, evaluate the effectiveness of various safety measures, and optimise the entire supply chain for better safety outcomes. This simulation approach ensures that potential stakeholders can consistently deliver safe products, reduce the risk of contamination, and enhance overall supply chain efficiency and sustainability. The simulation analysis in this research also examined the entire cycle time of beef production, from the initial stage to the final stage, to investigate how reducing cycle time through process automation impacts beef safety. Shorter cycle times can enhance beef safety by minimising the time beef products spend in various stages of production, reducing the risk of contamination and spoilage. This leads to fresher and safer products reaching consumers more quickly. Therefore, in this research, cycle time remained a crucial factor in the simulation analysis as it impacts beef safety and supply chain efficiency levels. The scenario analysis evaluated the cycle time in beef processing to provide detailed and critical insights on how cycle time reduction using process automation leads to higher operational efficiency, reduced waste, higher quality and nutritional value, lower financial costs, and greater consumer satisfaction.

Shelf-life

To achieve sustainable beef supply chains and meet retailer and consumer needs, beef shelf-life was also an important factor considered for simulation analysis in this research. Longer shelf-life of beef has been a challenge for beef supply chains as it impacts the quality standards and safety of beef production (Chinchkar *et al*., 2021). The long shelf-life of beef can be achieved if the processing line works faster and takes all the precautionary and monitory measures of safer beef processing. Less time taken to complete tasks, reduced human error and efficient packaging and storage system improves the shelf-life and quality of beef production. RPA technology is an emerging technology which facilitates and increases the pace of the processing line thus enhancing beef capacity and operational efficiency in beef supply chains. The integration of RPA along with human workforce allows to complete tasks with greater efficiency at each stage of the business process. As the beef supply chain is wide and complex, it is challenging to increase the shelf-life of beef production; however, adoption of RPA gives the opportunity to enhance the business processes and their functions as bot integration allows faster processing of tasks with less effort consumed. RPA reduces the bottlenecks at different stages of the beef supply chain thus reducing the chances of risks and errors that might hinder business processes. As lesser time and efforts are consumed in beef manufacturing and production, this enhances and positively impacts the beef supply chain shelf-life. Due to these important reasons, it is crucial to understand and analyse the shelf-life of beef and how it can be maximised using RPA facilities through better adoption process of the respective technology. Long shelf-life of beef means that its chances of contamination are reduced, and its consumption time frame increases which is very beneficial from both distributor and end consumer perspective (E-Fatima *et al*., 2022). Attaining long beef shelf-life also creates sustainability in beef manufacturing supply chains and provides competitive advantage by adding value to the business processes. This research parameter was also used as a basis for scenario analysis and the scenarios were tested to evaluate RPA role and impact in beef supply chains. Simulation to process model provided insights and assessment related to RPA work accuracy, performance, and adoption process. Resource input changes aided in a critical evaluation of RPA's impact on beef processing and supply chain performance. The testing and simulation of the process model allowed identification of potential risks in RPA adoption. Risk detection in advance can support decision-makers and enable them to plan more effectively and adopt the best approach for RPA implementation. Incorporating beef shelf-life as a significant parameter in beef supply chain simulation modelling played an essential role for optimising inventory management, reducing waste, and ensuring product quality. The cycle time in beef processing remains a key factor that impacts the beef shelf-life within the beef supply chain system. The simulation modelling considering the beef shelf-life parameter evaluated the cycle time of beef manufacturing, rate at which the carcass was processed from the first to the last stage (end consumer), operational efficiency and beef productivity levels. The respective parameter was also considered to assess how the adoption of RPA reduces the cycle time and efforts, improves efficiency levels, reduces waste and other associated risks, improves consumer satisfaction levels, and impacts the shelf-life of beef produced in sustainability aspects. The simulation model considering shelf-life as a parameter, can help identify critical points where improvements can be made, evaluate the effectiveness of various shelf-life extension strategies, and optimise the entire supply chain for better performance, greater profitability, and reduced cycle times. Simulation analysis considering shelf-life allows stakeholders to meet sustainability criterions, reduce processing times and costs, and improve financial and operational efficiency levels. The supply chain cycle time was also observed and assessed using process simulation to evaluate the supply chain efficiency, output levels, capacity, and human error with and without the deployment of RPA. The simulation approach helped in investigating how automation and process re-engineering accelerates the processing of beef from slaughter to packaging, reducing the time that the meat is exposed to potential contaminants. Quicker processing times mean that beef reaches its packaging stage faster, thereby retaining its freshness for a longer period which impacts its shelf-life. The scenario analysis in this research used beef shelf-life as a crucial parameter to simulate the beef supply chain. This simulation aimed to assess the capabilities of RPA in reducing cycle time, which in turn minimises human error and potential contamination or improper handling—factors that significantly impact shelf-life. By standardising processes, automation ensures that beef is processed under controlled, hygienic conditions, thereby enhancing shelf-life and consumer satisfaction levels. Process simulation in this study evaluated the cycle time of the entire supply chain, observing how automation ensures that beef products move quickly from production to retail. Faster movement of beef products through the supply chain extends their remaining shelf-life, providing fresher products to end-users and ensuring an efficient supply chain system. This was a key focus of the scenario analysis in this study considering beef shelf-life as a crucial parameter.

Financial or cost-related parameters

The cost-related aspects or financial parameters were also important to consider as high operational costs and beef productivity are some of the prevailing concerns in the beef sector. Beef production and manufacturing involves high operational costs that are associated at each stage of the beef supply chain. High production costs related to workforce, fuel, energy, technology, machinery etc., cause concerns for beef producers to meet high beef demand and satisfy consumers. Therefore, meeting economic and environmental goals in beef production becomes challenging for beef producers (Castonguay *et al*., 2023; E-Fatima *et al*., 2023). The beef supply chain is highly fragmented and complex comprising of various supply chain stages that are difficult in terms of functioning and monitoring. As the beef supply chain is considerably complex due to its dynamics and characteristics, it is usually associated with high operational costs in processing and manufacturing beef. The beef supply chain in the past has been mainly manual centric, however, the emergence of innovative technology like RPA enables task automation and provides promising benefits such as achieving higher productivity levels and reducing costs of business processes in beef production. RPA facilitates the beef supply chain through automation of strenuous tasks and helps save time, energy, and costs in beef production. The technology automates processes and saves fuel, energy and other operational costs meanwhile allowing higher beef productivity and capacity. Higher beef production and reduced operational costs adds value and create sustainability within beef supply chains and enhances financial efficiency. Thus, it is imperative and significant to consider the financial aspects in the adoption of RPA to allow business users to conduct a thorough cost analysis at each stage of the beef supply chain. Elimination or avoidance of financial risks in beef manufacturing and processing allows RPA to work with maximised potential. The successful adoption of RPA considering financial aspects result in adding value and achieving sustainability in beef supply chains, making them more viable, resilient, scalable, profitable, and efficient. Thus, consideration of financial or cost-related aspects was another important parameter for scenario testing and analysis using simulation method. Scenarios based on financial parameters were tested and process simulation allowed identification of financial risks in the adoption of RPA. This enables the beef sector to choose a better approach for RPA implementation considering the financial aspects in practical aspects. Robust RPA adoption considering the financial aspects improves financial and ethical decision-making of stakeholders and enables them to conduct a thorough cost analysis for beef production at lower costs. In-depth cost analysis also allows higher beef productivity and profitability in beef production through robust RPA adoption. The simulation analysis considering the financial aspects aids in optimising financial performance and enhancing the overall efficiency of beef supply chain. By focusing on costs, the simulation model can help identify critical cost drivers, evaluate the effectiveness of various cost-saving strategies, and optimise the beef supply chain for better financial performance. This improves financial decision-making of beef manufacturers who strive to deliver high-quality products at competitive prices while maintaining profitability and sustainability. Moreover, the consideration of the financial aspects in simulating modelling also helped in analysing the financial capabilities of RPA technology and its potential to reduce time, cost, and energy in beef manufacturing. The simulation testing in this research considered financial aspects in RPA adoption within beef supply chains to investigate the cost savings that can occur through automation. The simulation analysis also provides insights on the cost-benefit analysis, cycle times, profitability margins, productivity levels. Scenario analysis using simulation technique considering the financial aspects allows supply chain optimisation and enhances the overall financial performance of the supply chain. By focusing on the financial aspects, the simulation model helps identify critical cost drivers, evaluate the effectiveness of various cost-saving strategies like RPA integration, and ensure well-informed decisions on investments in RPA technological adoption to minimise costs. This simulation study investigated the profitability and sustainability of the beef supply chain with the integration of RPA, and it also assessed the financial performance without RPA deployment. Therefore, considering the financial aspects, process simulation was conducted to assess the profit margins, viability, resilience, human error, and productivity levels of the beef supply chain through RPA integration.

4.5.5 An overview of scenarios to assess sustainability through process simulation

Five scenarios were analysed by simulating the business process model in the software Simul8. An overview of the scenario 1, 2 and 3 is provided in Table 4.1 which outlines the progression of how the scenarios were developed and designed and what was expected to be observed and analysed by testing these scenarios in Simul8. Moreover, the scenario analysis and testing were also observed from the lens of sustainability, value addition through adoption of RPA in beef supply chains. The analysis of the data has been discussed in detail in the next section which explains the simulation results for all the developed and assumed 'what-if' scenarios. The simulation results were also evaluated and assessed from the perspective of sustainability through 'what-if' scenario analysis.

Table 4.1: An overview of scenarios 1, 2 and 3 for sustainability assessment through simulation

Scenario 1	▪ Simulation conducted using Simul8 software
	▪ Model included following stages: farming feeding, slaughtering, cutting, and boning, packaging and storage, retailer, and consumer
	▪ Human workforce as resource input – manual centric supply chain
	▪ Assessment of efficiency, time consumption, capacity, and shelf-life
	▪ Evaluation of beef quality, safety, and traceability
Scenario 2	▪ Simul8 simulation software employed
	▪ Model included various significant supply chain stages
	▪ RPA and humans as resource inputs
	▪ Process automation to evaluate operational efficiency, human error, capacity, time-taken and shelf-life
	▪ Beef quality, safety and shelf-life assessed

Scenario 3	▪ Comparative analysis of scenarios 1 and 2
	▪ Evaluation and comparison between manual centric supply chain and RPA adopted supply chain system
	▪ Observed the changes in supply chain performance and sustainability by increasing bot integration and minimising human workforce
	▪ Productivity, capacity, shelf-life, cycle time and quality assessed through simulation analysis

To further elaborate the Table 4.1, different scenarios were analysed, tested, and compared in Simul8 software to observe which scenario gained higher capacity, increased operational efficiency, and better shelf-life in beef supply chain. The ***scenarios 1, 2 and 3*** as depicted in Table 4.1 were based on ***beef quality, beef safety and shelf-life as parameters*** which were used as a basis for scenario development and assessment. The scenarios 1, 2 and 3 were analysed in Simul8 to identify the potential risks or main bottlenecks in the adoption process of RPA in beef supply chain. This can improve and enhance RPA performance levels, potential benefits, and accuracy in real-life scenarios as decision-makers or practitioners will have the opportunity to adopt the generic process model according to their own business needs and requirements. Simulation approach to scenarios also allows managers or stakeholders to adopt best approach for RPA adoption by alleviating the risk factors or bottlenecks in advance. The Table 4.1 thus provides an overview of how the scenarios were developed with regards to individual resource inputs to the process model that comprises of significant beef supply chain stages. The analysis of the scenarios has been discussed with simulation results in detail in the next chapter – analysis of data and simulation results. The scenario testing using simulation-based approach was also observed from sustainability lenses.

Table 4.2: An overview of the scenarios 4 and 5 to assess sustainability using simulation

Scenario 4	▪ Human workforce as resource input – manual centric supply chain
	▪ Sustainability assessment based on three dimensions (social, economic, and environmental)
	▪ Time consumption, costs, productivity levels, and financial and operational performance evaluated
	▪ Costs / financial aspects as parameters (quality, safety, and shelf-life assessed)
	▪ Income statements, KPI's and carbon emissions report generated
Scenario 5	▪ RPA and humans as workforce (resource inputs)
	▪ Sustainability assessment – social, economic, and environmental aspects ▪ Financial and operational performance, task delivery, capacity and productivity levels measured
	▪ Beef quality, safety, and shelf-life assessed through task automation
	▪ KPI's, income statement reports, and carbon emission reports generated

The Table 4.2 depicts an overview of scenarios 4 and 5 which were developed for simulation analysis using the business process model in Simul8 software. The ***scenarios 4 and 5*** were developed and assessed based on ***financial or cost-related parameters*** which served as the basis for simulation analysis. Simul8 software analysed scenarios in a virtual environment and identified the main bottlenecks and financial risks at different stages of the beef supply chain. The software also generated carbon emission reports for scenarios, which provided insights about carbon emissions at every phase of the supply chain and depicted the environmental impact in statistical form at all stages. The KPI values, income statement, and carbon emission report generated in each scenario support the business owners in their financial and ethical decision-making and help them to prevent any risks in real-life events. A comparison through the simulation of scenarios 4 and 5 evaluated the financial and operational performance of beef supply chains, both when RPA worked alongside the human workforce and when the human workforce performed alone to complete tasks as the only resource input. This comparison helped in assessing the advantages of RPA or software bots which worked on the beef processing line and depict how the sustainability-oriented technology could prove as a value addition to achieve economic, social, and environmental benefits from sustainability perspective. The sustainability assessment was conducted through process model simulation using the developed scenarios based on financial parameters considering the cost-related factors. The scenarios 4 and 5 were primarily developed to analyse and evaluate the cost effectiveness and higher productivity through RPA integration in beef supply chains. The simulation results and analysis of the assumed scenarios are discussed in detail in the next chapter.

4.5.6 The Approach towards Sustainability

Sustainability in supply chains has gained great importance in recent times and adds to value creation and gaining competitive advantage in business processes. Organisations and decision-makers are constantly struggling to incorporate sustainable development strategies, and technologies to improve supply chain processes and reduce business challenges and complexities (Beltagui *et al*., 2022). Sustainable innovations and technological adoptions like RPA, is a value addition to enhance process delivery, improve decision-making capabilities of management and achieve strategic business goals to satisfy customers. The business process model is a generic model to serve the sustainability aims and goals of beef supply chains and add value to its business operations. The business process model was analysed using different scenarios to enhance the adoption process of RPA to maximise its potential benefits. The scenarios were based upon various parameters that are beef shelf-life, quality safety and costs. The 'what-if' scenarios were analysed to evaluate the best approach towards RPA adoption so that it can be adopted by firms in a robust manner and improve supply chain sustainability. In broader aspect, this study focused on the three dimensions of sustainability which were assessed by process model simulations using different scenarios and parameters. This study investigated the potential risks to RPA adoption by analysing 'what-if' scenarios and identified the risks or hinderances in the beef manufacturing process. The RPA technology is considered as a value addition to the supply chain system as it replaces humans with bots to complete repetitive, strenuous tasks and enhance process delivery; also, the successful implementation of RPA helps the beef supply chains to become more sustainable and fast-paced in production and operational efficiency.

Beef manufacturers are focusing on service-oriented business strategies and procedures for increasing consumer satisfaction. From the perspective of sustainability, an organisations value creation is not only based on economic value and should recognise other value aspects. A business should also consider value creation with respect to environmental and social goals. This research contributes towards acknowledging the sustainability values – social, economic, and environmental in beef supply chains. The sustainability values were evaluated based on the results of the process model testing and analysis of different scenarios. Simulating the process model and investigating the different scenarios enabled the researcher to observe the sustainability aspect serving economic, social, and environmental values in beef supply chains. The RPA adoption improves the operational efficiency of processing line and enhances beef quality standards. The analysis and results of the simulations provided an opportunity to observe the beef supply chain in terms of economic, social, and environmental values or benefits. The study adopted a simulation-based approach to test scenarios and observe the sustainable value that RPA brings to business processes in beef supply chains.

As observed in Figure 4.4, the social values were seen from the perspective of employee-level and operational efficiency, human error, health and safety and quality standards in beef production. The environmental values that were important for observation and investigation through process model simulations were reduced beef waste, pollution prevention, less transmission of diseases, hygienic beef production for human consumption. Moreover, the economic values or gains that the process model testing evaluated was based on aspects such as business stability, cost reduction, long-term viability, and profit. The Figure 4.4 demonstrates a holistic view of the sustainability assessment model used for simulation analysis and the model depicts the three aspects of sustainability – social, environmental, and economic value. The study used the sustainability assessment model to evaluate and assess scenarios from sustainability lenses and observe the beef supply chain performance or efficiency from the three dimensions of sustainability. To further elaborate on the simulation-based research, the business process model was evaluated and tested across pre-defined scenarios 1, 2, 3, 4 and 5. Process simulation to scenarios 1, 2 and 3 examined the environmental and social aspects of the beef supply chain. The scenarios 1, 2 and 3 considered beef quality, safety, and shelf-life as parameters for simulation analysis, with the goal of assessing operational efficiency, capacity, cycle time and productivity levels. The simulation analysis conducted for these scenarios aimed to understand how RPA adoption contributes to sustainability in social and environmental aspects, using the sustainability assessment model depicted in Figure 4.4. In scenarios 1, 2 and 3, the beef supply chain simulations were designed to evaluate how process automation enhances environmental value by accelerating beef processing, reducing human error, and minimising contamination or disease transfer risks. The simulations in the respective scenarios also explored RPA's potential to decrease the environmental impact and carbon dioxide emissions associated with beef processing. The sustainability assessment model was crucial for evaluating the simulation results, particularly in terms of RPA's ability to improve social value by enhancing beef quality and safety, reducing human error, and boosting operational and employee-level efficiency.

Scenarios 4 and 5, which considered the financial aspects of RPA adoption in the beef supply chain, were also tested, and run to assess beef supply chain financial and operational performance. In these scenarios, the sustainability assessment model, shown in Figure 4.4, helped analyse the simulation results from social, environmental, and economic aspects. The simulations provided insights into how automation accelerates beef supply chain processes, reduces cycle times, lowers costs, and conserves energy. Additionally, simulation-based approach also helped in assessing RPA's role in improving operational and financial efficiency, enhancing quality and safety, reducing environmental impact and human error, and preventing pollution from beef production. Furthermore, the process model in scenarios 4 and 5 was simulated to demonstrate and provide insights on the economic aspects focusing on how automation reduces high operational costs, increases profit margins, enhances business stability and viability, and optimises resource utilisation. By using the sustainability assessment model, the study critically analysed how automation enhances the reliability, efficiency, and scalability of renewable energy systems, making them more viable and cost-effective compared to traditional beef processing methods in scenarios 4 and 5. Overall, the sustainability assessment model in Figure 4.4 was integral to this research, providing a comprehensive framework for critically analysing the simulation results across all pre-defined scenarios. The sustainability assessment model facilitated a holistic evaluation of RPA's impact on the beef supply chain, highlighting its potential to improve sustainability, efficiency, and profitability.

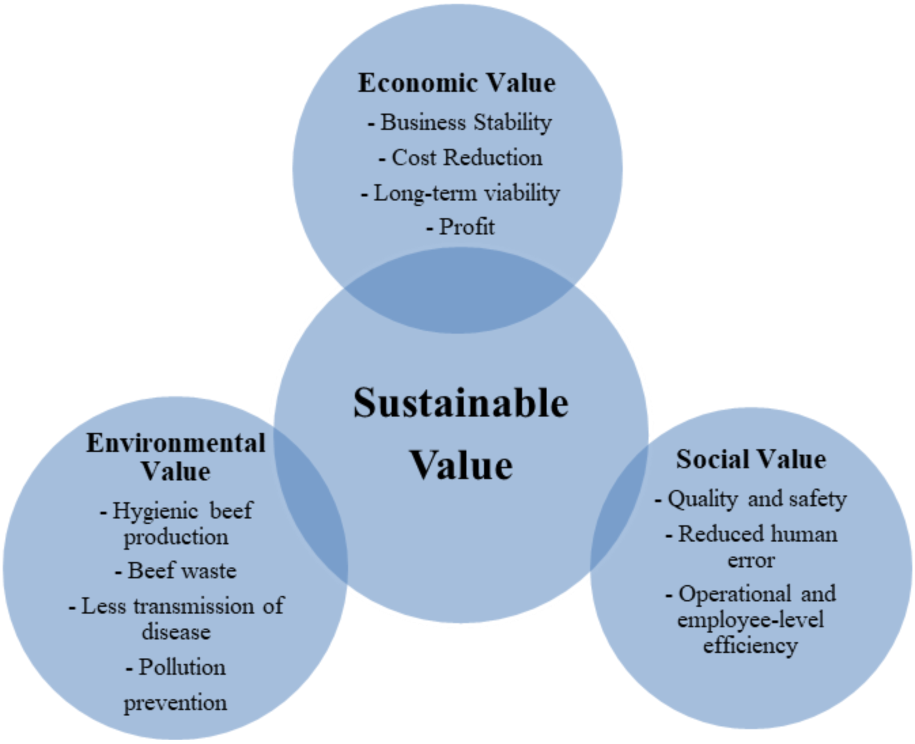


Figure 4.4: Sustainability assessment model for simulation analysis (Source: Author)

The analysis of scenarios in Simul8 provided simulation results which were further observed from sustainability and value creation aspects. The simulation results highlight the main bottlenecks and evaluate scenarios from social, environmental, and economic lens. The next chapter – data analysis and results, depicts how sustainability has been achieved in the beef supply chains and this was done by simulating the business process model using 'what-if' scenario analysis based on various parameters. Different scenarios were tested and run to analyse and investigate the operational, employee level and financial efficiency at various beef supply chain stages. The analysation of different scenarios was also done from the aspect of sustainability; to observe what social, environmental, and economic benefits can RPA adoption bring to the beef production and vice versa. Scenarios 1, 2 and 3 were analysed with respect to beef shelf-life, quality and safety as parameters or factors using process model simulation and were observed to assess their approach towards achieving social and environmental value in beef supply chains. Scenarios 4 and 5 were examined using financial parameters and hence, they were observed from the perspective of socio-economic benefits in beef supply chains.

4.6 The Ethical Considerations and Quality Criteria

It is essential to analyse and understand the importance of ethical considerations and maintaining quality criterions when conducting research (Bell *et al*., 2022). The researcher has ensured to follow ethical guidelines and norms, and the ethical approval has been provided by the University of Northampton's Research Ethics Committee for this study. This research used a simulation method to test different 'what-if' scenarios for analysis and therefore, utilised secondary data for simulation purpose. Moreover, the study used Simul8 software for scenario analysis to generate simulation results. The researcher used secondary data collection in this research as the information relevant to impact and role of RPA in beef supply chains was available and accessible. Also, the information regarding to the adoption process of RPA was also available for the respective study. As this study used secondary data collection and a simulation-based approach as research methodology for analysis, results, and findings; hence, it did not involve any human intervention or participation in the data collection process. The data was drawn from existing data sets and information relevant to beef supply chain trends, forecasts, meat consumption statistics, production indicators / facts and other literature relevant to RPA adoption process, beef safety, quality, and security. This means that there was no identifiable dataset or information being used as there are no human subjects involved in the research. In addition to this, the researcher had strictly and firmly followed all the quality criterions in data collection process and conducted this research to meet aims and objectives. The raw data has been kept in a secure and safe place which is password protected and can only be accessed by the researcher. Data storage is another important aspect of the doctoral project. The researcher saved the information to prevent any data loss and ensured that quality criterions were met. The data was stored in university's storage. University managed storage ensured that data was stored appropriately and had been backed-up properly. SharePoint, a collaborative web-based platform, was used to share files or information with the supervisors only. The university's repository had the stored dataset, that could only be accessed by entering the password. All the quality criterions were ensured and considered so that the data collected was protected, saved and backed-up to prevent any loss. The data was also encrypted, and password protected and can only be accessed by the researcher thus following and ensuring the ethical code of conduct to successfully complete this study. The secondary data collected or accessed was in the public domain. The data used in this simulation study was obtained without permission as it was not restricted or protected by copyright laws. It was freely acquired and used by the researcher for this doctoral project and simulation analysis.

4.7 The research limitations

The research conducted had some limitations to it as it was in a specific direction to meet the aims and objectives. The research was limited to the beef supply chains and investigated the impact and influence of RPA adoption within the business processes of the beef industry. Moreover, the study focused on the potential risks of RPA adoption in beef supply chains. It was focused and limited to the beef sector and emphasised on enhancing operational and financial efficiency, quality, shelf-life, and capacity in the beef supply chains. Additionally, this study concentrated on RPA technology for adoption within beef supply chains; future works could potentially integrate other technologies like Artificial Intelligence with RPA and analyse its impact in beef manufacturing. This research analysed various scenarios to assess the operational efficiency, beef capacity, quality, shelf-life, and costs in beef processing. More scenarios based on other important parameters could be analysed in future studies. The respective study primarily used discrete-event simulation to analyse scenarios; other simulation approaches could be potentially undertaken in future projects. Furthermore, the study was limited to analysing scenarios using Simul8 software. Works in future could possibly use other simulation software for obtaining results. These were the limitations determined from this research.

4.8 Chapter Summary

The chapter discussed in detail the methodology of this respective research. The philosophical position of the researcher was also reflected in this research methodology. The chapter explained the data collection method that was secondary data collection, using values or variables from existing statistical information to analyse the 'what-if' scenarios by formation of the process model. It was further discussed in the chapter that simulation approach has been adopted to analyse different scenarios based on various parameters. The business process model was formed and analysed in this study using different scenarios to evaluate beef operational and financial efficiency, capacity, quality standards, shelf-life, and cost of production. Furthermore, Simul8 software has been used in this study for simulation and analysation of the business process model as already being discussed above in detail. Moreover, the simulation modelling approach used to analyse the scenarios was Discrete-Event Simulation (DES) technique which is widely being used in food manufacturing supply chains to map the supply chain processes at each stage. The DES modelling technique provides insights of the business processes and enhance the user understanding of the overall supply chain stages. The scenarios were based on different research parameters derived from secondary sources. The parameters were important factors which influence the adoption of RPA in beef supply chains and contribute to efficient functioning and operations of business processes. These parameters play significant role in RPA adoption to produce sustainable beef. The next chapter examines the data to produce simulation results using Simul8 software.

CHAPTER FIVE: SIMULATION RESULTS AND DISCUSSION

5.1 Introduction

In this study, secondary data was used and collected from online-published sources and relevant literature that focused on the role and impact of RPA in beef supply chains. Different factors affect the operations of the beef supply chain and RPA adoption process for beef production. In this research, data was derived using existing information related to the beef supply chain process and stages, RPA adoption impacts on the beef supply chains and the importance of RPA technology in beef supply chain operations. There are different frameworks utilised in studies which focus on supply chain management such as the institutional theory and stakeholder theory. Institutional theory and stakeholder theory are both crucial frameworks in organisational studies and supply chain management, but they focus on different aspects of organisational behaviour and decision-making (Kivits *et al*., 2021). Institutional theory emphasises how organisations are influenced by the external environment, including cultural norms, legal regulations, and societal expectations. It stresses the importance of organisations conforming to these external pressures to gain legitimacy and social acceptance (Peters, 2022). On the other hand, stakeholder theory focuses on the relationships between an organisation and its various stakeholders, including employees, customers, suppliers, investors, and the community. The stakeholder theory emphasises the importance of balancing and addressing the interests and needs of all stakeholders to ensure long-term success and sustainability (Dmytriyev *et al*., 2021). While both institutional theory and stakeholder theory offer valuable insights for supply chain management, this research employed the TOE (Technology-Organisation-Environment) framework due to its alignment with the research goals and central focus. As highlighted and discussed in detail in chapter three, the TOE framework was particularly suitable for this study, aiding in meeting the research objectives comprehensively. The TOE framework was chosen because it provides a structured approach to analysing the adoption and implementation of RPA within beef supply chains. The TOE framework's utilisation in this simulation study provided a comprehensive theoretical foundation for understanding the adoption of RPA technology, which is increasingly valued in business organisations for its ability to enhance process efficiency, add value, and promote sustainability. Despite its benefits, organisations often struggle to fully implement RPA in beef supply chains. This study identifies potential risks to accelerate the adoption process and suggests strategic approaches for implementation. The TOE framework encompasses three critical constructs—technology, organisation, and environment—integral to this research for identifying key parameters influencing RPA adoption. By employing this framework, a systematic and thorough approach was taken to select the factors affecting the RPA adoption process in beef supply chains. The TOE framework aided in evaluating how innovations like RPA contributes to sustainability goals by examining environmental impacts and aligning technological and organisational strategies with sustainability objectives. This is particularly relevant for supply chains aiming to achieve economic, social, and environmental sustainability. Articulating theoretical ideas and propositions within the TOE framework enabled the researcher to address the research questions effectively and achieve the study's aim and objectives. Additionally, the framework allowed for the consideration of the study's limitations, ensuring a balanced and comprehensive analysis. By utilising the TOE framework in this study, the research systematically examined the factors influencing RPA adoption, leading to a deeper understanding and more strategic implementation recommendations. The framework promoted a systematic approach to research, guiding the collection and analysis of data across multiple dimensions. This structured methodology enhanced the reliability and validity of research findings related to RPA adoption in beef supply chains. Hence, the TOE (Technology-Organisation-Environment) framework is instrumental in studies related to innovation in supply chain systems as it provides a holistic view by integrating technological, organisational, and environmental aspects (Wang *et al*., 2022). In this research, this comprehensive perspective ensured that all relevant factors are considered when evaluating RPA adoption in beef supply chains, leading to more robust and effective implementation strategies. Therefore, the TOE framework employed in this research facilitated and guided the identification of key factors or parameters essential for scenario analysis in this study. This ensured a systematic and organised research approach and facilitated in understanding the parameters that impact the implementation process of RPA in beef supply chains. The key parameters considered and extracted using the TOE framework were beef quality, safety, shelf-life, and cost-related aspects. These parameters were crucial for consideration in this simulation research as they played a significant role in effective functioning of the beef supply chains and RPA adoption to automate processes. To summarise, the TOE framework not only helped in providing insights on the RPA adoption process in beef supply chains and the crucial factors that impact its implementation; the framework also facilitated a holistic understanding of how technological, organisational, and environmental factors interact and contribute to the successful implementation of RPA.

In this simulation-based study, a business process model was formed based on the beef supply chain operations and stages with the parameters and variables extracted from secondary data available. The parameters comprised of the time taken by the entity (beef) to get processed through different processing units across the beef supply chain, time consumed by the employees to perform their responsibilities, the number of employees designated at workstations and costs or finances associated with beef processing and manufacturing at different supply chain stages. The resources were gathered for use in the supply chain operations. Simulation is an effective technique to analyse 'what-if' scenarios and eliminate risks in supply chain systems. Simulation helps in improving the beef supply chain by identifying the potential risks and adopt the best approach for gaining operational, financial, and employee-level efficiency through successful RPA integration. Simulation to process model also improves financial decision-making of business users as it provides the opportunity to beef manufacturers to conduct a thorough cost analysis. Scenario analyses allows to alleviate risks in advance and boost RPA accuracy. This helps to achieve RPA's full potential and reduce reliance and integration of human workforce for a progressive beef supply chain system.

The second part of analysis calculated and evaluated the influence of these parameters that were selected based on the secondary data available. Relationship was formed between the parameters that impact RPA implementation and its potential advantages in beef supply chains. The operational efficiency was assessed using simulation and analysis of 'what-if' scenarios. The extant literature depicts various factors that determine operational efficiency with and without the adoption of RPA in the beef supply chain. In relation to the attributes and characteristics of the beef supply chain mentioned in previous chapters, a model was formed in Figure 5.1, which displays the significant factors that contribute to a well-organised beef supply chain with the adoption of RPA. The arrows shown in the model also depict the relationship amongst the variables. The research parameters were important factors that influence the efficiency of beef supply chains. The factors or parameters that were highly important to consider were beef shelf-life, quality, and safety as shown in Figure 5.1. These factors help in improving RPA efficiency in processing high-quality, nutritious beef leading to increased shelf-life and safety. These research parameters were the basis for formation and development of assumed scenarios using the process model. The Figure 5.1 shows the relationship between the factors of beef supply chain.

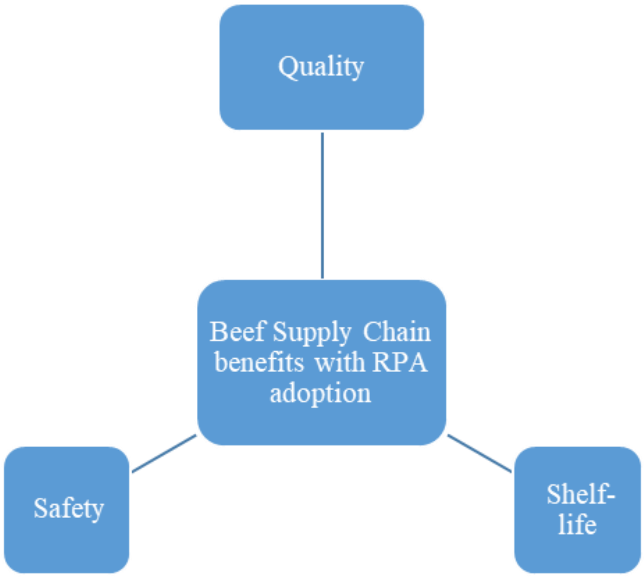


Figure 5.1: The relationship between factors (Source: Author)

To further emphasise, these three research parameters or factors were highly important in the effective functioning and processing of the beef supply chain. In this age of technological advancements and fast-paced business environments, it is highly important for beef supply chains to be responsive to the high demands of the consumers. Having said that, it is crucial to realise the quality standards and health-concerns related to the beef manufacturing and production. It has always been challenging for the beef supply chains to be sustainable, efficient, and fast-paced and meet the retailer and consumer demands of producing high-quality, safe beef which has greater shelf-life. The efficient adoption of RPA improves the production of high-quality, healthy beef with much lesser chances of contamination due to less human dealing and involvement in conducting mundane tasks. RPA also facilitates the human workforce by reducing their burden of performing boring, repetitive tasks and greatly reduces human error in processes like beef trimming, cutting, and packaging process. This allows contribution towards sustainable beef production with great shelf-life and lesser chances of the meat getting contaminated. Hence, the contribution of these research parameters was valuable in effective RPA adoption with enhanced work accuracy and performance towards sustainable beef production. The research parameters were also the base for the formation of the scenarios which were tested and run in the Simul8 software. Simulation and optimisation of the process model which maps the different stage of the beef supply chain helped in identification of the potential risks to RPA adoption in beef supply chains.

Another important parameter that was significant in terms of its consideration for robust RPA adoption was financial or cost-related parameter. It was crucially important to analyse the relationship between the financial factors that influence and impact the adoption process of RPA in the beef supply chain. Hence, cost-related information and aspects at various stages of beef manufacturing and processing were a significant part of the analysis as well. Literature focusing on the beef supply chain characteristics, manufacturing stages, financial aspects, and sustainability challenges was used to form a relationship model. Figure 5.2 depicts the financial factors that play a vital role in the successful adoption of RPA technology in the beef supply chain. These factors were important to evaluate as they impact the implementation of RPA, as well as its potential advantages by easing process delivery, reducing operational costs, enhancing beef quality, and improving productivity to gain sustainable value. Figure 5.2 shows the relationship between the financial factors that help create value and sustainability in the beef supply chain processes and impact the financial performance, business viability, and scalability in beef production. RPA, as an important sustainability tool and innovative strategy, facilitates beef supply chains by reducing operational costs at different stages and enhances productivity, efficiency, and the capacity to satisfy the growing demand for beef. Reducing the processing costs of beef with the goal of achieving higher output levels remains a focus for business owners. The consideration of financial parameters not only aid in smooth and robust adoption of RPA, but also allow the technology to become a game changer and act as a tool to add sustainability. The financial factors or parameters depicted in the relationship model in Figure 5.2 were fixed costs, direct or in-direct costs, and variable costs associated with RPA implementation in beef supply chains.

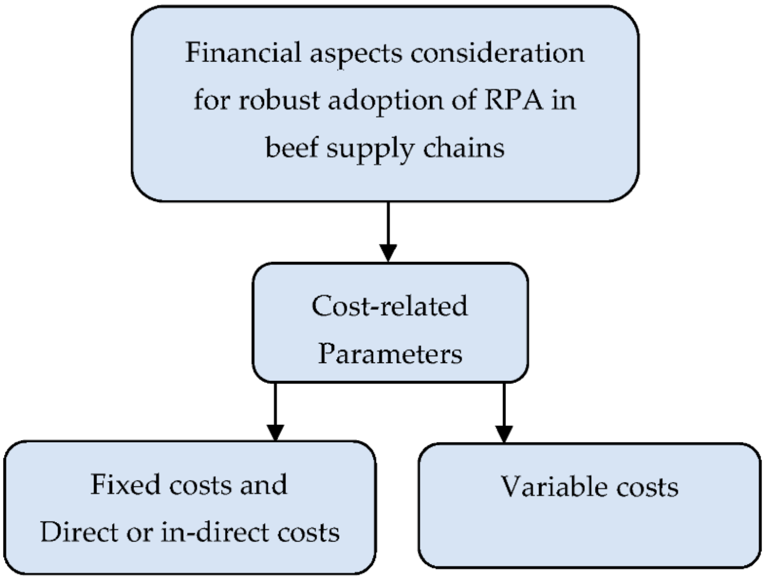


Figure 5.2: The link between financial parameters in RPA adoption (Source: Author)

The process model was created in the software Simul8 and simulation to the process model observes operational efficiency, capacity, safety, shelf-life, and financial performance in different stages of the beef supply chain. Moreover, simulation to the process model also examines beef quality, safety, shelf-life, and costs in wider aspect of beef production for delivering to the retailers or distributers and then to the consumers. Furthermore, the process model highlights different stages of the beef supply chain adapted from real-life supply chains. It was crucial to project the different stages of the beef supply chain in the process model so that it was analysed and simulated with a more realistic approach and can be used widely and easily by decision-makers, stakeholders, and managers in the beef sector. There were various processes mentioned in the beef supply chain and those processes were also displayed in the model. Thus, the process model depicts the entire beef processing process until it reaches the end consumer. The generic process model has been designed for use in real-life scenarios and can be utilised widely by the beef industry for efficient adoption of RPA. The process model is not complex in nature so that it can be easily adopted or implemented across different beef supply chains and can be modified according to the individual needs of decision-makers or managers in beef sector. The data was collected using available secondary information and knowledge based on beef supply chain stages and RPA adoption at various phases. Thereafter, the data has been analysed in Simul8 through simulation approach to 'what-if' scenarios. The following Table 5.1 projects the key processes or stages of a functioning beef supply chain. The process model includes all the stages observed in Table 5.1 and is designed accordingly in the software Simul8 used for simulation of the beef supply chain in this study.

Table 5.1: Beef supply chain process or stages involved (Source: Author)

SI No	Process
1	Farm feeding
2	Slaughtering
3	Cutting and boning
4	Packaging and storage
5	Retailer or distribution
6	End consumer

The Table 5.1 mentions all the six stages of the beef supply chain that were important to analyse and project in the business process model. The first stage is the farm feeding stage after which the carcass is delivered to the slaughtering stage. After completion of the slaughtering stage the carcass is transferred and processed for the cutting and boning stage. Once the beef is processed in the cutting and boning stage it is delivered and passed on to the packaging and storage stage. After the packaging and storage stage, the beef is then processed further and sent to the retailer or distributer for human consumption. The last stage of the beef supply chain is reaching the end consumer. All the beef supply chain stages form the business system of beef manufacturing and processing; hence, all these stages are mapped in the process model which is then analysed using various scenarios to improve beef quality, safety and security and ensure successful RPA adoption. Successful RPA adoption incorporates sustainability and provides competitive advantage to beef supply chains by adding value throughout the process. Faster production line and increased operational efficiency minimises the beef wasted during processing thus adding value to the supply chain and additionally enables the supply chain to manufacture healthier and nutritious meat for human consumption.

The scenarios developed in this study are comprehensive and sufficient to address the research questions effectively, as they incorporate several key parameters and underlying variables essential for the efficient functioning of beef supply chains and the implementation of RPA to produce sustainable beef. Various 'what-if' scenarios were simulated to test supply chain performance, productivity, efficiency, and costs related to beef processing and manufacturing. These pre-defined scenarios considered significant parameters crucial for assessing the beef supply chain and the adoption of RPA to automate processes. The research aims to critically investigate the risks and bottlenecks in RPA adoption within beef supply chains, as well as to evaluate the role and impact of RPA from a sustainability perspective. To align with the research objectives, different parameters were extracted and considered to answer the research questions and achieve the study's goals through the assessment of various 'what-if' scenarios. Key parameters such as beef quality, safety, shelf-life, and costs were central to the scenario analysis. These parameters were used to investigate supply chain performance with and without RPA implementation and to evaluate RPA's capabilities in enhancing sustainability. The simulation modelling utilised these parameters to identify the main bottlenecks and risks associated with RPA adoption at various stages of the supply chain. Successful RPA adoption enables beef manufacturers to create sustainable value and produce high-quality, safe beef that meets consumer satisfaction. Given the study's focus on identifying risks in RPA implementation and ensuring its robust adoption to achieve sustainability goals across social, economic, and environmental dimensions, parameters like beef quality, safety, shelf-life, and costs were critical for addressing the research problem comprehensively. Moreover, the research emphasises the broader implications for the UK beef sector, which aims to achieve sustainability and fully leverage RPA technology. By simulating the beef supply chain and highlighting its significant stages, the study provides valuable insights into how RPA can optimise the supply chain and contribute to sustainable beef production.

5.2 Discrete-Event Simulation Modelling Setup for Scenario Analysis

Simulation is imitation of a process, situation, or operations of a real-life scenario. It evaluates a model numerically by data collection to analyse the actual features of the model. Simulation estimates and explores impacts of changes made to a system and can help decision-makers identifying potential risks (Banks, 2000; Robinson, 2008; Ingalls, 2011). There are two categories of simulation models i.e., continuous, and discrete simulation models. Discrete systems model changes intravenously at different points in time whereas, continuous simulation have variables changing continuously with respect to time. Discrete event simulation is event-based simulation normally used in manufacturing, logistics etc., (Fishman, 2001; Robinson, 2005; Kiriş, 2020). Discrete-event simulation is widely used in the food sector and helps to improve supply chain processes, improve food security and safety concerns, and identify the constraints in perishable food items. The DES modelling technique provides an enhanced understanding and exploration on the dynamics of food supply chains and enables evaluation of different scenarios to improve logistics, structure, and coordination in supply chain systems (Spiker *et al*., 2023). Moreover, discrete-event simulation is also utilised in manufacturing supply chains and simulation approach helps to minimise and identify the main bottlenecks in a production line. Identification of the bottlenecks allows manufacturing supply chains to be more cost-effective, improve production levels and evaluate system changes. The DES simulation also enables users to establish connection between the real system and the model. Additionally, the respective simulation modelling technique allows decision-makers in manufacturing business environments to assess the production lines and predict future with more confidence. Therefore, DES simulation technique is also perceived as an effective decision-making tool which supports work-flow management systems, improves quality and efficiency in manufacturing supply chains (Barlas and Heavey, 2016; Javadi *et al*., 2023).

The process model was formed mentioning beef supply chain stages the data was extracted using secondary information based on the four research parameters. The parameters considered in this simulation study were beef safety, beef quality, beef shelf-life and financial or cost-related aspects. The business process model used five scenarios for testing and analysis based on different parameters as discussed above. ***Scenarios 1, 2 and 3*** were developed and designed based on the respective parameters that impact RPA adoption process i.e., ***beef safety, quality, and shelf-life***. Moreover, the ***scenarios 4 and 5*** considered ***financial or cost-related parameters*** which served as the basis for scenario development and simulation analysis of the respective scenarios. Process simulation to all the scenarios depicted results through trails and runs conducted in the ***Simul8 software***. There were different scenarios tested using the process model with different efficiency, resource input, capacity, and risk levels. The simulation model was then tested and run for the period or span of 12 hours per day for seven days a week at 5 times replication. In this study, simulation modelling to pre-defined scenarios used stop criterion, also known as stopping rule, to determine the end of simulation. In simulation modelling, a stop criterion (or stopping criterion) is a predefined condition that determines when a simulation run should terminate. The purpose of the stop criterion is to ensure that the simulation runs for an appropriate amount of time to produce meaningful and accurate results.

This was also a focal point in this research concerning supply chain optimisation. The stop criterion used in this research was fixed simulation time. Fixed simulation time refers to the simulation runs until a specified amount of simulated time has elapsed. In this simulation study, the model was run for a span of 12 hours per day for seven days a week and this was replicated at a frequency of 5. In this research, a fixed simulation time was a crucial stop criterion, as the objective was to evaluate system behaviour over a specific period. For this study, a five-week period was chosen to observe and analyse the performance of the manufacturing supply chain effectively. Therefore, the simulation period in this research was one month and a week (total 5 weeks) to assess system performance in beef manufacturing and processing. Another significant stopping criterion in this research was steady-state achievement which is essential in analysing supply chain efficiency and performance levels in simulation modelling. In this study, the model was run until it reached a steady state, with no significant variation over time. Specifically, the simulation continued until the key performance indicators (KPIs) or metrics stabilised, ensuring consistent system performance without significant fluctuations. Therefore, in this study, two stopping criterions were used simultaneously in simulation modelling. This approach ensured that the simulation runs for an appropriate amount of time and meets specific performance or accuracy goals. The simulation was set up to stop using the time-based criterion and performance-based criterion. Using multiple stopping criterions helped in ensuring meaningful and accurate simulation results while also meeting pre-defined objectives. As highlighted above, the study used significant parameters for process modelling which were beef quality, safety, shelf-life, and costs, and these were observed as a basis for scenario analysis. For business process modelling, variables were employed and altered for a comprehensive assessment using simulation technique. The variables utilised in the study allowed the creating of a comprehensive and realistic model to accurately reflect real-world situations. The key variables for the pre-defined scenarios (1, 2, 3, 4 and 5) included:

1. Mortality Rate: Reflects the rate of cattle loss, impacting overall production efficiency, beef capacity and quality.
2. Beef and Veal Production: Measures the output of the beef supply chain, essential for assessing productivity, supply chain efficiency, and safety.
3. Average Carcass Weight of Slaughtered Cattle: Influences the amount of meat produced, affecting supply chain profitability, quality, and efficiency.
4. Average Meat Consumption in the UK: Provides context for demand levels, critical for aligning production with market needs and impacting demand forecasting and capacity.

5. Fat Inefficiency (Quality): Affects the quality of the meat, which is important for consumer satisfaction, marketability, and quality.
6. Red Meat Shelf-Life: Impacts the logistics and storage requirements, crucial for minimising waste and ensuring freshness.
7. Economic Cost of Production: Includes various cost components such as £ per head output, variable costs (livestock expenses, feed, forage, bedding) and fixed costs (machinery, labour, utilities, overheads, RPA deployment costs), which are essential for financial analysis and sustainability assessments. Also, labour Hours (Paid and Unpaid) which reflects the human resource investment, influencing overall operational efficiency and cost management.

The variables used for simulation analysis to determine supply chain efficiency levels were stochastic. Stochastic variables are crucial for capturing the inherent uncertainties and variabilities in the system. Stochastic variables in this research helped in modelling real-world uncertainties and variabilities that deterministic models are unable to capture. This allowed for reliable and realistic simulation outcomes. The stochastic variables also helped in making the simulation model more accurate and robust and allowed for the exploration of different scenarios and their impacts on the supply chain, providing a comprehensive understanding of system behaviour. In summary, stochastic variables used in this research provided a realistic representation of the uncertainties and variabilities in the beef supply chain, thereby improving the accuracy, reliability, and usefulness of the simulation outcomes. In this simulation research, stochastic variables played a crucial role in risk assessment and identifying potential bottlenecks in the adoption of RPA within the beef supply chain. This focus was central to the research objectives. Therefore, the stochastic variables played a pivotal role in simulation modelling as they allowed for the testing of different 'what-if' scenarios to evaluate business system performance, identify bottlenecks, and assess the impact of potential changes. By incorporating these variables, the simulation provided valuable insights into the beef supply chain's operational and financial efficiency, productivity, and sustainability, guiding decision-making processes for better resource utilisation and improved outcomes. The stochastic variables also allowed for guiding the best approach for RPA adoption, to gain higher productivity/capacity, improved shelf-life, quality, and lower operational costs. Scenarios with RPA integration was evaluated and assessed to observe the socio-economic and environmental impact of beef supply chain through process automation.

Modelling assumptions in supply chain optimisation are crucial for a realistic and manageable representation of the supply chain. These assumptions help simplify complex real-world dynamics and make the simulation feasible to analyse. For simulation to 'what-if' scenarios in this study, there were some model assumptions with respect to beef supply chain optimisation. The modelling assumptions in this study were:

- Supply Chain Structure: The supply chain was assumed to follow a specific structure, such as a series of stages or phases from farm feeding stage to end consumer in this study.
- Initial Conditions: The simulation started with specific initial conditions, such as the number of resource inputs at workstations. The resource inputs utilised in scenarios were either human workforce or RPA integration or both in some scenarios.
- Demand Forecast: Assumptions about future demand for beef products, based on historical data or existing market analysis, which were used to drive production and supply chain activities.
- Resource Availability: Assumptions about the availability of resources such as labour, and equipment to work at different beef supply chain stages and perform tasks.
- Stochastic Elements: Some aspects of the model, such as demand variability, or random failures in the supply chain, were treated as stochastic variables with defined probability distributions.

The above-mentioned model assumptions were considered in the simulation study. The research aimed to evaluate the main bottlenecks in RPA adoption in beef supply chains. The study also focused on investigating the impact of RPA from sustainability lens to evaluate supply chain performance and efficiency through task automation. Therefore, to evaluate supply chain performance with and without the deployment of bots, the model had certain assumptions. The supply chain was assumed to follow a specific structure for scenario analysis however this was a depiction of real-world beef supply chain stages. Moreover, the initial conditions with respect to resource inputs (humans and RPA) were set for each scenario to assess supply chain operational and financial efficiency. This was required to assess supply chain performance by changing resource inputs in each scenario. To evaluate and investigate beef supply chain productivity levels and quality and system changes, assumptions like demand forecast and resource availability were considered. Assumptions regarding future demand for beef products were based on existing market analysis and historical data. Furthermore, some assumptions regarding supply chain failures and demand variability were treated as stochastic variables in simulations. The justifications provided above for model assumptions for simulation purpose further helped in enhancing the credibility and validity of the simulation results. It also provided transparency regarding the underlying assumptions made during the modelling process, allowing stakeholders to better understand the limitations and scope of the study. Overall, the modelling assumptions were aligned with the research objectives to ensure relevance, accuracy, and reliability of the simulation findings.

Furthermore, pseudocodes play a significant role in supply chain optimisation by providing a clear and simplified way to design and communicate processes. In simulation modelling, pseudocodes break down complex algorithms into simple, understandable steps, making it easier for stakeholders to grasp the logic behind optimisation strategies without needing deep technical knowledge. From the context of this simulation study, the utilisation of pseudo coding served to simply the simulation modelling process and facilitated better collaboration and understanding. In this study, pseudo coding aided in visualising and solving supply chain problems by outlining step-by-step processes to improve efficiency, reduce costs, and enhance decision-making. As the study investigated 'what-if' scenarios to test beef supply chain performance and efficiency and evaluated RPA's potential to create sustainable value reducing human error, the development of pseudocodes greatly helped in supply chain optimisation as they offer a straightforward, effective way to design, communicate, and refine complex processes, ultimately enhancing the efficiency and effectiveness of supply chain operations. Figure 5.3 illustrates the pseudocode developed for this simulation-based study. This pseudocode outlines a straightforward supply chain modelling process, making it easier to understand and update the system as needed. It serves as a useful form of documentation that captures the logic and process of supply chain optimisation, ensuring a systematic simulation process. The pseudocode used in this study outlines the step-by-step process for optimising the supply chain model, starting with the process model design that depicts the beef supply chain stages. It then moves through the process simulation conducted in the study and concludes with the provision of the optimised model. Figure 5.3 demonstrates the aggregated results for scenario analysis, including KPI values (such as average time in systems, number of completed jobs, average queuing time), MORE plots depicting risk and error in the model, income statement reports focusing on profit/loss, and carbon emissions reports concentrating on the environmental impact of beef production. Additionally, Figure 5.3 shows the decision rules essential for running the process model, including resource inputs at workstations (RPA and human workforce), capacity, cycle time, simulation frequency/replications, and costs. In summary, the development and utilisation of pseudocodes in this simulation research provided a clear and systematic approach to designing and implementing the simulation model for scenario analysis.

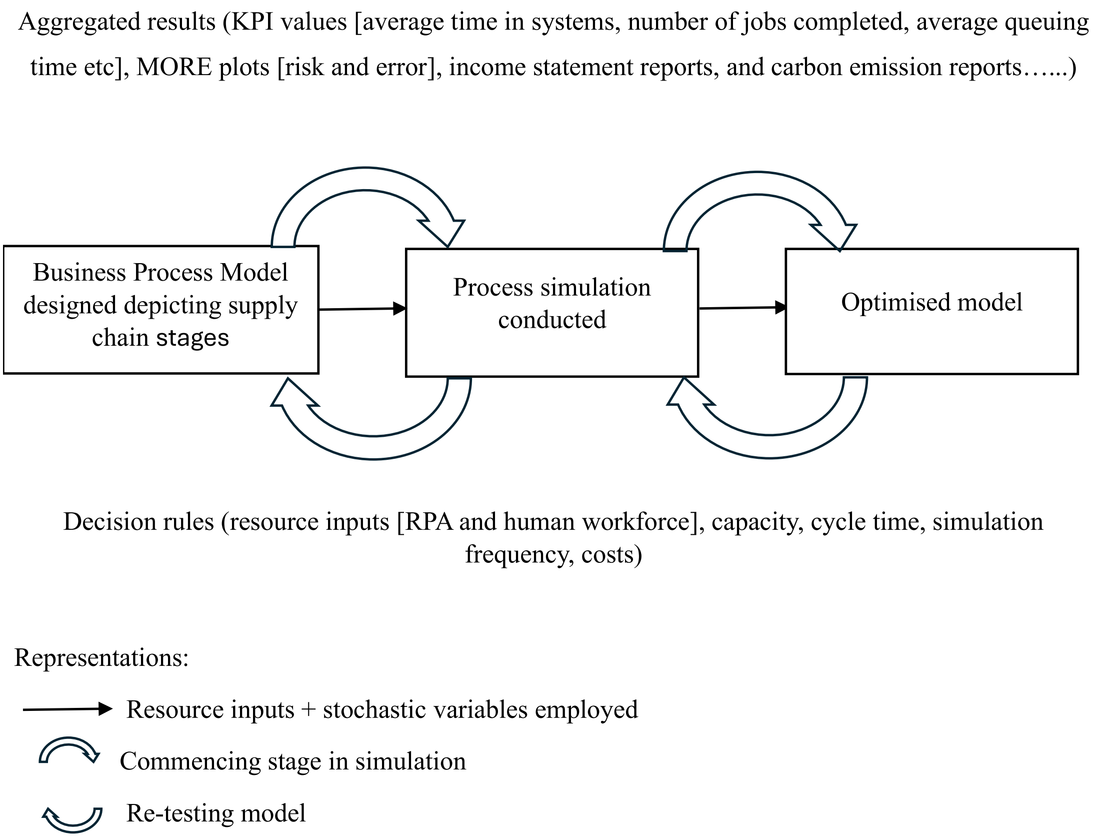


Figure 5.3: Pseudocode for the simulation optimisation approach in assumed scenarios (Source: Author)

Moreover, it was understood from the process model that resources were utilised for evaluation of beef supply chain system performance with and without the adoption of RPA technology. All the simulation models included six significant stages of the beef supply chain. This was a standard process model used for analysing different 'what-if' scenarios. In this simulation study, the business model was developed in a way that it replicated the beef supply chain in practical aspects. The study designed and developed various scenarios for process simulation and supply chain analysis, utilising two primary resource inputs: human workforce and RPA. These scenarios were created to evaluate the performance of the beef supply chain under different conditions. The scenarios 1 and 4 solely relied on human labour for task completion throughout the beef supply chain stages. The scenario 3 began with human workers alone, then added bots alongside for a comparative analysis of performance with and without RPA. Scenarios 2 and 5 combined human workers and RPA to complete tasks. Scenario 1 utilised 10 human workers at various workstations to test operational and supply chain performance across different beef supply chain stages. Scenario 2 employed 10 human workers and 10 bots to process and manufacture beef. Scenario 3 featured four distinct simulation models where the first model used 10 human workers, creating a manually driven supply chain. Second model employed 10 human workers and 10 bots for beef processing. The third model utilised 4 human workers and 7 bots to analyse system performance in scenario 3. The fourth model in scenario 3 relied solely on 4 human workers. The scenario 4 focused on financial aspects, using 50 human workers to execute tasks. The scenario 5 combined 25 human workers and 25 bots to assess system performance. The maximum warehouse capacity varied by scenario and according to the assumption in simulation set-up, the maximum capacity in scenarios 1, 2 and 3 was set to 22. In scenarios 4 and 5 the assumed maximum capacity was set to 43. Desired task completion time was 12 hours for resources to complete tasks. This was because simulations were set-up and designed to run for 12 hours per day for one week. This represented that the desired time for the completion of tasks and for beef processing and manufacturing was 12 hours. The time between two successive failures was expected to be 42 hours in case of any disruption or repair work for the bots. Given that bots were operational for 84 hours a week (12 hours per day for 7 days), the time between two successive failures was assumed to be 42 hours in the event of bots' failure twice. However, this was a contingency assumption; in practice, the bots were fully operational throughout the simulation analysis, automating processes and reducing supply chain complexity. The simulations included six significant stages of the beef supply chain, designed to replicate real-life operations. The scenarios assumed an optimistic demand, allowing for backlog and lost sales. The production cost of 1 kg of beef was set to be from £1.16 per kg to £1.89 per kg. By testing various combinations of human and RPA inputs, the study provided insights into the operational and financial efficiency of the beef supply chain under different resource configurations. The study's simulations provided critical insights into the performance of the beef supply chain under various resource configurations. The findings support the effective implementation of RPA to enhance supply chain performance, minimise human error, and streamline operations. By analysing different scenarios, the study offers valuable guidance for decision-makers in the beef industry on how to best integrate RPA for optimal results.

The scenarios observed how the operational and financial efficiency, average time taken for task performance, beef capacity and shelf-life differed with changes in resource inputs. Each scenario had been developed and designed according to the research parameters which were crucial for investigating the operational and financial performance levels of beef processing and packaging at all stages of the beef supply chain. The scenarios 1 and 2 were tested and run to observe the difference between a manual centric and RPA adopted beef supply chain system and how these two resources impact the operational and employee-level efficiency in the beef processing. The scenario 3 gives a clear comparative analysis on the software Simul8 where scenarios 1 and 2 were compared and investigated based on their operational efficiency and ability to produce high-quality, safe, and nutritious beef. If the beef supply chain is manual-centric, in the slaughtering stage a lot of employees work to process the carcass further and prepare it for cutting or boning. On the contrary with the help of RPA working with humans in the slaughtering stage, 300-400 carcass can be slaughtered for further processing at a much faster pace and less human workforce. This increases the operational efficiency, speeds up the beef supply chain process and reduces chances of beef contamination that might have occurred due to human touch or handling. This ensures high-quality and hygienic beef production with less human error. The scenarios 4 and 5, considering the financial aspects in RPA adoption in beef supply chains, were investigated to observe the financial efficiency and throughput of beef supply chain. The scenarios 4 and 5 were evaluated and assessed to identify the financial risks that could potentially hinder the supply chain process; the simulation considering cost-related parameters allowed recognition and identification of any financial risks and supported business users to avoid them in advance and adopt RPA with enhanced potential. The five scenarios were also assessed and analysed from the three facets of sustainability – social, environmental, and economic. The scenario analysis observed and evaluated the best approach to adopt RPA which acts as a strategic catalyst to obtain sustainable value in beef supply chains.

5.3 'What-if' analysis for Scenarios 1, 2 and 3 considering beef quality, safety, and shelf-life as parameters for process simulation

The scenarios 1, 2 and 3 were designed and developed to test and analyse the business process model using Simul8 software and the respective scenarios considered beef quality, beef safety and shelf-life as parameters and basis for scenario assessment. A simple and generic business process model was used in this simulation study which mapped different stages of the beef supply chain for scenario analysis. The model was designed in a standardised manner making its utilisation and adaptation easier for managers or business users in the beef sector. The simulation study in scenarios 1, 2 and 3 used quality, safety, and shelf-life as parameters for simulation analysis to overcome and reduce the quality and safety concerns in beef supply chains from both retailer and consumer perspective. Therefore, to efficiently address the quality, and health and safety challenges in beef production, the scenarios 1, 2 and 3 used the respective parameters for process analysis. Scenarios 1, 2 and 3 used different resource inputs to test the process model and the simulations were run several times to achieve robust and accurate results through simulation and optimisation of the beef supply chain. The respective scenarios were simulated using the process model to observe and evaluate the operational and employee-level efficiency at different stages of the beef supply chains. The scenarios were also analysed through process testing to evaluate time-taken for beef processing and manufacturing, beef capacity and shelf-life at various stages of the supply chain. The assumed scenarios 1, 2 and 3 were also simulated to assess critically the main bottlenecks and risks at different beef supply chain stages. Simulation results observe the main bottlenecks and risks through simulated process model in each scenario, KPI values and MORE Plot which depicts the risk and error through process testing. The scenarios 1, 2 and 3 were also observed from the lens of sustainability to evaluate RPA integration and adoption benefits and assess its potential in beef supply chains to produce sustainable beef. The scenarios were also tested to assess how RPA enhances supply chain efficiency through task automation; simulation to scenarios also helped in identification of potential risks in RPA adoption. The simulation analysis and results are discussed further with each respect to each scenario which have been examined with respect to operational efficiency, quality, safety and shelf-life in beef processing and manufacturing. The scenarios were also tested to evaluate the supply chain performance with and without the implementation of RPA in beef supply chain.

5.3.1 'What-if' analysis for Scenario 1 in Simul8 – Human workforce as resource

The model was created in the software Simul8 and used human workforce as a resource to perform tasks at different stages of the supply chain such as slaughter stage, cutting and deboning and packaging. The model created and simulated in the software is shown in Figure 3. The simulation model was run five times in replication with 12 working hours a day for seven days a week. It was found from the results that the main bottleneck occurred in the following areas:

1. Slaughtering stage

2. Cutting and boning stage

3. Packaging and storage stage

The result was assessed in seconds for the overall testing of model. It was observed that average value time for the carcasses was 995.28 minutes i.e., 16.5 hours to go through the processes. A detailed KPI has been provided in Table 5, which shows working percentage as 47.27% of the carcass processing in the system. There were many flaws observed in the process and the process was slow and took too much time due to tasks done by human workforce alone which dropped the efficiency of supply chain. The capacity had been seen reducing overtime in the supply chain starting from 9 and lowering to 4 in the last stage i.e., retailer or distribution centre. From the in-depth analysis, this process has been slow in terms of efficiency and higher in time consumed. It is also evaluated that tracking and traceability is poor once the carcass is sliced and cut and sent to the packaging stage. The tracing technique are employed in different places, however, due to humans handling mostly the supply chain processes, it becomes difficult to handle once the product reaches the cutting unit. Resource utilisation is inefficient and effective management and feedback system is required to improve operations and functions across the beef supply chain. In this scenario, human workforce causes human error and high chances of carcass contamination due to human touch and thus it is important for RPA to be adopted for enhanced operational and employee-level efficiency.

Furthermore, based on assumed scenario, the model was purposely run to analyse and observe the impact of human workforce on the beef supply chain and their performance in the Simul8 software. The process model has been simulated in Figure 5.2 to evaluate the operational efficiency and capacity of the beef supply chain at different stages. This is scenario 1 and process model is simulated using the human workforce as resource input. It is evident in scenario 1, that the capacity decreases with the progression of time and this also lowers the operational efficiency. The capacity is observed to be 9 in the first stage i.e., farm feeding to slaughtering stage and this impacts the efficiency as well as it reduces production of beef, and more time is consumed. At stage 2, from slaughtering to cutting stage, the capacity decreases to 7 which lowers the efficiency and increases processing time of beef. As more time progresses, the capacity lowers to 5 in the packaging and storage stage and this further reduces the efficiency level. The last stage is the retailer or distribution centre where the capacity lowers to 4. Human workforce as input in scenario 1 experiences in more time consumed and less efficiency levels within turn have an impact on costs and quality, safety of beef processed. In scenario 1, there are higher chances of beef contamination and less production of beef due to humans performing tasks. This reduces the operational efficiency and increases operational costs in processing beef in the supply chain.

The Figure 5.4 shows the stages of the beef supply chain as it has been simulated along with depicting the efficiency of the human workforce which decreases with passing time. The simulated model also indicated lower operational efficiency and capacity and increased time taken to perform tasks. This also posed threat to quality standards of beef production as higher time was taken to complete tasks which reduced the beef shelf-life. Moreover, as the supply chain was manually driven and had increased human involvement and handling these raised chances of contaminated beef production. As observed in the Figure 5.4, the beef capacity initially was 9 and until it reaches the end consumer it was reduced to 4. The simulation model of the beef supply chain revealed a notable trend of decreasing capacity, also referred to as beef manufacturing volume, as the supply chain advanced through its stages. This capacity reduction was most pronounced at the final stage, involving the retailer and end consumer. The observed decline in capacity at each successive stage was attributed to several factors such as slow supply chain performance, increased processing time, high human error and risks, and low operational efficiency. The overall performance of the supply chain was sluggish, contributing significantly to the decreasing capacity. Moreover, the time required for beef manufacturing and processing escalated at each stage, further diminishing the overall capacity. The supply chain was dependent on human workforce for completion of tasks which led to an increase in errors and associated risks, adversely affecting efficiency. As the tasks were manually handled, this also resulted in lower operational efficiency. The reliance on human labour to perform mundane and repetitive operations caused the carcass processing to be more time-consuming and energy intensive. Therefore, as evident that the beef supply chain was predominantly manual, with tasks being handled solely by human workers at various workstations, the incidence of human error increased. This manual-centric approach not only slowed down operations but also led to risky supply chain system. The need for human intervention in performing complex and repetitive tasks prolonged the processing time of carcasses, reducing the throughput at each stage of the supply chain. Consequently, the supply chain's operational efficiency was compromised due to the reliance on human labour. The simulated model illustrated that low efficiency was a key factor in the decreasing beef manufacturing volume or capacity as the carcass moved from one stage to the next. The manual handling of supply chain processes, without the integration of automated solutions, resulted in significant time and energy consumption, further lowering the overall capacity. In summary, the simulation highlighted that the capacity of the beef supply chain diminished progressively at each stage due to the manual nature of operations, which increased human error, processing time, and reduced efficiency level. The decreasing capacity at each stage of the supply chain, observed as phases and time progressed, served as an efficiency measure in the simulation model.. As carcass passed through various stages, the extended handling time exposed it to more contaminants from the environment, equipment, and human contact. Thus, the beef shelf-life and quality were also reduced due to longer processing times which elevated the risks of contamination. Extended processing times mean workers were exposed to hazardous conditions for longer periods. This included risks from sharp tools, machinery, and cold environments in processing facilities, raising the likelihood of accidents and injuries. Therefore, in a slow, manual-centric supply chain which includes high human-error, ensuring that workers consistently adhere to hygiene protocols can be challenging. Hence a slow beef supply chain system, as depicted in Figure 5.4, necessitates heightened attention to worker safety, beef hygiene, and shelf-life. The frequency of testing and simulating the model was 5 times to ensure accuracy in results.

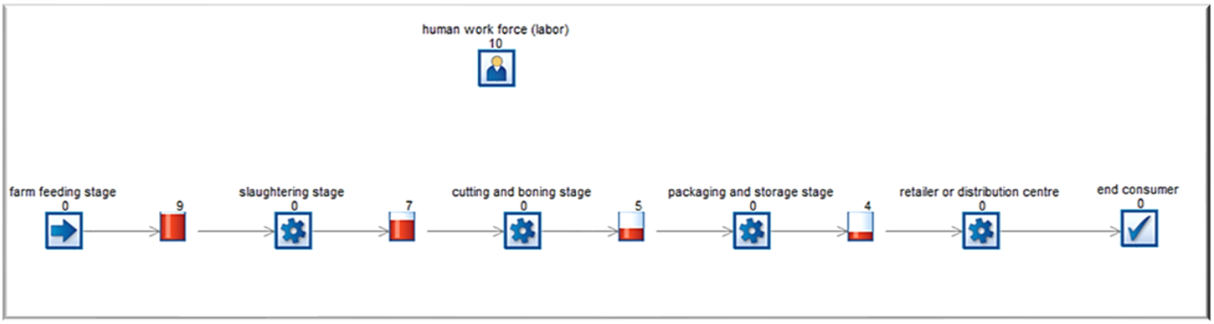


Figure 5.4: Scenario 1 simulation model of beef supply chain

Table 5.2 shows the KPI generated from the software Simul8 and depicts the results for better and enhanced understanding. The key performance indicators (KPI's) depict the simulation results and provide insights on beef supply chain performance and efficiency levels. The KPI values also provide information and understating on the how the model reacted to the resource input (human workforce) in scenario 1 and shows the simulation results of the scenario to better understand the simulation runs conducted. In scenario 1, the KPI values provided simulation result for the end consumer stage of beef supply chain. It was noted that the average time in systems taken for the carcass to reach the end consumer stage was 995.28 minutes (16.58

hours). According to the KPI values generated through the Simul8 software in the cutting and boning stage, the average result for blocked percentage was 13.72 and stopped percentage was 39.01. The average number of jobs completed were 113.60 in the respective cutting and boning stage which was a crucial stage in beef processing and manufacturing. The KPI provided average result in accordance with the stages of the beef supply chain. The KPI values that have generated and showcase a collection of the results also depict less 95% range and high 95% range and the average results with regards to the simulation runs which were 5 in this study. Additionally, the KPI values show the end consumer stage with regards to average time in system taken and provided average result along with less than 95% range and high 95% range. Similarly, the KPI values also explained the cutting and boning stage with respect to the working%, blocked%, stopped%, changeover%, off shift%, resource starved%, maintenance, and number of completed jobs%. The working% can be defined as the working time during which resources, such as labour or machinery, are actively engaged in productive activities or operations. The KPI value for average working% in the cutting and boning stage was 47.27% which meant that this was the time during which the labour was engaged in performing tasks and activities. In scenario1, in the cutting and boning stage, 47.27% was the average working% and the remaining 52.73% represents downtime or idle time. The "blocked%" refers to the percentage of time during which resources, such as labour, machinery, or inventory, are unable to progress or perform their intended tasks due to obstacles or constraints within the system. This metric is crucial for identifying bottlenecks and inefficiencies that hinder the smooth flow of operations. The stopped% can be explained as the percentage where the supply chain was slow in its performance and stopped in conducting tasks which led to further supply chain disruptions. In the context of Key Performance Indicators (KPIs) for a supply chain simulation, "changeover%" refers to the percentage of time spent on changing over or switching production processes from one type or batch to another. This was observed to be 0% in scenario 1 as the carcass was processed from the first stage until it reached the end consumer – and there was no switching of production processes in the cutting and boning stage. Off Shift% measures the proportion of total available time that resources (such as workers or machines) are not in operation. The off shift% measure in the cutting and boning stage was 0 as the resource input (human workforce) were observed to be working and in operation in the cutting and boning stage. The "resource starved%" refers to the percentage of time that a particular process, workstation, or operation is idle due to a lack of necessary resources. The resource starved% was observed to be 0 in the cutting and boning stage as the resource input (human workforce at the workstation) was working to perform tasks and not idle. The Key Performance Indicators

(KPIs) also depict the "maintenance%" which refers to the percentage of total operational time that is spent on maintaining equipment and machinery. According to the indicator, the maintenance% was 0 in the cutting and boning stage as the tasks were mostly completed manually due to the complexity of the stage and as the supply chain was manually handled, as depicted in the results. As highlighted before, the average number of jobs completed% was 113.60 in this scenario and the "number of jobs completed%" represents the percentage of planned or scheduled jobs or tasks that have been successfully completed within a specific timeframe. The key performance indicators (KPIs) illustrate the simulation results and offer valuable insights into the performance and efficiency levels of the beef supply chain. These KPI values also shed light on how the model responded to the resource input, specifically the human workforce, in Scenario 1. By examining these values, one can gain a better understanding of the simulation runs conducted. In Scenario 1, the KPI values provided detailed simulation results for the end consumer stage of the beef supply chain. The average time spent in systems was 995.28 (16.5 hours), indicating a prolonged duration to reach the end consumer stage. Additionally, the stopped% (39.01) and blocked% (13.72) metrics were notably elevated, suggesting sluggish supply chain performance, heightened disruptions, and increased instances of human error, likely stemming from manual handling of the supply chain system. The data also highlights the risks and bottlenecks within the supply chain, emphasising the significant time required for processing and handling due to the reliance on manual labour. The extended duration underscores the need for strategies to improve operational efficiency, such as integrating automation and optimising workflow processes. Furthermore, these KPIs not only reveal the current state of supply chain performance but also serve as benchmarks for assessing the impact of potential improvements and interventions. By continuously monitoring and analysing these indicators, stakeholders can make informed decisions aimed at enhancing the overall efficiency and effectiveness of the beef supply chain. The KPI values for the end consumer stage and the cutting and boning stage are clearly provided in Table 5.2 and these KPI's were generated after numerous runs and trails of the simulated process model.

Table 5.2: KPI Values for the beef supply chain simulated model

		Less 95% range	**Average result**	**High 95% range**
End Consumer	Average time in systems	883.08	995.28	1107.47

Cutting and boning stage	Waiting%	0.00	0.00	0.00
	Working%	45.06	47.27	49.27
	Blocked%	10.96	13.72	16.48
	Stopped%	38.15	39.01	39.86
	Change Over %	0.00	0.00	0.00
	Off Shift %	0.00	0.00	0.00
	Resource Starved %	0.00	0.00	0.00
	Maintenance %	0.00	0.00	0.00
	Number of completed Jobs	106.67	113.60	118.53

The Figure 5.5 shows a Measure of Risk and Error (MORE) Plot which displays risk and error for future support and decision-making. Once trials were run MORE Plot was generated in Simul8 for each KPI. It basically displays the trail runs results in a graphical illustration similar as seen below in Figure 5.4 which shows the likely (in green) and the unlikely (in red). The left side of the histogram observes the unlikely which was the 5^{th} Percentile of all runs and the right most side depicts the upper 95^{th} percentile of the all the runs during trail. There were 5 runs during the trail from which the results have been observed. Simul8 software used for simulation in this study provides confidence intervals for evaluating mean which served as an output when trials were runs. The simulation was done again and again to ensure more trails serve as a basis for generating efficient results. The confidence intervals on the right most and left most side of the MORE Plot – known as Unlikely, is a measure of the error. This MORE Plot in Figure 5.5 depicts that the average time in system for carcass processing and reaching the end consumer was 995.28 minutes for 5 runs. The MORE Plot is useful to support decision-making as it displays the risk and error which facilitates the user or decision-maker to evaluate the average time required for carcass processing through 5 runs. The number of runs or frequency ensures that the results are more realistic and higher chances for them to be likely true and accurate. The variability of results shows that the likelihood of the average time consumers for beef processing and reaching the end consumer was in between 886.05 mins and 1066.98 mins with respect to 5 runs trial in the software Simul8. The bars represent the frequency of the results occurring within trials. The MORE Plot as seen in Figure 5.5 shows the results in the form of graph for enhanced understanding and examination from user's perspective.

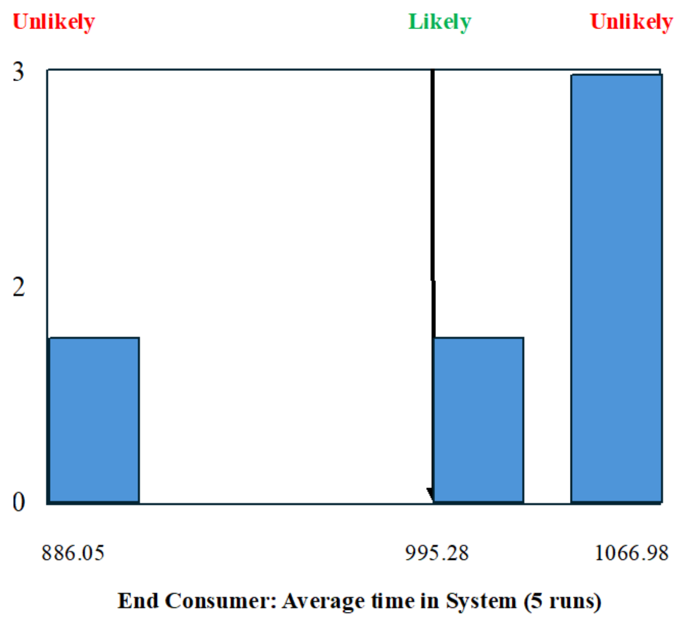


Figure 5.5: MORE Plot for average time in system for end consumer

Another MORE Plot shown in Figure 5.6, depicts average working percentage for the cutting and boning stage i.e., 47.27%. It also observes the likely and unlikely bars.. The Measure of Risk and Error (MORE) plot displaying two unlikely bars and one likely bar suggests an analysis of different risk factors or error categories within the supply chain. The unlikely bars represent categories or scenario where the likelihood of risk or error occurring is low. Despite being unlikely, these risks or errors were depicted and included in the plot to provide a comprehensive overview of potential issues. These could involve rare events, exceptional circumstances, or highly controlled processes where errors are not commonly observed. The likely bar indicates the likelihood of risk or error is high. This points to areas within the supply chain that were more prone to disruptions, inefficiencies, or human errors. For instance, manual handling processes, bottlenecks, or processes in the supply chain dependent on human intervention fall into this category. The plot serves to highlight the areas where attention and improvements are most needed (the likely bar) while also acknowledging potential, albeit less probable, risks and errors (the unlikely bars). This visualisation helps in prioritising efforts to mitigate the most significant risks and streamline supply chain operations effectively. There were two unlikely bars observed in the cutting and boning stage due to no resource starvation%, changeover%, and off shift% which was noted to be 0 in the respective beef supply stage –

however, risks were present due to manual centric supply chain system and other potential issues associated with it. The likely bar demonstrates the risk and error account due to blockage, supply chain disruptions (stopped%), high human error and manually handled supply chain system. The MORE plot displays the results which have been generated through running the trial. The MORE plot below depicts that 5 runs were conducted during the trial procedure and depicts the percentile of the cutting and boning stage. The right-side depicting a bar shows the upper 95% confidence interval of average, and the left most bar depicts the lower 95% confidence interval of average. The bars are the representation and indication of the frequency of results occurring in trials. The MORE plot is essential in managerial aspects as it helps to understand and analyse the factual variability in the results in the cutting and boning stage. The KPI values alone might not every time give the indication of how risky the decision is. Additionally, the MORE plot in this scenario observed runs in the form of a visual representation which enhances the understanding of the user with regards to variations in the results. The graph in Figure 5.6 depicts that the average working% is in between 45.48 and 49.08. Hence, it can be confidently said that the average was going to fall in between the two figures.

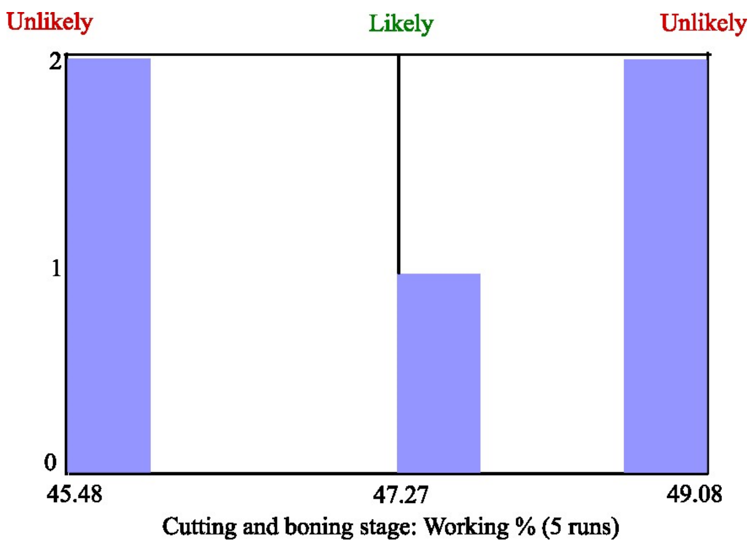


Figure 5.6: MORE Plot for working% in cutting and boning stage

5.3.2 'What-if' analysis for Scenario 2 in Simul8 - Human workforce and RPA as resources

The model simulated in the software Simul8 used both human workforce and RPA technology for performing operations and beef supply chain processes. The average time in system for the carcass in the beef supply chain was 805.32 minutes i.e., 13.4 hours. The working percentage for the beef supply chain process in packaging stage was 88.33%. The capacity and efficiency in different stages of the supply chain process was observed to be at higher side and increased. The beef supply chain had better operational efficiency as seen in the simulated model. This meant that due to the adoption of RPA in the beef processing, the supply chain worked better and increased its functionality. The use of RPA reduced human error due to which high-quality beef are produced and cut for packaging. The shelf-life of beef, which is an important factor in beef safety, also increases due to faster production line. Regarding this scenario, RPA adoption enhances operational efficiency and beef safety and traceability. This also enhances beef production due to fast-paced processing supply chain. Scenario 2 has two resource inputs i.e., human workforce and RPA technology. Scenario 2 observes sustained and increased capacity and operational efficiency. In stage 1, from farm feeding to slaughtering, the capacity is seen to be at a higher side i.e., 19 and so it depicts higher operational efficiency and less time consumed for beef processing. The capacity slightly dropped to 18 but remained at a higher end in the cutting/boning and packaging stage. This means that the beef processing operational efficiency was high, and beef processed has greater shelf-life and quality in stage 2 and 3. The last stage i.e., retailer/distribution centre depicted 19 capacity and so the overall supply chain operational efficiency increased. Therefore, scenario 2 produced high-quality and safer beef. Less time was consumed as the beef processing line remained fast due to higher efficiency levels and this led to lower operational costs. To summarise, the processing line was observed and analysed to be more stable, efficient, and faster in beef production. This adds value to the supply chain system as it creates sustainability and efficiency in beef processing. Fast paced processing line and reduced human error due to RPA adoption decreases the waste produced during beef processing. Enhanced operational efficiency also provides competitive advantage to the beef supply chain. The Figure 5.7 shows scenario 2 simulation model of the beef supply chain formed in Simul8 software. The model is simulated using 5 runs to confirm accuracy of the results.

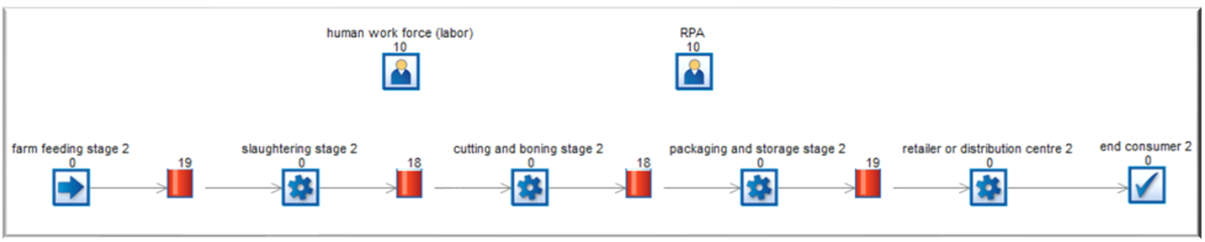


Figure 5.7: Scenario 2 simulation model of beef supply chain

The Table 5.3 depicts KPI report generated through the Simul8 software. The KPI values give a detailed overview of the simulation done to the process model and evaluate any changes in the supply chain process in a virtual environment. The Table 5.3 provides the KPI values for the end consumer and farm feeding stage 2. The key performance indicators (KPI's) evaluated and measured the success of different processes within the beef supply chain. They played a significant role in providing insights into the performance, efficiency, and sustainability of the beef supply chain. In the end consumer stage, the average time in systems was observed to be 886.32 minutes (14 hours and 46 minutes) for the carcass to reach the end stage. The number of jobs completed at the end consumer stage was recorded at 215.80. Moreover, the maximum time system was 870.00 minutes and the minimum time in system was 725.84. In accordance with the KPI values generated from simulation in this scenario, the average result for the blocked percentage in farm feeding stage 2 was observed to be 1.61. The stopped percentage observed in the farm feeding stage 2 was 10.06. The number entered recorded in the farm feeding stage 2 was 240.60 and the number lost was noted to be 30.00. The net number entered the farm feeding stage 2 was 210.60. In farm feeding stage 2, the waiting% was 0 which indicated that there were no delays or idle times at this stage of the supply chain. In the context of beef supply chain optimisation, a 0% waiting percentage (waiting%) was a significant indicator of efficiency. 0% waiting percentage also meant that the resources (RPA and human workforce) were scheduled appropriately, ensuring that processes were seamless and smooth. Moreover, the average working% was seen to be 88.33 which indicated that, on average, resources (such as RPA and human labour) were actively engaged in productive work for 88.33% of the available time. With resources working 88.33% of the time, there was only 11.67% of the time when resources were idle. This low idle time helped in minimising waste of both time and resources, contributing to the overall efficiency. A high working percentage correlates with higher throughput, meaning more beef products are processed and moved through the supply chain in given period as observed in the farm feeding stage 2. The blocked% in the respective stage was 1.61 which was also very low. This low percentage indicated that the stage experienced minimal interruptions, allowing for a smooth and continuous flow of operations. In other words, the resources at this stage were rarely idle or waiting due to downstream constraints, contributing to overall efficiency and productivity in the supply chain. The stopped% at the farm feeding stage 2 was 10.06 which indicated that the processes at this stage were halted or inactive for 10.06% of the total operational time. This relatively low percentage meant that the supply chain was mostly efficient and operational for most of the time, with processes running smoothly and effectively during the remaining 89.94% of the period. The changeover% noted was 0 at the farm feeding stage 2. The off shift % was also 0 at the respective stage which meant that there were no periods where the operations were intentionally paused or stopped due to scheduled off-shift times. This indicated that the stage was active and operational continuously, without planned downtime or breaks in production. The resource starved percentage (resource starved%) was recorded at 0%, indicating that there were no periods during which the stage lacked the necessary resources (such as labour, and RPA) to continue operations. This meant that the stage had the required resources available, ensuring continuous and uninterrupted production without any delays caused by resource shortages. The maintenance percentage (maintenance%) was measured to be 0%, indicating that there were no periods during which the stage was undergoing maintenance activities. This meant that the processes at this stage did not require any maintenance during the observed period. In the farm feeding stage 2, the average number of completed jobs were 211.60 as observed in Table 5.3. Overall, the KPI's indicated that the supply chain performance was efficient, and the supply chain experienced less interruptions and risks due to implementation of bots working alongside human workforce. The KPI values were calculated by the software to give an insight of the beef supply chain operations, time consumed, working and risks involved. The KPI values indicated figures related to various processes in the end consumer stage and farm feeding stage 2. The end consumer stage provided KPI values for average time in systems, number completed, maximum time in system and minimum time in system. The farm feeding stage 2 which was the initial phase of the supply chain observed KPI values for number entered, number lost, net number entered, waiting%, working%, stopped% and others as depicted in Table 5.3.

Table 5.3: KPI Values for beef supply chain simulated model

		Less 95% range	**Average result**	**High 95% range**
End Consumer	Average time in systems	720.14	886.32	890.64
	Number completed	207.72	215.80	223.48

	'In system less than' time	10.00	10.00	10.00
	% in system less than time limit	0.00	0.00	0.00
	St Dev Of	13.00	37.28	80.68
	Maximum time in system	812.47	870.00	927.72
	Minimum time in system	612.55	725.84	831.13
Farm feeding stage 2	Number entered	222.83	240.60	258.37
	Number lost	12.38	30.00	47.62
	Net Number entered	207.74	210.60	213.46
	Waiting%	0.00	0.00	0.00
	Working %	84.94	88.33	91.73
	Blocked%	0.00	1.61	4.47
	Stopped %	8.80	10.06	11.32
	Changeover%	0.00	0.00	0.00
	Off shift%	0.00	0.00	0.00
	Resource starved%	0.00	0.00	0.00
	Maintenance%	0.00	0.00	0.00
	Number completed jobs	206.99	211.60	216.21
	Minimum use	0.00	0.00	0.00
	Average use	1.00	1.00	1.00
	Maximum use	1.00	1.00	1.00
	Current contents	1.00	1.00	1.00

The graph in Figure 5.8 projects a MORE Plot which depicts risks and errors. The MORE Plot identifies risks and errors for stakeholders and managers of beef supply chain, so they can reduce or alleviate them. The plot shows the unlikely or risk factors that may have chances to occur due to uncertainties. It also shows the average time in system for end consumer 2, i.e., 805.32 in 5 runs. The right most bar represents the upper 95% confidence interval of average and the left most bar depict the lower 95% confidence interval of the median or average.

Through detailed observation of the MORE plot in Figure 5.8, it can be confidently suggested that the average is going to be in between 714.27 and 863.11. In the context of beef production at the end consumer stage, the Measure of Risk and Error (MORE) plot with two unlikely and two likely bars has been represented in Figure 5.8, where the resources involved both RPA and human workers at different workstations. The unlikely bars represent situations within the beef production process where the likelihood of risk or error is low due to the presence of RPA working alongside human workers. These are less frequent but still monitored for a comprehensive risk management strategy. The unlikely bars include low risks of automated quality control errors and human error in automated processes. Errors can be made in quality control checks performed by RPA systems though chances of this are typically very low due to RPA being highly accurate and consistent in performing repetitive tasks. Also, mistakes can be made by humans in maintaining and monitoring RPA automated systems. Though, this is also unlikely as once RPA systems are set up and calibrated correctly, the need for human intervention is minimal, and errors in these activities are infrequent. On the other hand, the likely bars represent areas within the beef production process where the likelihood of risk or error is high, even with the involvement of RPA and human workers. The likely bars within the MORE plot, included some risks and errors related to manual handling errors, and supply chain disruptions. The manual handling can potentially occur due to mistakes made by human workers during manual tasks that are not automated, such as packaging or final inspections. Moreover, human involvement in manual processes is prone to variability and errors, making this a common risk area despite the presence of RPA in other parts of the process. The supply chain disruptions can also occur as the beef supply chain has a complex business system which involves multiple actors and stages, making it susceptible to frequent disruptions that can impact timely delivery to the end consumer. Manual handling errors and supply chain disruptions are more prevalent and require targeted efforts to reduce their impact. Strategies might include additional training for workers, increasing automation where feasible, and enhancing supply chain logistics and communication. The MORE plot enables the decision-making with enhanced confidence as it projects and identifies the possibility of risk and error in the end consumer 2 stage as depicted in Figure 5.8.

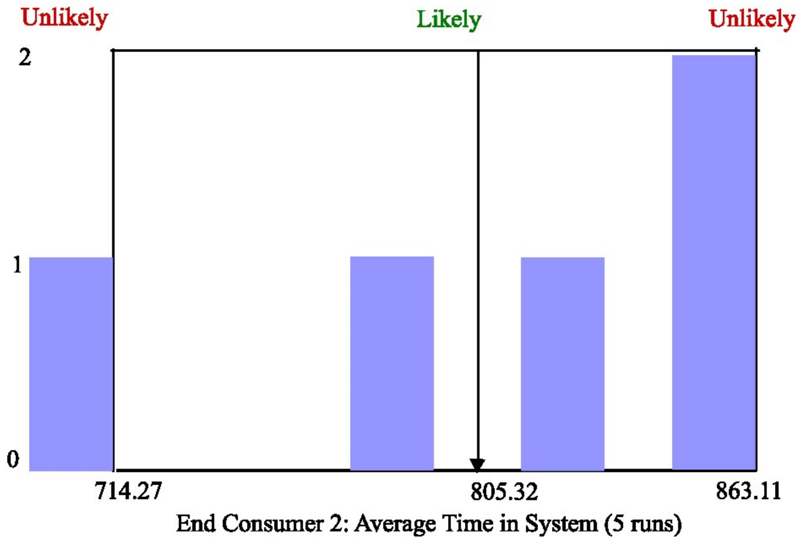


Figure 5.8: MORE Plot for average time in systems for end consumer 2

The MORE Plot shown in Figure 5.9 depicts the working percentage for packaging and storage 2, i.e., 88.33 in 5 runs. The errors or risks are observed in the MORE Plot so that they can be avoided or eliminated in real-life environment. The right side of the bar observed the 95^{th} percentile of 5 runs and the left most side of the bar depicts the 5^{th} percentile of 5 runs or trails of the process model. 84.99 is the lower 95% confidence interval of the average and 90.93 is the upper 95% confidence interval of the average. Therefore, it can be confidently suggested that the average working% was going to be in between 84.99 and 90.93. The MORE plot provides an insight and detailed representation of the risks and error and supports with enhanced understanding by observing variations in results. It helps with the decision-making of the processes within packaging and storage stage 2 and potential risks can be alleviated in the beef supply chain processes through these findings. The MORE plot generation through Simul8 software allows elimination or avoidance of these risks and error through better managerial approach, enhanced planning and use of sustainable business strategies or business solutions in real-world situations to help cater these risks.

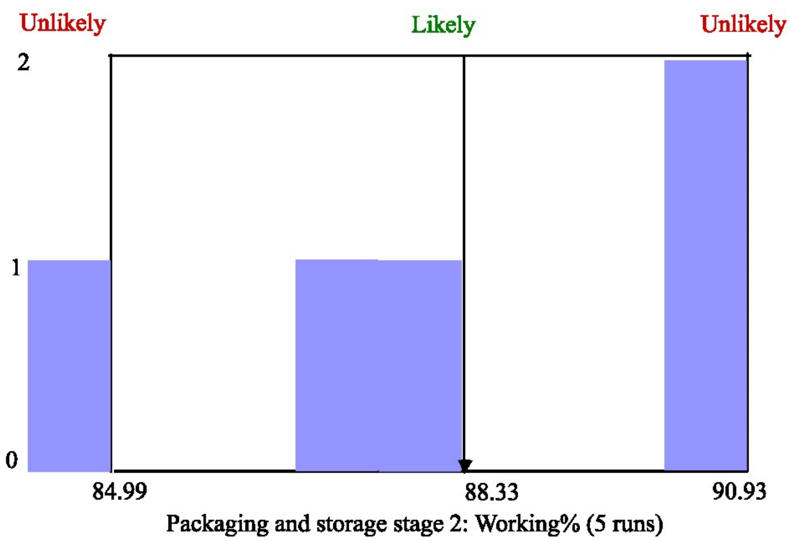


Figure 5.9: MORE Plot for working% in packaging and storage stage 2

5.3.3 'What-if' analysis for scenario 3 – comparative testing and analysis

Based on scenario 3 in the Figure 5.10, the efficiency and capacity of scenarios 1 and 2 was analysed and compared in the software Simul8. In scenario 3, it was observed that when human workforce with input as 10 workers alone worked at the farm feeding stage 1 the efficiency initially was seen at a higher end but as it reached the slaughtering stage, cutting and packaging stage, and storage stage, the efficiency and capacity of beef processing became unstable and decreased with increasing time. The main bottlenecks were seen at the slaughtering stage, cutting and boning stage and packaging and storage stage. This meant that there were increased risk factors and high human error present in all these stages. The beef produced at the end for the retailer and end consumer had low capacity and therefore failed to satisfy the high demand. As observed in the simulated process model, the beef capacity was 4 when it reached the retailer due to human error and time taken to complete tasks. Poor supply chain performance and operational efficiency resulted in compromised or low quality of beef and higher chances of beef contamination due to human handling and involvement to complete tasks. The capacity initially was 9 and then it decreased to 7 in the cutting and boning stage. When the processed beef reached the packaging and storage stage the capacity and efficiency further reduced to 5 and at the end it was observed at 4 when it reached the retailer or distributor.

The process model was then compared to another scenario where the resource inputs were human workforce and RPA technology. The workforce reduced to 4 as depicted in scenario 3 and the RPA bots were 10 as input to the model for simulation. As projected and analysed by running trails with frequency of 5 times, the beef supply chain stages and business processes seemed much more efficient and effective in task completion. The operational efficiency and beef capacity as seen in Figure 5.10 increased positively, and supply chain processes were more sustainable, faster, and efficient in producing high-quality, nutritious beef with greater shelf-life for the retailers and consumers. The scenario with less workforce and higher bots' induction at the processing line, served as an advantage with regards to the human-health concerns of consuming healthy beef. The beef operational efficiency and capacity observed stability i.e., 10 in slaughtering stage, and cutting and boning stage. Then an increase was observed in the packaging and storage stage with efficiency and capacity reaching 12 and then 13 in the retailer or distributor stage. The business processes were observed to be more sustainable, efficient, progressive, and faster with the increase in RPA deployment and decrease in human workforce. This greatly and positively enhanced the operational and employee efficiency as bots completed tasks that were strenuous, repetitive, and mundane. As evident from the simulation analysis, greater operational efficiency and increased capacity enhanced beef production levels and ensured quality beef production with less time and energy consumption.

In Figure 5.10, the scenario 3 depicts the simulated process model with comparative analysis and testing to provide effective and efficient simulation results. The comparison provides detailed and enhanced understanding for practitioners and decision-makers looking for solutions to complex beef supply chains and meeting beef quality standards with aim to enhance efficiency levels. The process model comparative analysis also reflects the impacts of technological adoption like RPA in this model to facilitate the beef supply chain processes and investigate and identify the main bottlenecks in different stages to alleviate these in real-life situations. The identification of potential risks also improves the RPA adoption process and enables future adopters of RPA to enjoy its maximised benefits and facilities. The accuracy of RPA adoption increases the sustainability criteria of producing high quality, healthy beef and reduces waste generated along the processing line.

In Scenario 3, a comparative analysis revealed significant differences in the efficiency and capacity of beef processing at various stages, particularly when contrasting traditional human-only workforce operations with those incorporating RPA. At the outset, with human workforce as the sole resource in the first simulated model, the efficiency and capacity of beef processing stood at 9. This stage, referred to as farm feeding stage 0, demonstrated that the operations were heavily reliant on human labour. Over time, as the process advanced from the farm feeding stage 0 to the point where the beef reached the end consumer, the capacity diminished significantly to 4. The decline in operational efficiency and capacity was evident, and this reduction was accompanied by an increased risk of contamination. The human involvement in the process, with its inherent variability and potential for errors, contributed to these issues. The analysis highlighted several critical bottlenecks throughout the beef processing stages:

Slaughtering Stage: This stage encountered significant inefficiencies and was identified as a major bottleneck due to its labour-intensive nature and susceptibility to human error.

Cutting and Boning Stage: Similarly, the cutting and boning stage suffered from reduced efficiency, compounded by the physical demands on the human workforce and the precision required.

Packaging and Storage Stage: This final stage also faced substantial challenges in maintaining efficiency and quality, further impacted by the risk of contamination and inconsistent human performance.

On the other hand, in the second simulated model which started from farm feeding stage 2, With the integration of RPA alongside human workforce, a notable improvement was observed. At farm feeding stage 2, the efficiency and capacity of beef processing were stable and consistent. The process commenced at the slaughtering stage with an efficiency and capacity value of 19, which impressively remained constant through to the end consumer stage. The incorporation of RPA alongside human labour brought several advantages such as increased speed and steadiness, enhanced efficiency, reduced human error, and improved quality and shelf-life. To emphasise on the second simulation model which implemented RPA, the business processes became much faster and steadier, with automation handling repetitive and precision tasks efficiently. The operational efficiency of beef production saw a significant boost, maintaining a high capacity of 19 with minor fluctuation only, throughout the process. Moreover, automation reduced the potential for human error, thereby improving overall process reliability. The beef's quality standards were enhanced, resulting in a longer shelf-life. The reduced risk of contamination due to minimised human handling made the product safer and healthier for consumption. The comparative analysis in Scenario 3 clearly indicates that the traditional human-only workforce model struggles with efficiency, capacity, and contamination risks at multiple stages of beef processing. In contrast, the integration of RPA at farm feeding stage 2 not only stabilised but also maximised efficiency and capacity, ensuring consistent performance from the slaughtering stage to the end consumer. The use of RPA, in conjunction with human labour, streamlined the operations, minimised errors, and enhanced the overall quality and safety of the beef products.

In the third simulated model of the beef supply chain, another comparative analysis was conducted to evaluate the impact of different labour configurations on efficiency and capacity. This model introduced a mixed workforce consisting of a reduced human labour force and an increased number of robots (RPA input). The model employed 4 human workers and 7 bots, and the simulation began at farm feeding stage 115. At the initial slaughtering stage, the beef capacity was 10. This marked a stable starting point for the process. The capacity remained consistent at 10 through the cutting and boning stage. The stability in capacity at this stage was attributed to the efficiency of bots in performing precise and repetitive tasks without error. At the packaging and storage stage, the beef capacity increased to 12. This increase indicated that the integration of bots significantly enhanced the process efficiency, leading to higher throughput at this critical stage. By the time the beef reached the retailer or distributor, the capacity further increased to 13. The continual increase in capacity through each stage highlights the compounded benefits of robotic efficiency over time. The introduction of 7 bots led to a noticeable improvement in operational efficiency and beef capacity at each stage of the supply chain. This was particularly evident as the beef capacity not only remained stable but increased progressively through the stages. The increased use of bots also contributed to an extended beef shelf-life. With fewer human interactions, the risk of contamination was significantly reduced, which, in turn, improved the quality and safety of the beef products. The model demonstrated that with a higher number of robots, the system could handle increased capacity without compromising efficiency. This scalability is crucial for meeting higher demand and ensuring consistent supply. The third simulation model clearly illustrates the positive impact of reducing human labour while increasing robotic input in the beef supply chain. Starting from farm feeding stage 115, the beef capacity at the slaughtering stage was 10, remained stable through the cutting and boning stage, increased to 12 at the packaging and storage stage, and finally reached 13 at the retailer/distributor stage. The enhanced operational efficiency and beef capacity, attributed to the 7 bots, resulted in faster, more reliable processes with improved beef quality and shelf-life. This simulation underscores the benefits of integrating advanced automation in the supply chain to optimise performance and product quality.

In the fourth simulation model, which started at farm feeding stage 2, only human labour was used as the resource input. The simulation revealed that in the slaughtering stage 2 the beef capacity was 14. As the supply chain progressed to the cutting and boning stage 2, the beef capacity slightly increased to 17. The capacity then dropped to 15 at the packaging and storage stage 2. By the time the beef reached the final stage, the capacity had further decreased to 8. The last model indicated that a human-centric supply chain resulted in lower overall beef capacity and a slower supply chain system. The reliance on human labour introduced higher rates of error and disruptions, leading to a significant reduction in capacity by the time the beef reached the end consumer. This demonstrated the inefficiencies and performance issues associated with using only human resources in the supply chain.

The comparative analysis in scenario 3 highlighted the significant benefits of adopting RPA and demonstrated that a manually driven supply chain results in poor operational efficiency and lower beef capacity due to high human error. The reduced operational efficiency in a manual supply chain led to longer task completion times and slower progress. Consequently, beef production decreased because more effort, energy, and time were consumed, and numerous bottlenecks emerged due to human dependency. In contrast, increasing the number of robots improved the supply chain's operational efficiency by reducing the time required for task completion. This enhancement created sustainable value in the beef supply chain, as improved efficiency levels reduced the likelihood of beef waste and contamination. Ensuring quality beef production is a major concern for beef supply chains, and the integration of RPA supports this goal by enhancing efficiency, maintaining product quality, and extending shelf-life, as evidenced by the comparative analysis in scenario 3.

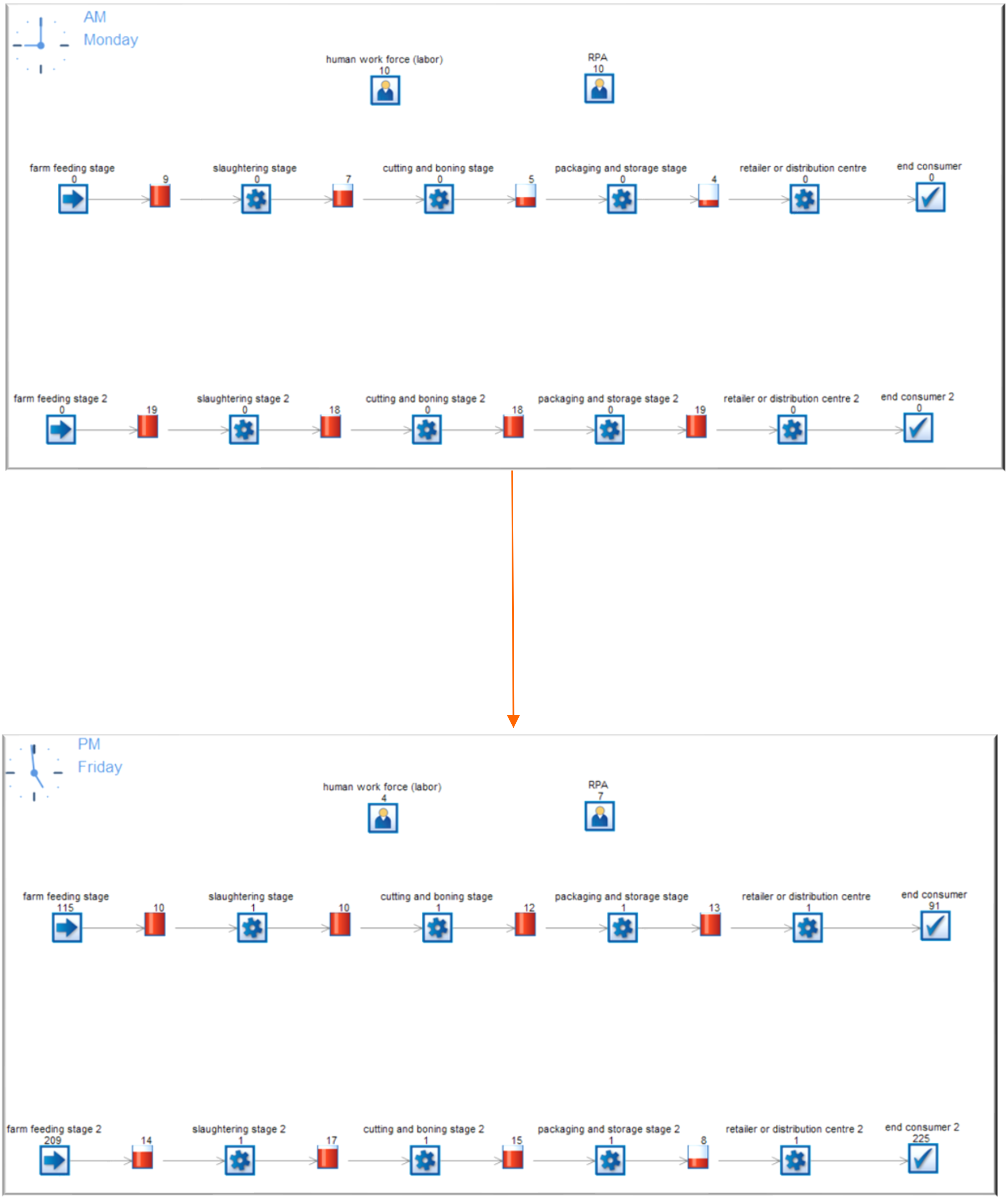


Figure 5.10: Scenario 3 Simulated Model – testing and comparative analysis

5.6 Process Model and Simulation Results for Scenarios 4 and 5 —Financial Parameters as a Basis

The simulation research also focuses on another significant direction for the scenario analysis based on financial aspects or parameters that has not been discussed in previous research or past studies; this is an important dimension for consideration when adopting RPA in beef supply chains. The process model was comprised of different stages of the beef supply chain, providing insight into the supply chain processes. The process model shows the overall important stages of the beef manufacturing supply chain, from the processing and production of beef to the consumption by the customer. Financial aspects and cost-related statistics were considered for all stages of the business processes to investigate the economic conditions and financial health of the supply chain with and without the implementation of RPA technology. The economic performance of the supply chain is an important part of the analysis as it impacts the beef productivity, profits, and business scalability and viability. The process model that was already developed was further used for simulation purpose considering the financial aspects which was another important parameter for model testing in Simul8 software. Therefore, the assumed scenarios 4 and 5 were designed to address the cost-related or financial concerns of RPA adoption in beef supply chain. Simulation process in scenarios 4 and 5 helped to address the financial challenges in RPA implementation and allowed recognition and identification of financial risks in beef supply chain.

Scenarios 4 and 5 were tested based on the financial aspects of RPA adoption in beef supply chain; the supply chain processes in these two scenarios were analysed from the three dimensions of sustainability. Scenario 4 used human workforce as the only resource input at different workstations of the beef supply chain. Scenario 5 utilised the human workforce working alongside RPA technology to observe operational and financial efficiency in beef supply chain. The process model was tested, simulated, and run for 1 week to achieve more accurate results. The simulation model was tested and run at several frequencies to ensure robust results. The simulation used different financial parameters for model testing and scenario analysis; these were the basis for the scenarios developed. Simulation involved running the model under various scenarios to predict its behaviour and performance. This helped in understanding how the model would react under different conditions and identifying potential improvements. The model was run and tested for 7 days (one week) at the frequency of 5 to capture more detailed and accurate results. This extended run provided a more comprehensive view of the process dynamics and performance over time. Running the model for one week offered several advantages such as accuracy, reliability, improvement identification in scenario analysis, and decision support. In the simulation analysis, longer runs provided a more realistic and detailed picture of the process, reducing the impact of short-term fluctuations and anomalies. This ensured accuracy of simulation results in beef supply chain optimisation. The beef supply chain involves several stages and actors which increases its complexity in management. From the context of beef supply chain simulation in scenarios 4 and 5, extended testing ensured that the model was robust and capable of handling real-world complexities over time. Moreover, continuous operation highlighted areas for improvement, helping to fine-tune the process and enhance overall efficiency. This allowed improvement identification and a better understanding of the beef supply chain performance with changing resource inputs and variables. Accurate and reliable model outputs provided valuable insights for potential decision-makers, aiding in strategic planning and operational adjustments. In summary, the process model was rigorously tested, simulated under various conditions, and run for a week to gather detailed, accurate data. This comprehensive approach ensured the model was reliable and effective in representing the beef production supply chain, leading to better-informed decisions and improved performance.

The discrete event simulation model used a simulation-based approach to investigate the changes in the financial and operational performance of the supply chain by providing various cost-related parameters. The simulation used resource inputs and other data based on financial aspects to observe the business performance at different stages of the supply chain (Ghadge *et al.*, 2020). A simulation-based approach imitates a situation, circumstance, process, or operation to evaluate the risks in a supply chain system (Bhardwaj *et al.*, 2023). The simulation technique helps stakeholders and business users test the supply chain activities and performance level in a virtual environment and provides organisations an opportunity to avoid these risks in real-life situations. It also helps food manufacturers enhance their financial performance and produce food products of a high value and quality. By considering financial aspects using the simulation technique, food manufacturers can enhance their financial decision-making and increase productivity levels (Gallego-García *et al.*, 2023).

5.6.1 Scenario 4—Financial Considerations Using the Human Workforce as a Resource

The process model simulation in Scenario 4 used a manual-centric supply chain and only the human workforce was throughout the various stages of the beef supply chain. The model was tested and run for 1 week (7 days (12 hours per day)); it was replicated several times at a frequency of 5 to record and evaluate the results with increased accuracy. To ensure the process model's accuracy and reliability in the beef production supply chain, it was tested and simulated to generate simulation results. The objective to run the process model was to evaluate the model and replicate real-world conditions. Also, the aim was to test various aspects of the beef supply chain such as main bottlenecks or risks, human error, performance level (financial and operational), and productivity levels. The model was run continuously for one week to capture comprehensive insights and data that includes daily variations and typical operational and financial challenges. The process was executed five times during this period to ensure the results' robustness and repeatability. By running the process model five times over a week, the collected data accounted for variability and provided a more accurate representation of typical operations and cost-related aspects. The frequency of runs helped in identifying patterns, common disruptions, and the average performance metrics, leading to more reliable conclusions. As highlighted before, the scenario 4 used financial or cost-related parameters as a basis for scenario analysis. Stochastic variables were used for evaluating the financial and operational performance in the respective scenario for simulation analysis. The beef supply chain, like many others, is subject to numerous unpredictable factors such as weather conditions, disease outbreaks, market demand fluctuations, and sustainability concerns. Stochastic variables help model these uncertainties, making the simulation more realistic. Stochastic variables utilisation in this simulation study allowed the simulation to identify potential risks and their impact on the supply chain. Stochastic variables helped in modelling variations in beef capacity, queuing times, and provided insights on the costs with humans working as the only resource input. The variables used for scenario analysis considering cost-related parameters included economic cost of production. The economic cost of production was further categorised in different components such as £ per head output, variable costs (livestock expenses, feed, forage, bedding) and fixed costs (machinery, labour, utilities, overheads, RPA deployment costs, which were essentially important for cost analysis and sustainability assessments. Also, labour hours (paid and unpaid labour hours) were also considered as they reflected human resource investment, influencing cost management and operational and financial efficiency. The repeated runs in Simul8 used financial data and information to assess and evaluate the financial performance and operational efficiency of the business activities. The average time taken for the carcass to reach the end customer phase was also analysed using the simulation model. Based on the assumed scenario, the results showed the performance of humans in the manufacturing line and evaluated the queuing time for the carcass to reach the next phase in the supply chain. Figure 5.11 shows the simulated process model that used labour or human workforce as the only resource input to perform the tasks. It was observed that beef capacity decreased as the stages progressed over time. It took longer for the carcass to reach to the progressing stage and the supply chain became slower. The overall productivity of beef production was also reduced at every stage of the supply chain; this means there was high human-error and wastage of beef along the processing line. As depicted in Figure 5.11, the beef capacity or volume steadily decreased at each successive stage over time. Initially, the capacity was 40 units at the start of the stunning and slaughtering stage. This capacity dropped to 36 units during the cutting and boning stage. In the processing and packaging phase, the capacity further declined to 34 units. Upon reaching the retailer or distribution centre, the capacity fell significantly to 10 units. Consequently, by the final phase, much less beef was available to reach the customer. The observed reduction in beef volume at each stage suggested that less beef was ultimately available for the end consumer due to decreasing capacity or volume throughout the supply chain. This reduction indicated slow supply chain performance and increased time taken to complete tasks, largely due to a manual-centric supply chain system. Moreover, the lower beef volumes at the final stages indicated higher wastage along the processing line, primarily caused by human error. This inference was supported by the simulated model presented in Figure 5.11, which highlights reduction in beef capacity due to slow-paced supply chain processes and manual centric supply chain system ultimately leading to increased beef waste along the processing line. In this scenario, human efficiency was seen to be low, and the operational efficiency was also evidently very low, with a low beef production capacity at the end. To further analyse the simulated model, as more time was taken when humans performed and conducted business activities at different stages of the supply chain, the costs for performing the activities on the processing line also increased, thus reducing the financial performance of the supply chain (Figure 5.11). In Figure 5.11, the numbers 230 in the cattle feeding phase and 247 in the end consumer phase represent the stage numbers used for scenario analysis. As depicted in Figure 5.11, the main bottlenecks and risks were seen in the following phases: cutting and boning, beef processing and packaging, and retail.

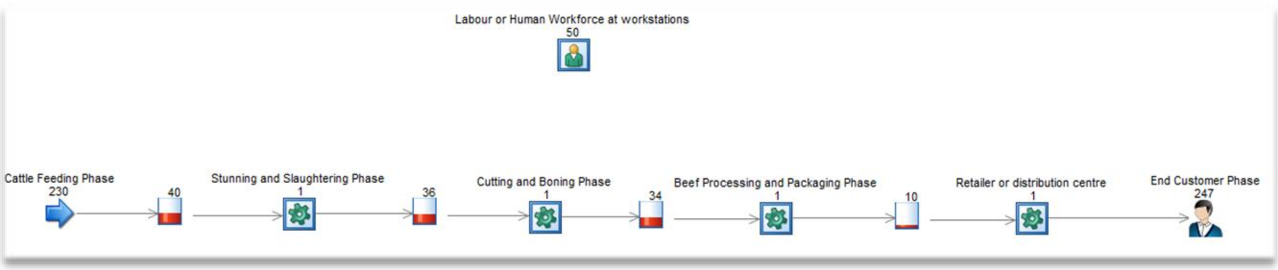


Figure 5.11: Process modelling using financial parameters in Simul8

The simulated process model also generated financial KPIs to provide insight regarding the working performance of the beef supply chain. Financial KPIs are key performance indicators that summarise the overall performance level; this is assessed by testing and running the process model in the software. Table 5.4 depicts the analysis of the simulation process and the financial KPIs generated in Simul8. The average time in system for beef processing to reach the end consumer stage was noted at 1428.76 min–23.81 h. The working% of the beef processing and packaging phase was 37.15, which was recorded to be low. A working percentage (working%) of 37.15% for the beef processing and packaging phase implied that only 37.15% of the total available time was utilised for productive work in this stage. In other words, most of the time during the beef processing and packaging phase was spent in non-productive activities or idle periods. This low working percentage suggested inefficiencies or challenges in the process that need to be addressed to improve productivity and optimise the use of resources in this stage of the supply chain. In the beef processing and packaging phase, the average working percentage of 37.15% suggested that a relatively small portion of the total available time was spent on productive activities. This indicated potential inefficiencies or challenges within this phase of the supply chain that impacted the productivity and overall performance. The average queue for the beef processing and packaging phase was an average size of 20.40. The average queuing time in this stage was noted to be 253.50 min–4.2 h in the processing phase and the maximum queueing time was observed to be 295.04–4.9 h, as illustrated in Table 5.4. The average queuing time of 253.50 minutes (or 4.2 hours) in the processing phase and the maximum queuing time of 295.04 minutes (or 4.9 hours) indicated the amount of time that products spent waiting in queue before being processed within this stage of the supply chain. This suggested that there were significant delays or bottlenecks in the processing phase, leading to prolonged wait times for products before they could undergo further processing or packaging. These delays contributed to inefficiencies, increased lead times, and potentially impacted the overall throughput and performance of the supply chain. The simulation analysis revealed a noticeable uptick in the average duration required for the carcass to reach the end customer stage. Concurrently, both the queuing size and time exhibited high values, culminating in a slowdown of the processing line and a subsequent rise in production costs. This prolonged processing time not only compromised the financial and operational efficiency of the supply chain but also heightened the risk of beef wastage and the production of subpar quality beef, primarily due to increased instances of human error.

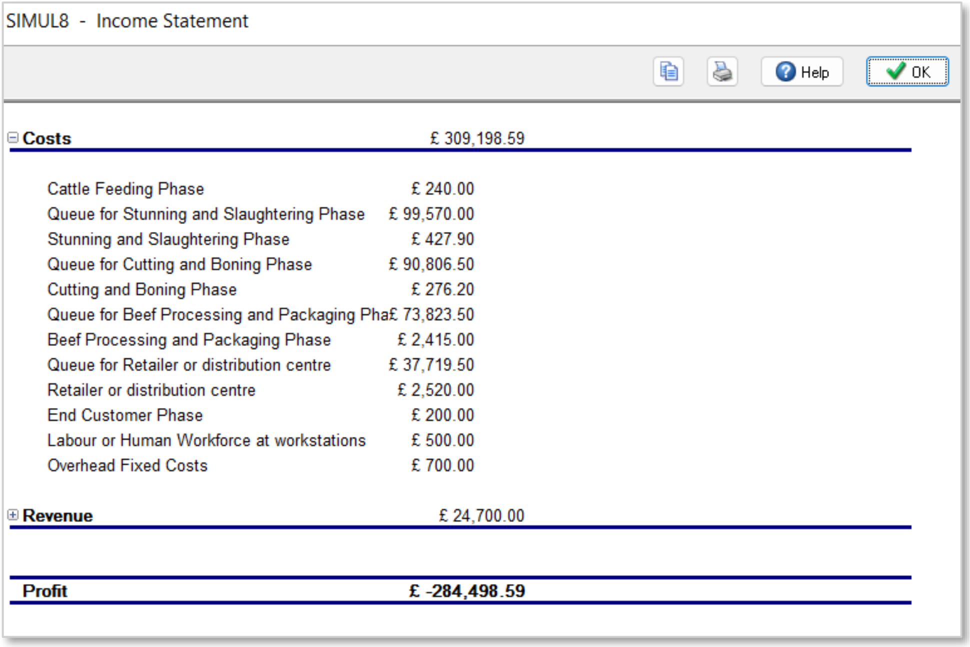
Furthermore, the challenges within the supply chain were thoroughly examined, considering their implications from social, economic, and environmental standpoints, as reflected in the values presented in Table 5.4. This comprehensive analysis aimed to shed light on the sustainability aspects of the supply chain, emphasising the need for targeted interventions to mitigate the identified hazards and enhance overall performance and resilience. The findings revealed a rise in supply chain risks and disruptions, alongside an escalation in queuing size and duration across different stages of the beef supply chain. As illustrated in Table 5.4, the KPI values derived from the simulation of the process model in scenario 4 provided insights into the performance of various phases. The analysis indicated that the supply chain operations were characterised by time-consuming and sluggish processes, leading to a detrimental impact on operational efficiency. This was primarily attributed to prolonged queuing times, resulting in diminished beef capacity, compromised quality, and shortened shelf-life. Moreover, the inefficiencies incurred escalated operational costs, time consumption, and energy utilisation.

Table 5.4: KPI values generated in Simul8 based on financial parameters

Phases	**KPI % System Results**	**Low 95% Range**	**Average Result**	**High 95% Range**
End Customer Phase	Average Time in System	1308.84	1428.76	1548.67
Beef Processing and Packaging Phase	Waiting%	0.00	0.00	0.00
	Working%	38.19	37.15	39.11
	Maximum Use	1.00	1.00	1.00
	Average Use	1.00	1.00	1.00
	Current Content	1.00	1.00	1.00
Queue for Beef Processing and Packaging	Average Queue Size	13.24	20.40	27.56
	Average Queuing Time	184.21	253.30	322.40
	Maximum Queuing Time	252.10	295.04	337.98

To assess the overall financial performance of Scenario 4 for the manual-centric supply chain using the human workforce as a resource to complete task delivery, the software generated an income statement for the simulation. Simul8 provides an income statement, which helps business decision-makers decide whether the supply chain performance will generate profits or losses by assessing the costs and revenues at different stages of the supply chain. The secondary data and statistical information helped to assess the scenario using the human workforce to perform complex business procedures in the supply chain. Figure 5.12 shows the income statement, which had a poor financial and operational performance (as also seen in Table 5.4) as the costs were excessive due to increased human error because of the supply chain being manually driven for task completion. The income statement shows that the profit reached a negative value, indicating that the financial performance was low, and the business activity costs were high, resulting in financial loss in the beef production. The average time taken from beef production until reaching the final customer was long and the supply chain lagged in efficiency and productivity. This was because of the higher average queuing size of 20.40 and increased average time in the beef processing and packaging stage, which was 253.30 min (4.3 h). Beef possessing cost 309,198.59 GBP and the revenue was only 24,700 GBP; this resulted in a negative number with a loss of −284,498.59 GBP. The generated income statement shows that because of the low financial and operational performance, Scenario 4 was unable to make a profit due to the slow processing line and high human error, and it did not achieve sustainable social, economic, and environmental value. Figure 5.11 shows the simulated model where low beef productivity and capacity were observed at each progressing stage. Figure 5.12 shows the high operational costs and increased energy and time consumption, which resulted in low production in the final stage; hence, the high demand for beef was not satisfied in this scenario. The supply chain costs exceeded the revenue, resulting in a poor financial performance and loss for the business in the assumed scenario analysis, as shown in the income statement report in Figure 5.12. The process model in scenario 4 was simulated at a frequency of 5 for seven days (one week) to generate robust results and gain comprehensive understanding on the profit or loss account of the beef supply chain by using humans as the only resource input. To further emphasise, the average queuing size of 20.40 indicated significant delays at various stages of the supply chain. This high queuing size was a clear sign of bottlenecks and errors, contributing to prolonged processing times. The average time spent in this stage was 253.30 minutes (4.3 hours), further demonstrating low performance levels. Long processing times resulted in delays in subsequent stages, affecting the overall supply chain performance. The total cost incurred for beef processing was 309,198.59 GBP which included costs such as cattle feeding phase

(£240.00), queue for stunning and slaughtering phase (£99,570.00), stunning and slaughtering phase (£427.90), queue for cutting and boning phase (£90,806.50), cutting and boning phase (£276.20), queue for beef processing and packaging phase (£73,823.50), beef processing and packaging phase (£2,415.00), queue for retailer or distribution phase (£37,719.50), retailer or distribution phase (£2,520.00), end customer phase (£200.00), labour at workstations (£500.00), and overhead costs (£700.00). The Figure 5.12 encompasses all expenses related to production, handling, and processing of beef. The substantial difference between costs and revenue resulted in a net loss of -284,498.59 GBP. This negative outcome underscores the economic issues within the supply chain. The slow processing line, characterised by extended processing times and high queuing sizes, was a major impediment. These delays were attributed to manual handling, high processing times, costs and efforts in the supply chain processes. The high rate of human error further exacerbated the beef supply chain financial performance. Manual processes are prone to mistakes due to human dependency, leading to high operational costs, low quality and increased risks and errors. Scenario 4 failed to generate sustainable social and economic value due to its inability to operate efficiently and profitably. The high costs and low revenue indicated a lack of economic sustainability. Scenario 4's poor performance was evident in both financial losses and poor operational efficiency. The excessive processing times and high queuing sizes point to significant bottlenecks and delays. Additionally, high human error rates and manual handling contributed to overall poor financial performance. The financial data reveals a substantial loss, indicating that the assumed scenario was not economically viable due to sole reliance on human workforce as depicted through the income statement report in Figure 5.12.

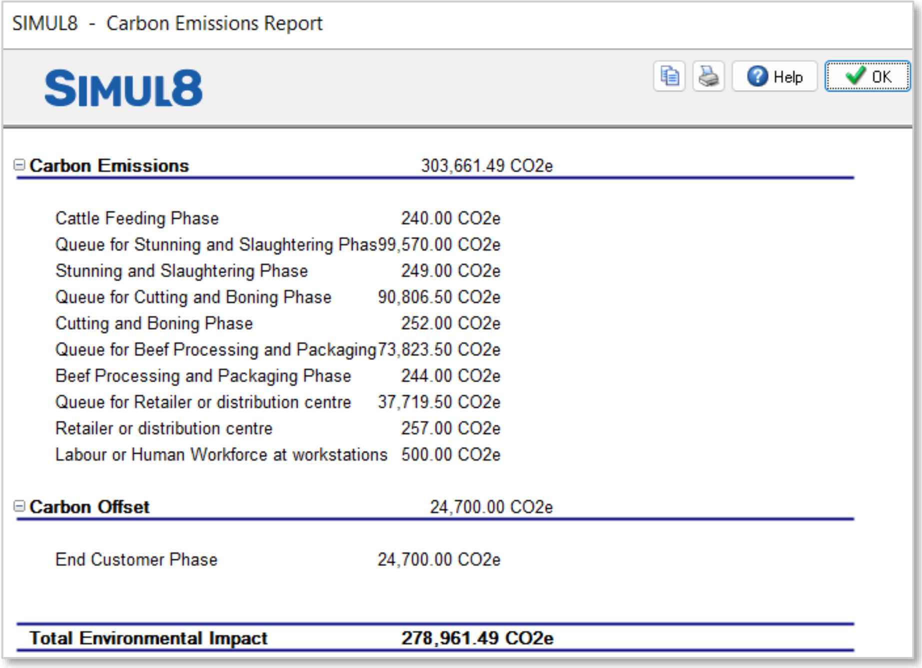


SIMUL8 - Income Statement

Costs	£ 309,198.59
Cattle Feeding Phase	£ 240.00
Queue for Stunning and Slaughtering Phase	£ 99,570.00
Stunning and Slaughtering Phase	£ 427.90
Queue for Cutting and Boning Phase	£ 90,806.50
Cutting and Boning Phase	£ 276.20
Queue for Beef Processing and Packaging Pha	£ 73,823.50
Beef Processing and Packaging Phase	£ 2,415.00
Queue for Retailer or distribution centre	£ 37,719.50
Retailer or distribution centre	£ 2,520.00
End Customer Phase	£ 200.00
Labour or Human Workforce at workstations	£ 500.00
Overhead Fixed Costs	£ 700.00
Revenue	£ 24,700.00
Profit	**£ -284,498.59**

Figure 5.12: Income statement generated from the scenario analysis in Simul8

Furthermore, Simul8 also generated a carbon emission report for Scenario 4. As shown in Figure 5.13, the carbon emission report depicted the values related to emissions for each phase and activity of the supply chain. The carbon features from this report were broken down to analyse the values for emissions from each level. The carbon emissions for each stage of the beef life cycle in the supply chain were because of the energy use, fuel, packaging, extraction and use of raw materials, distribution, etc. The carbon emission report depicted the environmental impact caused during beef processing and manufacturing. As shown in the report in Figure 5.13, the environmental impact through carbon emissions was 278,961.49 CO2e in Scenario 4, which was very high as the supply chain was manual-centric. The increased amount of carbon emissions at different phases of the supply chain and the lower value of carbon offset resulted in a high environmental impact, showing a high risk of air pollution, low quality beef production, and health threats to workers. There was also increased risk of beef contamination due to poor air quality and other environmental hazards. The carbon offset refers to removal or reduction of carbon emissions or other gases and was observed to be 24,700.00 CO2e (Figure 5.13), which was low. This report, generated using Simul8 software, details the emissions associated with each phase and activity of the beef production supply chain. It is based on high operational costs, increased processing and queuing times, and energy usage. The report provides a thorough analysis by breaking down the carbon features at every level of the supply chain. The findings highlight significant environmental and operational challenges faced by the supply chain, with direct implications on costs and processing times. The sources of emissions were increased amount of energy and fuel used in different beef supply chain stages. There was significant energy consumption throughout the supply chain stages and excessive use of fuel for transportation and machinery. The extraction and utilisation of raw materials also contribute to carbon output. The total carbon emissions for Scenario 4 amounted to 278,961.49 CO2e as highlighted above, indicating a substantial environmental impact. This high level of emissions was primarily due to the manual-centric nature of the supply chain. The carbon offset, which measures the reduction or removal of carbon emissions, was only 24,700.00 CO2e. This low offset value underscores the inefficiency in mitigating the environmental impact due to high operational costs, slow supply chain system, increased processing and queuing times and high energy usage due to manually handled tasks in beef processing. The reliance on manual processes led to higher operational costs due to increased energy use, fuel consumption, and inefficient resource utilisation. As discussed above, the manual-centric approach contributed to longer processing times, with the average time in the beef processing and packaging stage being 253.30 minutes (4.3 hours). This inefficiency was exacerbated by high queuing sizes, leading to delays at each stage. Extended processing times resulted in greater energy consumption and resource use, further increasing carbon emissions and operational costs. As the supply chain in scenario 4 was manually driven, this increased the supply chain's queuing size and times leading to higher use of resources, energy and time-taken to complete tasks. Given that the supply chain experienced poor operational and financial performance, increased time, energy, and resources were used to conduct supply chain processes. This also led to high human error as the supply chain adopted manual labour, thereby increasing processing times and costs. The carbon emission report for Scenario 4, as shown in Figure 5.13, highlights significant environmental and operational inefficiencies within the manual-centric beef supply chain. The high emissions (278,961.49 CO2e) and low carbon offset (24,700.00 CO2e) illustrate the need for substantial improvements and implementation of energy efficient technologies.


SIMUL8 - Carbon Emissions Report

SIMUL8

Carbon Emissions	303,661.49 CO2e
Cattle Feeding Phase	240.00 CO2e
Queue for Stunning and Slaughtering Phas	99,570.00 CO2e
Stunning and Slaughtering Phase	249.00 CO2e
Queue for Cutting and Boning Phase	90,806.50 CO2e
Cutting and Boning Phase	252.00 CO2e
Queue for Beef Processing and Packaging	73,823.50 CO2e
Beef Processing and Packaging Phase	244.00 CO2e
Queue for Retailer or distribution centre	37,719.50 CO2e
Retailer or distribution centre	257.00 CO2e
Labour or Human Workforce at workstations	500.00 CO2e
Carbon Offset	24,700.00 CO2e
End Customer Phase	24,700.00 CO2e
Total Environmental Impact	**278,961.49 CO2e**

Figure 5.13: Carbon emission report generated in Simul8

5.6.2 Scenario 5—Financial Parameters as a Basis using RPA Integration with Humans as a Resource

Scenario 5 used two resource inputs at different workstations where RPA functioned alongside the human workforce to ease supply chain processes and automate tasks where RPA performed best. Scenario 5 considered the adoption of RPA technology to accelerate time taken, reduce human error, and increase throughput. This scenario integrated RPA along with humans to automate rule-based, repetitive tasks, and to provide autonomous solutions to create supply chain resilience. As seen in Figure 5.14, the simulation was conducted over 1 week (7 days) and testing was conducted through several replications to achieve the appropriate simulation results. The scenario showed that the implementation of RPA to automate tasks was productive and efficient. The beef capacity remained more consistent in this scenario and was observed to increase at each progressing phase. The beef capacity in the stunning and slaughtering stage was 15 and reached to 18 in the cutting and boning phase and 19 in the beef processing phase. The beef capacity increased to 35 in the retailer and distribution stage, where it was observed to be at its maximum. As time increased, the capacity of beef produced also increased in every stage, which resulted in higher beef production and availability at the end customer phase. This scenario took less time to produce high-quality beef with reduced human error and wastage along the processing line, as seen in the simulated model in Figure 5.14. It also indicated a better financial performance because of the fast-paced processing line and greater beef production capacity.

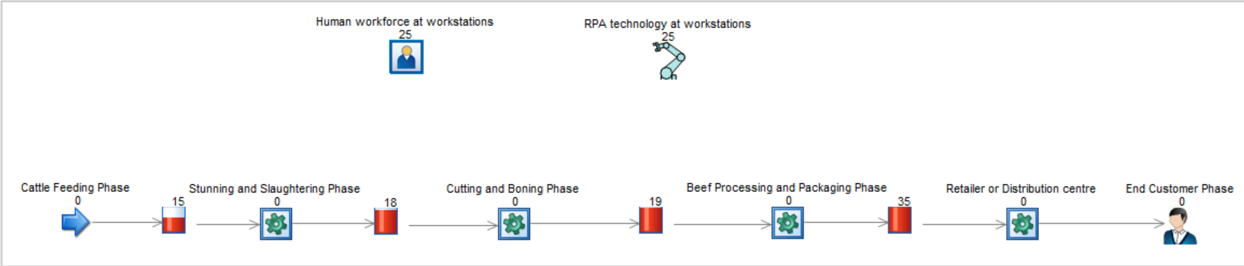


Figure 5.14: Process modelling considering financial parameters from the simulation

Simul8 software also generated KPI values based on process simulation and provided a report to analyse the functional performance of the beef supply chain. Table 5.5 shows the KPI values, which were used to evaluate the operational and financial performance of business activities using financial parameters that influence the adoption process of RPA in the beef supply chain. The average time in system for the end customer phase was 705.91 min–11.7 h, which was much less than the results for Scenario 4. This meant that the carcass took 11.7 h to reach to the end customer phase. The working percentage of the beef processing and packaging was 90.87% in scenario 5, which was double the working% in Scenario 4. The higher working percentage in scenario 5 indicated a more efficient utilisation of resources and a smoother flow of operations within the beef processing and packaging phase compared to scenario 4. This indicated that a significant portion of the total available time was utilised for productive activities in this phase. The waiting percentage (waiting%) of 0.00 in the beef processing and packaging phase indicated that there were no periods during which products or processes were idle or waiting in queue. This meant that the workflow within this phase was continuous and uninterrupted, with minimal to no delays or bottlenecks. The average queue size was 17.75 at the beef processing and packaging stage, and the average queuing time was 181.84 min to 3 h. The maximum queuing time as per the KPI values was 370.13 min to 6 h. The fact that both the average queue size and average queuing time in the beef processing and packaging phase were relatively low and indicated efficient throughput and minimal delays in the beef processing and packaging stage. This suggested that the stage was operating efficiently and effectively, with a streamlined workflow and prompt processing of products. The KPI report indicates that the average time taken for the carcass to reach the end customer was much less than for Scenario 4; also, the working% was almost double in this case, meaning that the processing line was more efficient and faster. The average queuing time was also observed to be less than for Scenario 4. The KPI values indicated that automation enhanced business processes, resulting in increased beef production in decreased time and cost. In summary, Scenario 5 demonstrated significant enhancements in operational efficiency, speed, and cost-effectiveness compared to Scenario 4, largely attributed to the implementation of RPA. Process automation positively impacts various aspects of the supply chain, including production capacity, customer satisfaction, and overall profitability and enhances working performance as illustrated in the Table 5.5. The KPI values indicated that the implementation of automation in Scenario 5 enhanced business processes. Automation likely improved the speed, accuracy, and reliability of tasks, leading to increased beef production within decreased timeframes and at lower costs. This automation-driven efficiency likely contributed to the overall improvements observed in Scenario 5 compared to Scenario 4.

Table 5.5: KPI values generated in Simul8 software based on financial parameters in the scenario 5

Phases	**KPI % System Results**	**Low 95% Range**	**Average Result**	**High 95% Range**
End Customer Phase	Average Time in System	679.91	705.91	731.91
Beef Processing and Packaging Phase	Waiting%	0.00	0.00	0.00
	Working%	88.23	90.87	93.51
	Maximum Use	1.00	1.00	1.00
	Average Use	1.00	1.00	1.00
	Current Content	1.00	1.00	1.00
Queue for Beef Processing and Packaging Phase	Average Queue Size	15.61	17.75	19.88
	Average Queuing Time	156.71	181.84	206.96
	Maximum Queuing Time	331.55	370.13	408.71

Furthermore, the simulation software also generated an income statement based on the simulation runs conducted. Figure 5.15 displays the income statement showing the financial performance of the beef supply chain. The income statement from Simul8 was used to better analyse and evaluate the supply chain costs and revenue according to the resource inputs and cost-related parameters from the simulation runs. This scenario used RPA integration to automate tasks where possible and used suitable and manual workforce to aid through monitory purposes or for support with tasks that could not be fully automated due to the complexity of the beef supply chain. The income statement showed a good financial performance and effective function of the business activities as it indicated profits earned through the adoption of RPA, which served to facilitate strenuous tasks by reducing human error, thus reducing operational costs (as seen in Figure 5.15). The revenue in the final customer phase was greater than the costs of performing business activities throughout all phases; therefore, the supply chain provided profits of 221, 300.39 GBP. The costs of beef production were 2,198,699.61 GBP in total and the revenue in the final stage was 2,420,000 GBP. Here, RPA showed promising cost-reduction benefits for supply chain processes by providing autonomous solutions and enhancing operational efficiency in the processing line. Less time was taken due to the reduced queue size and average time for carcass processing, which helped by reducing expenses and energy and provided an effective financial performance by earning profit, as displayed in the income statement generated by Simul8 in Figure 5.15. The income statement shows a profitable beef supply chain in scenario 5.

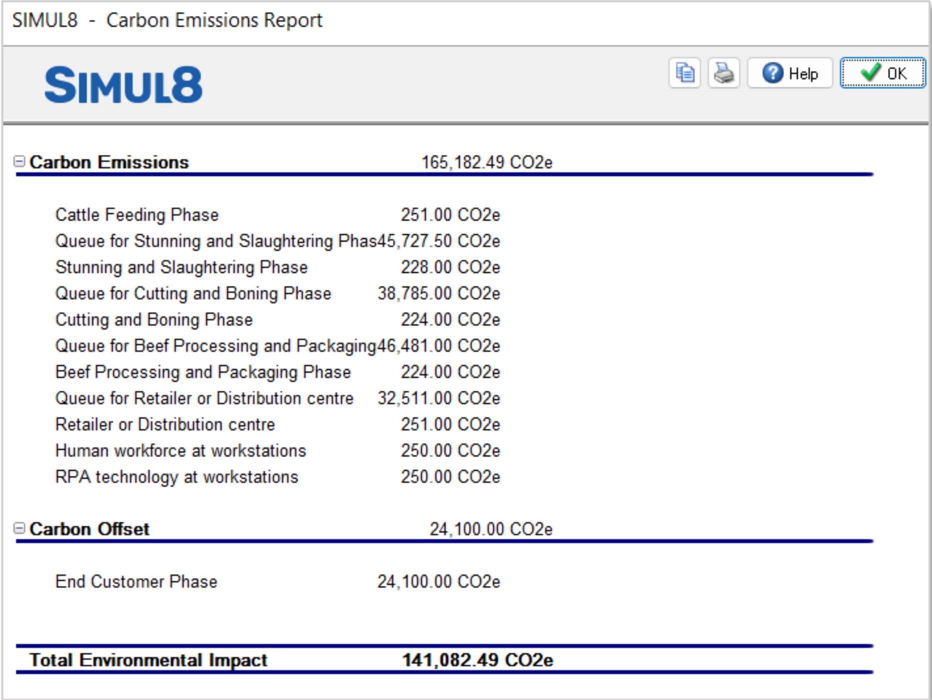
SIMUL8 - Income Statement

Costs	£ 2,198,699.61
Cattle Feeding Phase	£ 167.00
Queue for Stunning and Slaughtering Phase	£ 500,646.48
Stunning and Slaughtering Phase	£ 148.00
Queue for Cutting and Boning Phase	£ 512,438.98
Cutting and Boning Phase	£ 99.20
Queue for Beef Processing and Packaging Ph	£ 523,293.98
Beef Processing and Packaging Phase	£ 738.00
Queue for Retailer or Distribution centre	£ 534,701.98
Retailer or Distribution centre	£ 741.00
End Customer Phase	£ 75.00
Human workforce at workstations	£ 250.00
RPA technology at workstations	£ 125,000.00
Overhead Fixed Costs	£ 400.00
Revenue	£ 2,420,000.00
End Customer Phase	£ 2,420,000.00
Profit	**£ 221,300.39**

Figure 5.15: Income statement generated in Simul8

The simulation-based approach in Scenario 5 also provided an opportunity to assess the environmental impact of business activities during beef processing and manufacturing. Simul8 also produced a carbon emission report, as depicted in Figure 5.16, to analyse the impact of RPA and humans working together in the processing line to perform various tasks. The carbon emission report generated by Simul8 software through the simulation indicated that the environmental impact of Scenario 5 was 141,082.49 CO2e. The carbon emissions were 165,182.49 CO2e and the carbon offset was 24,100.00 CO2e. As assessed from the report in Figure 5.16, Scenario 5 had a much lower environmental impact than Scenario 4. The environmental impact of Scenario 5 was lower; however, it still had an impact on the environment because the supply chain was not yet fully automated as there were some complex procedures that still required human presence. As the environmental impact was not high and was measured as low, there were lower risks to human health and the environment in this scenario. In addition, these was a higher chance of high-quality beef production as the processing line was fast-paced due to the adoption of RPA and process excellence. Furthermore, the risk of disease transmission, beef contamination, and beef wastage along the processing line were minimal due to the lower environmental impact as evaluated and revealed in the report. Therefore, through the simulation assessment and carbon emission report in

Figure 5.16, Scenario 5 showed a lower environmental impact and safer, high-quality beef production.


SIMUL8 - Carbon Emissions Report

SIMUL8

Carbon Emissions	165,182.49 CO2e
Cattle Feeding Phase	251.00 CO2e
Queue for Stunning and Slaughtering Phas	45,727.50 CO2e
Stunning and Slaughtering Phase	228.00 CO2e
Queue for Cutting and Boning Phase	38,785.00 CO2e
Cutting and Boning Phase	224.00 CO2e
Queue for Beef Processing and Packaging	46,481.00 CO2e
Beef Processing and Packaging Phase	224.00 CO2e
Queue for Retailer or Distribution centre	32,511.00 CO2e
Retailer or Distribution centre	251.00 CO2e
Human workforce at workstations	250.00 CO2e
RPA technology at workstations	250.00 CO2e
Carbon Offset	24,100.00 CO2e
End Customer Phase	24,100.00 CO2e
Total Environmental Impact	**141,082.49 CO2e**

Figure 5.16: The carbon emission report for Scenario 5

5.7 An overview of the simulation results for 'what-if' scenarios

The Simul8 software is used for the simulation and analysation of the scenarios as discussed with respect to their results in the section above. The above-mentioned discussion provides the results and analysis for all five scenarios which used research parameters – beef quality, beef safety, shelf-life and financial or cost-related parameters as the basis for the formation and development of these scenarios. Simulation analysis to scenarios was also observed from sustainability lenses to assess the beef supply chain with respect to sustainable value and competitive advantage with and without the adoption of RPA. The ***scenarios 1, 2 and 3*** considered beef quality, safety, and shelf-life as research parameters whereas, ***scenarios 4 and 5*** used financial parameters as basis for simulation analysis to generate results. The simulation results in ***scenarios 1, 2 and 3*** generated KPI values and MORE Plot as part of the result analysis and simulation testing of the process model used for simulation purpose in respective scenarios. The simulation results in scenarios 4 and 5, generated KPI values, income statement report, and carbon emission reports. The scenarios 4 and 5 did not produce MORE plot as the software generated key performance indicators which highlighted the main disruptions, queuing times and sizes, and supply chain efficiency levels; income statement reports, and carbon emissions report were also generated to highlight the profit and loss account and environmental impact in beef processing. As financial parameters and variables served as a basis for scenario analysis in scenarios 4 and 5, therefore, the results highlighted supply chain bottlenecks, profit and loss account and environmental impact caused by beef processing. In pre-defined scenarios, the KPI values generated after several frequencies or trails of the process model depict a collection of the results for the simulation runs. The MORE Plot, generated in scenarios 1, 2, and 3 depicted the risk and errors after running the simulations or trails of the process model. The KPI values are important and hold importance with respect to evaluating the results and ensuring how change or addition in resource input can impact the results and enhance the supply chain process in different stages. The KPI values generated also help in analysing and depicting where the main bottlenecks within the business processes can be observed and this can provide useful information for the practitioners and decision-makers to potentially plan and counter the risk factors in real-life scenarios. In scenario 1, human workforce alone managed and executed tasks for beef supply chain operations at all stages. In scenario 2, RPA integration with human workforce operated tasks with greater efficiency and effectiveness which resulted in less time consumption for task delivery. In scenario 1, the average time taken for carcass processing was 995.28 minutes (16.5 hours) whereas, in scenario 2 average time taken was 805.32 minutes (13.4 hours). Scenario 2 used RPA for task automation and greater beef capacity and efficiency was observed along with reduced human error and risk factors. Beef nutritional value, hygiene, safety, and traceability was greatly enhanced in scenario 2 due to fast-paced production and beef processing at all stages in the supply chain. The working% in scenario 2 was 88.33 which was double the percentage in scenario 1. Hence, the operational efficiency, cost effectiveness and beef standards were much better in scenario 2 with the usage and implementation of RPA. RPA as a resource input with addition to Human workforce has proved more beneficial for the beef supply chain processes as it helped in completing tasks in less time and more pro-actively and efficiently. This was observed by reviewing the KPI values generated in scenario 2, that the adoption of RPA has increased the number of tasks completed in a shorter time span and more effectively. Also, the MORE Plot also depicted the same that the operational efficiency had improved and there were less errors in the scenario 2 than 1. Lesser errors and improved operational efficiency in scenario 2, with the implementation of RPA, resulted in increased beef capacity, production levels and helped in production of high-quality, healthy beef as observed by the KPI results and reflected in the simulated process model. The scenario 3 was a critical comparative analysis of scenarios 1 and 2, with respect to beef capacity, quality, and operational efficiency in the Simul8 software. The scenario 3 was compared to observe the supply chain efficiency levels with and without the adoption of RPA in beef supply chains. The scenario 3 observed that RPA adoption enhances employee-level efficiency, operational performance and beef quality and safety in beef processing and manufacturing. The scenario 3 also depicted through process simulation and further testing of the model, that an increase in bots and reduction in human workforce also enhance and improve operational efficiency and beef capacity resulting in increased beef quality and safety along the processing line. In scenario 3 the model was further simulated, and the number of bots integrated were 7 and human workers amounting to 4 were used on the processing line to evaluate operational efficiency and capacity with an increase in bots and reduction in human workforce. The scenario 3 highlights that adopting more bots and decreasing the number of humans on different workstations or stages enhances beef capacity, shelf-life and reduces human error due to less human handling and more reliance on process automation. Adoption of RPA working alongside humans ensure smooth supply chain operations, higher productivity, and capacity, decreased time and energy consumption and sustainable production of high-quality beef to satisfy growing beef demand. Increasing number of bots in comparison to human as labour allows improvement in operational and functional efficiency and enhanced employee-level performance; it also helps supply chain to add value to their business processes as less bottlenecks and risks in beef processing and manufacturing due to task automation of strenuous, routine-based tasks. This further allowed the beef supply chain in scenario 3 to gain competitive advantage and achieve corporate social responsibility to create sustainable value in beef supply chain stages. The Figure 5.10 shows the simulated process model representing the comparative analysis of scenarios 1 and 2, along with further testing and simulating the process model with increasing RPA and decreasing humans as resource to assess operational efficiency and beef quality and safety from sustainability perspective. The scenario analysis in ***scenarios 1, 2 and 3*** were seen from the lens of sustainability in the social and environmental dimensions. The simulation analysis and results depict that scenarios 2 and 3 successfully achieved social and environmental value through adoption and use of RPA which served as sustainability tool to enhance operational and employee-level efficiency, beef capacity, quality, and shelf-life; whereas scenario 1 experienced high human error, risks, and major bottlenecks due to manual-centric supply chain system, leading to low operational and employee-level performance and thus was unable to achieve sustainable value in beef supply chain.

The ***scenarios 4 and 5*** were tested and used financial parameters as a basis for simulation analysis as depicted in the result analysis. KPI values, income statement reports, and carbon emission reports were generated as part of simulation analysis of the scenarios to evaluate and assess the financial and operational efficiency of the beef supply chain in both scenarios. The scenarios were also tested to critically assess the costs associated at all beef supply chain stages to observe the financial efficiency of business processes in beef processing and manufacturing. The income statement reports generated in both scenarios 4 and 5 depicted the profit or loss account to observe the financial performance of beef supply chain. Moreover, the carbon emission reports were also generated by Simul8 through process testing which observed the environmental impact each scenario had on the work surroundings. The scenarios 4 and 5 were assessed and observed from a sustainability perspective to evaluate social, environmental, and economic value gained in beef supply chains. In scenario 4, the beef supply chain was manually driven, and the scenario was tested based on financial parameters. The scenario 5 was developed with two resource inputs to observe process delivery i.e., RPA adoption and presence at workstations along with human workforce as labour. In scenario 4 the average time consumed for beef to reach the end consumer stage was 1428.76 min – 23.81 hours, whereas in scenario 5, the average time taken to reach the ending stage was 705.91 min – 11.7 hours. Thus, through process simulation results it was evaluated that scenario 4 observed delays, higher queuing time as shown through KPI results, and lower efficiency levels in comparison to scenario 5. The scenario 5 experienced less average time taken for beef processing, less queuing times and greater operational efficiency levels as depicted in the simulation results – KPI values in Table 5.5. Moreover, scenario 4 also experienced high operational costs and lower revenue generation resulting in poor financial performance and loss amounting to -284,498.59 GBP as depicted in the income statement report in Figure 5.12. On the contrary, scenario 5 was evaluated to be profitable and viable in terms of its business operations due to low operational costs and higher revenue generated at ending stage of beef supply chain thus resulting in profit amounting to 221,300.39 GBP. Scenario 5 had good financial performance in comparison to scenario 4 which experienced loss as depicted through income statement reports in both scenarios. As there was high human error, increased queuing times and high costs related to beef processing due to manual handling in scenario 4, the supply chain experienced high environmental impact that was 278, 961.49 CO2e as produced by the carbon emission report in Figure 5.13. Increased carbon emissions at different beef supply chain phases and lower carbon offset results in hazardous working conditions due to air pollution leading to an unsafe working environment which is risky for both humans and beef production and this increases chances of beef contamination and human health concerns. The scenario 5 on the other hand experienced an environmentally friendly and safe working environment due to task automation, process excellence and reduced human handling which led to lower environmental impact that was 141, 082.49 CO_2e and safer working conditions as shown in the carbon emission report in Figure 5.16. Thus, the simulation results depict that scenario 5 gained higher financial and operational efficiency and had more business viability and productivity in comparison to scenario 4 which suffered loss and experienced hazardous working conditions in beef processing. The scenarios 4 and 5 were assessed from the three dimensions of sustainability i.e., social, economic, and environmental. The simulation analysis depicts and illustrate that scenario 5 achieved sustainable value through sustainable beef production at lower costs than scenario 4 which observed low quality beef production at high operational costs and hazardous working environment resulting in an inefficient supply chain system.

Ensuring that a simulation model accurately mirrors the real-life behaviour of the beef supply chain is critical for effective decision-making and implementation. This simulation-based study undertook several comprehensive steps to ensure that the simulation model closely mimicked real-world scenarios. Key steps included defining the objectives and scope of the simulation, collecting, and analysing real-time data, validating the model, and continuously refining it. The study began by clearly identifying the objectives and scope of the simulation. The primary goals were to detect the main bottlenecks or risks associated with RPA adoption in the beef supply chain, and to evaluate RPA's potential to create sustainability and add value. The scope encompassed all relevant stages of the beef supply chain, ensuring a thorough determination of the simulation's boundaries. Real-time statistical data was meticulously collected, encompassing various aspects of the beef supply chain. This data included: mortality rates in beef stores and finishing, beef and veal production volumes, average carcass weights of slaughtered cattle, average meat consumption in the UK, fat inefficiency (quality), red meat shelf-life, and economic cost of production (£ per head output costs, variable costs, fixed costs, and labour hours). The accuracy and reliability of this data were ensured by sourcing it from official and credible sources, which was crucial in building a robust simulation model. To validate the model, the study employed discrete-event simulation (DES) due to its suitability for the research objectives. The simulation scenarios were designed to align with the study's aims and goals, focusing on identifying bottlenecks and assessing the sustainability impact of RPA integration within the beef supply chain. The simulations were run at various frequencies to observe how the model reacted to changes, such as RPA integration, replicating real-life scenario adjustments.

The model's performance was continuously refined by adjusting parameters and stochastic variables to ensure accurate output levels. Various scenarios were tested to evaluate the model's generalisation to different real-world conditions. This iterative process of refinement and validation ensured that the model closely mirrored real-life supply chain behaviours. Transparency was maintained throughout the study, particularly in the utilisation of existing data and model development. This transparency extended to reflecting significant stages of the beef supply chain as they occur in real-life business systems. This approach in the study, built confidence in the model's reliability, relevance, and accuracy. By following these rigorous steps, the researcher ensured that the simulation model closely mirrored the real-life behaviour of the beef supply chain. The results from the simulation, especially the 'what-if' scenarios, provided crucial insights for stakeholders aiming to achieve sustainability in beef production through robust RPA adoption processes. The findings from the simulation were invaluable for understanding potential impacts and making informed decisions about implementing RPA in the beef supply chain, ultimately contributing to more sustainable and efficient operations. This comprehensive approach underscored the importance of a well-validated simulation model in facilitating effective decision-making and strategic planning in the beef supply chain, ensuring that the model's outputs were both accurate and actionable.

5.7.1 Scenario analysis from sustainability aspect

Scenarios 1, 2 and 3 were based on the respective parameters – beef quality, safety, and shelf-life. According to the simulation results and scenario testing, the beef supply chains were more sustainable and efficient in scenarios 2 and 3 than scenario 1. Scenario 1 was observed inefficient due to a manual centric supply chain system with greater chances of human error and beef contamination which posed a threat to beef production. Bottlenecks and risks were also detected at various stages of the supply chain in scenario 1 as evaluated through the KPI results and the MORE Plot. Scenario 1 observed reduced beef capacity and productivity due to time consuming supply chain processes and bottlenecks at different stages. Moreover, simulation results in scenario 1 depicted a risky supply chain system due to increased human handling and intervention leading to low operational and employee efficiency. The scenario 2 and 3 incorporated and adopted human workforce along with RPA technology. The approach to improving RPA accuracy and efficiency, the positive impact of RPA in quality beef processing and production with longer shelf-life and lesser time taken to complete tasks makes the beef supply chain more sustainable. In scenarios 2 and 3, reduced beef waste was produced on the processing line during beef production, as RPA adoption decreased human error and improved employee efficiency along with supply chain performance. The MORE Plot indicated the risks and errors thus supporting decision-makers to pre-plan and alleviate risks in advance to ensure successful adoption of RPA in real-life business environments. The successful adoption of RPA and increased RPA work accuracy, impacts positively on the operational and employee-level efficiency and results in reduction of waste produced within the supply chain processes. Shorter time span for task completion also improves and promises greater shelf-life and high-quality beef production. This allows the beef supply chains to become more sustainable for the consumer and business environment. The adoption of bots on the processing line also helps in cost reduction thus providing economic gains to the beef supply chain. RPA adoption serves as value addition to the beef supply chain and enhances sustainability within business processes and enables the supply chain to be more competitive and fast-paced. The adoption of RPA creates sustainability within beef supply chains and allows business owners to produce high-quality and safer beef for human consumption. In the context of beef production, RPA adoption significantly contributes to social sustainability in beef production by enhancing worker safety, improving animal welfare, optimising antibiotic, and technology use, and supporting the culture and traditions of beef producers. RPA reduces the need for manual labor in repetitive and physically demanding tasks, decreasing the risk of injuries and accidents. Automated systems can handle heavy lifting, cutting, and other hazardous activities, ensuring workers are less exposed to potential harm as observed in scenarios 2 and 3 where RPA was deployed alongside human workforce to perform tasks. By automating monotonous and time-consuming tasks, RPA allows workers to focus on more engaging and less strenuous activities, improving job satisfaction and reducing stress levels. Moreover, in terms social sustainability, RPA automates the handling of animals in a way that minimises stress and discomfort. Automated systems ensure precise and gentle handling, reducing the likelihood of injuries or distress for the animals. Automated processes ensure that handling and processing stages are consistent and repeatable, reducing variability that can negatively impact animal welfare. To further emphasise, automation leads to more precise control over production parameters, reducing the chances of contamination and the subsequent need for antibiotics. Automated systems efficiently monitor health parameters and administer treatments only when necessary, ensuring judicious use of antibiotics. The deployment of bots in beef supply chain also opens new opportunities for training and skill development for workers, helping them adapt to and thrive in a more technologically advanced working environment without losing sight of traditional values. RPA plays a crucial role in promoting social sustainability in beef production. It enhances worker safety by reducing manual labour and improving working conditions. For animal welfare, RPA ensures humane handling and consistent processes. RPA's precision and efficiency help reduce antibiotic use and integrate advanced technologies, promoting better health practices. Moreover, RPA supports the culture and traditions of beef producers by complementing traditional methods, empowering producers, and providing opportunities for training and skill development. Through these contributions, RPA helps create a more sustainable and ethical beef production supply chain. As evident from the simulation findings in Scenarios 2 and 3, the results demonstrated sustainable beef production by enhancing social and environmental sustainability in the beef supply chain processes. The automation of tasks ensured sustainable beef production and contributed to a resilient supply chain system. As observed in Scenarios 2 and 3, successful RPA adoption provided a competitive advantage, ensured corporate social responsibility in the beef supply chain, and improved overall supply chain sustainability.

The process model was simulated and optimised to analyse the business processes at all beef supply chain stages in Scenarios 4 and 5. The scenarios 4 and 5 were developed and assessed based on financial parameters or cost-related factors to evaluate the financial and operational efficiency of beef supply chain at all phases. The scenarios 4 and 5 were also assessed from the three dimensions of sustainability – social, economic, and environmental. The simulation analysis from model testing observed that scenario 5 achieved sustainable value in beef processing and manufacturing whereas scenario 4 experienced low financial and operational efficiency. The scenario 4 used human resource as the only resource input therefore, there was heavy reliance on human as work labour to perform at various workstations in the beef supply chain. Due to the supply chain being manually run, the time taken for beef processing and manufacturing was increased which caused delays in the supply chain systems. In scenario 4, the simulated model also observed low beef capacity and shelf-life with progressing time and stage. The supply chain also identified major bottlenecks at significant stages and there was increased queuing time in beef production which made the business processes riskier and more vulnerable as evaluated and observed through the simulated process model and KPI values generated in Simul8 software in scenario 4. Process simulation in scenario 4 also depicted poor financial efficiency and high environmental impact in beef processing and manufacturing. The income statement report generated by the software indicated that the supply chain operational costs exceeded the revenue thus making the supply chain processes costly due to which the beef supply chain observed poor financial performance in scenario 4. The carbon emission report in this scenario also depicted high environmental impact thus increasing risks of contamination in beef production, hazardous work environment due to air pollution (high CO2 emissions) and health and safety risks for workers. Greater use of fuel and energy increases threats to the environment as the supply chain in scenario 4 was manual-centric. As reflected through simulation results in scenario 4, which was a manually driven supply chain, the processes were more prone to increased human error and the supply chain experienced production of low-quality beef at high costs. In scenario 4, the beef supply chain did not meet the sustainability criterions due to poor financial and operational efficiency as observed through simulation analysis.

In comparison to scenario 4, the simulation analysis and results in scenario 5 depicted that in this scenario sustainable value was achieved in beef production and manufacturing. The scenario 5 was also simulated from the perspective of sustainability assessment to observe the financial and operational efficiency, along with assessing cost-effectiveness and beef productivity in the supply chain. The scenario 5 in comparison to scenario 4, had two resource inputs where RPA worked alongside the human labour at different workstations in the beef supply chain. Scenario 5 experienced integration and facilitation of RPA technology which automated strenuous tasks, and the humans worked alongside to handle and cater complex jobs. The simulation analysis of scenario 5 depict that the beef capacity and shelf-life increase at each progressing stage and the queuing time for beef processing and packaging stage was lesser than scenario 4. The simulation to process model in scenario 5 showed that the supply chain performance was more efficient, and less time was consumed for beef production. The scenario 5 also experienced production of nutritious, high-quality, and healthy beef according to quality standards due to supply chain being faster, more efficient, and resilient; there was also reduced human error at different stages of the supply chain due automation of tasks and less reliance on human as labour making the supply chain less prone to risks. Automation added value to the supply chain in scenario 5 and the KPI values and simulated process model showed higher beef capacity and shelf-life thus enhancing the operational efficiency of supply chain. The income statement report also depicted that due to lesser queuing time, fast-paced supply chain operations, reduced human error the supply chain achieved financial efficiency and cost-effectiveness and was proven to be profitable according to the simulation analysis. The carbon emission report in scenario 5 also depicted that RPA integration with human workforce also resulted in less environmental impact than scenario 4. This means that the supply chain was less hazardous and risky to the environment and surroundings and safer for humans to work due to reduced air pollution and carbon emissions at each stage of the supply chain. Less use of fuel and energy and efficient supply chain processes resulted in reduced carbon emissions at various stages thus ensuring eco-friendly working environment where there were less chances of beef contamination. Thus, in scenario 5, there was increased beef productivity at low operational costs and the supply chain was profitable and had an eco-friendly working environment due to less air pollution and production of sustainable beef. In scenario 5, the beef supply chain achieved social, economic, and environmental value and gained a competitive advantage due to autonomous and a well-integrated, effective, and sustainable supply chain system.

5.8 Discussion on Simulation Findings

Simulations are relatable to dynamic models and the model is created to represent the evolving time of real system. Simulation can also be described as imitation of another process (Durán, 2020). The benefits of simulation include economic and operational supply chain efficiency and supply chain risk management. Simulation also helps in identification of potential risks or errors in the supply chain system and improves the process of decision-making for managers or stakeholders (Oliveira *et al.*, 2019). Through simulation approach various 'what-if' scenarios can be compared with respect to performance indicators. It is time-consuming to build a simulation model accurately; however, it is a powerful tool to analyse and evaluate operational processes and avoid risks in real-life application. To evaluate the impact of a tactical or strategic move beforehand, decision-makers need advance systems. 'What-if' scenario analysis enables supply chains to compare and understand different scenarios. Moreover, it helps to adopt better approach to improve business processes and eliminate risks (Golfarelli *et al.*, 2006; Chan and Uncles, 2022). This chapter provides a comprehensive analysis of the study findings based on the simulation results provided above and observes the results from sustainability dimensions. Moreover, the forthcoming sections compare how the research findings differ from similar studies in the domain. The commencing sections also discuss findings from previous studies or research in the past and compares with the new results generated in this simulation study. The discussion focuses on the findings of this research which are distinctive and significant in the field of RPA and beef supply chains. Additionally, insights are provided into the simulation findings, focusing on how RPA boosts sustainability in the beef supply chain, streamlining business processes.

To re-emphasise, this study investigated the potential risks in the adoption of RPA in UK beef supply chains. 'What-if' scenarios were analysed based on different research parameters that play a vital part in the smooth functioning of beef supply chains and RPA deployment in beef sector. The research parameters were used as a basis in the development of scenarios. The parameters selected and considered were shelf-life, quality, safety and financial or cost-related aspects. All these factors or parameters were highly important in consideration due to their contribution towards production of high-quality, healthy, and safe beef for consumers at low operational costs. The 'what-if' scenario analysis in Simul8 software allowed to evaluate and investigate the changes in resource inputs and how these alterations in resources impact the beef supply chain operations. Moreover, the 'what-if' analysis of different scenarios allowed to simulate the business process model and detect the main bottlenecks in different stages of the beef supply chain. Detection of the bottlenecks within the manufacturing beef supply chain allowed to evaluate the stages of the supply chain where increased complexity was observed and there was requirement of resource alterations and enhanced monitoring. The bottlenecks were identified because of simulation and optimisation of the business process model which examined the stages / phases where RPA was most suitable and required to enhance supply chain efficiency. It was observed that RPA integration with humans in performing tedious, strenuous, and repetitive tasks improved beef processing time due to decrease in human error and handling. RPA adoption improved process delivery in three stages of the beef supply chain where the main bottlenecks were observed when these were handled manually. The supply chain stages were slaughtering, cutting, and boning and packaging stage. The 'what-if' scenario analysis also assessed that increased operational efficiency and higher capacity and productivity were observed when two resource inputs were used in the process model which were, human workforce along with RPA technology. The beef capacity was seen at a higher side with the adoption of RPA as a resource input. Overall, the 'what-if' analysis provided insights on manual centric supply chains and the integration of RPA to automate processes and improve task delivery. It was observed through simulation analysis that RPA adoption played a crucial role in increasing operational and financial efficiency, and improved employee capabilities. Production of high-quality beef with low operational costs to satisfy high demands of consumer has always been a cause of concern for the beef supply chains. Scenario analysis helps alleviate the human error and efforts in beef supply chains and allows successful adoption of RPA. Identification of risks in advance allows stakeholders and managers to efficiently adopt RPA and provides the opportunity to avail its maximised benefits for sustainable beef production. Analysis of different scenarios provides a comparison between manually driven and RPA adopted supply chain system and depicts the performance levels at different stages of beef supply chain. This helps beef supply chains to plan more efficiently beforehand and alleviate risks in RPA implementation to gain improved operational and financial output.

As highlighted before***, Scenarios 1, 2, 3, 4 and 5*** were analysed and evaluated through process simulation and model testing in the Simul8 software. ***Scenarios 1, 2 and 3*** were developed and assessed considering ***beef quality, safety, and shelf-life*** as the significant parameters or factors that impact the adoption of RPA. ***Scenarios 4 and 5***, respectively, were analysed considering the ***financial or cost-related parameters*** that were important in consideration to evaluate the approach and adoption of RPA technology in beef supply chains. All these four parameters were essential for scenario testing and therefore were used to depict supply chain efficiency and detect the potential risks in RPA adoption. The results obtained through the simulation analysis in this specific domain are new and have not been explored in previous studies. This research is significant as it analyses different scenarios based on various parameters in the adoption of RPA, and it explores RPA implementation from the three facets of sustainability. The study findings provide an improved approach for adopting RPA by considering the beef quality, safety, shelf-life, and costs as essential parameters. This emerging technology is not only considered in terms of its adoption, but also from the perspective of sustainability in beef supply chains. RPA acts as a ***sustainability tool*** to enhance supply chain business operations and improve financial and operational performance through reduction in cost, time, and energy.

The Table 5.6 outlines the parameters considered and used in the simulation process for scenario analysis.

Table 5.6: An overview of scenarios simulated based on different parameters in Simul8 (Source: Author)

Scenarios	**Parameters**
Scenarios 1, 2 and 3	Beef quality, safety, and shelf-life
Scenarios 4 and 5	Financial or cost-related parameters

Largely, the existing literature discusses the emergence of RPA and its potential advantages (Rutaganda *et al.*, 2017; Jiménez-Ramírez *et al.*, 2023). However, limited studies have explored the role of RPA and the potential risks to its adoption in beef supply chains. In this context, the risks or errors to RPA implementation have been neglected and there is no thorough assessment in academic literature with respect to the beef sector. This chapter also provides and compares the results of previous studies in the relevant domain along with the findings of the simulation study.

5.9 A critical analysis on scenarios 1, 2 and 3 simulation findings – beef quality, safety, and shelf-life as parameters

5.9.1 Scenario 1

In this study, scenario 1 changed the capacity / volume at different stages of the beef supply chain and used only human workforce as resource to perform tasks in the entire process. The initial model in scenario 1 used greater time taken, in minutes, to perform the operations and functions across the beef supply chain. The simulation results observed low capacity as the carcass progressed to further stages along with experiencing lower operational efficiency. The efficiency, storage capacity and shelf life were less when the trial was run for a replication of 5 times in this scenario. The working% was also seen at the lower side i.e., 47.27, which was half in efficiency as compared to scenario 2. This also resulted in poor management in beef traceability, quality, and safety. With human workforce increase as input resource in scenario 1, the MORE Plot evaluated unlikely, risks or errors that might occur to a high of 1066.98. Unlikely shown in the MORE Plot depict chances of risks or errors that might appear in real-life environment due to human error.

Many studies have focused on the need to improve business processes due to prevalent threats posed to human health from consumption of low-quality, contaminated beef. The findings from scenario 1 depict that increased human handling and intervention slows processing line and results in poor beef quality, capacity and shelf-life. Adzitey et al (2011) study highlights that there are several factors that affect the quality of meat such as handling, transportation, genotype, environment etc. Therefore, particular attention is required throughout the production and processing stages. Poor animal handling leads to low quality, contaminated beef production which can be threating to human health from consumption perspective. Das et al (2019) study evaluated that with rapidly changing working environments, consumers demand, import and export policies, sustainability regulations, it has become challenging for meat sector to produce high-quality and safe beef for human consumption. This is due to the presence of biological, physical, and chemical risks at all stages of manufacturing and processing which require efficient handling. Romanov et al (2022) shares a similar view and stresses on the need to automate red meat supply chains where autonomous systems can be employed to collaborate with humans to offer compact, fast-paced, scalable, and cost-effective production line to combat risks and produce sustainable meat. Integration and application of software bots can potentially help in promoting higher standards in human working conditions and meat safety. Another study revealed that improper and unhygienic human handling and intervention reduces the quality and safety of beef and to meet the quality standards in beef production, the meat processors constantly seek for innovative technologies for sustainable beef production (Sanchez *et al*., 2022). Therefore, as evidenced by the simulation results of scenario 1, increased reliance on humans not only reduced supply chain operational and employee performance but also increased human error which led to contamination and production of low-quality, unsafe beef with lower shelf-life. Simulation analysis in scenario 1 highlighted main bottlenecks in manually driven supply chain and depicted low operational and employee efficiency which led to poor supply chain performance.

5.9.2 Scenario 2

Scenario 2 considered the addition of RPA as resource along with human workforce. As a result, lesser time was taken for the carcass to process for the end consumer. The capacity and efficiency were observed to be much better and greater than scenario 1. The implementation and adoption of RPA enhanced the overall beef supply chain functions in stages like slaughtering, cutting, and boning, packaging and storage and retailer. The efficiency, shelf-life and capacity were enhanced when trail for 5 times was run in the software. The working percentage depicted in KPI report were seen at a higher side i.e., 88.33%, which means that an increase of 41.06 percent was experienced. This resulted in almost double the working percentage in scenario 2 in comparison to scenario 1. The risks and errors that might happen were also evaluated by the software generated MORE Plot. These were also lower in percentage as the risks were reduced due to adoption of RPA in different stages of the beef supply chain. The average time in system in scenario 2 was 886.32 minutes which were 108.96 minutes less time taken than scenario 1. This is because the operational efficiency was enhanced as less average time was taken by the carcass for further processing. The shelf-life also increased along with the capacity and beef produced was safer, healthier, and nutritious in scenario 2 due to fast-paced production line. Automation improves production line and there are less chances of producing contaminated beef due to less human touch as mostly the tasks are completed by RPA in slaughtering, cutting, and packaging stage.

Based on Echegaray et al (2022) study, the industry 4.0 technologies such as RPA, provide potential solutions to complex supply chain systems such as the beef sector. The need for digitalised systems has increased drastically especially after the business faced disruptions due to COVID-19 pandemic. Hassoun et al (2022), however, argues stating that a continuous process of research and development, as well as intense collaboration between the industry, research institutions and regulators is required to take advantage of Industry 4.0's opportunities in the meat sector. The study findings of Weersink et al (2021) shared a similar opinion and pointed out that automating the beef sector has been quite complex and challenging due to various parameters or factors such as variations in animal sizes, high initial expenses, poor management and planning, lack of expertise etc., however, high beef demand, reduced manual power due to pandemic and sustainability concerns have motivated the beef industry to adopt RPA. Another study highlights that automation in manufacturing supply chains allows mechanised operations, cost-effectiveness, fast speed systems, and more safety and reliability in perishable food items like beef (Edan *et al*., 2023). Ojstersek et al (2023) studied and examined the attributes of human-robot collaboration to achieve optimised manufacturing systems. The study adopted different simulation modelling techniques to evaluate the robot's speed alongside product flow time and quantity. According to the presented results in the study, optimising robot speed is key to achieving a highly efficient manufacturing process. The simulation method employed in the study also depicted that individual analysis is essential with respect to human-robot or Cobot integration in manufacturing supply chains (Ojstersek *et al*., 2023). The simulation analysis in this research – scenario 2, provided new results in domain of process automation from the context of beef supply chains based on significant parameters – beef quality, safety, and shelf-life. The simulation results in this research evaluated that RPA adoption and integration improved process delivery, increased operational and employee efficiency and enhanced beef quality, safety, and shelf-life. Previous studies lack attention, knowledge and information related to the potential risks in RPA adoption in beef supply chains (Adrita *et al*., 2021; Ross *et al*., 2022). This study adopted simulation method to test and analyse 'what-if' scenarios and the simulation results in scenario 2 identified the main bottlenecks in RPA implementation through provision of MORE Plots and simulated model. The findings of scenario 2 also depicted that RPA integration had a positive impact on beef supply chain with respect to improved operational efficiency, beef quality, safety, capacity, and shelf-life.

5.9.3 Scenario 3

The scenario 3 was comparative analysis with initially human workforce or labour being the only resource input. The simulation findings observed that in scenario 3, initially, the labour number was 10 and at the very beginning the capacity was seen at a higher side but as the carcass reached the slaughtering stage and subsequent stages, the efficiency and capacity decreased with increasing time. The main bottlenecks or risks were observed in the slaughtering stage, cutting and boning stage and packaging and storage stage. This was because of the complexity of procedures or tasks in these stages with lower efficiency levels as humans were the only workforce to deliver tasks. The capacity was initially observed to be at 9 after which it dropped to 7 as depicted in the cutting and boning stage. Then in further beef processing the capacity lowered to 5 when it reached the packaging and storage stage. Finally, the capacity reduced to 4 when it reached the retailer. Then the process model was compared to another scenario where there were two resource inputs – human workforce and RPA technology. The human workforce lowered in number to 4 and 10 bots were adopted to perform tasks. The adoption of RPA helped to improve supply chain performance and operational efficiency as it facilitated with task automation which reduced human error or input. The beef supply chain observed stability and consistency with regards to capacity and operational efficiency in slaughtering stage and cutting and boning stage. Moving further, an increase in capacity was observed in the packaging and storage stage i.e., 12. In the retailer and distribution stage the capacity increased to 13. The simulation results depicted that an increase in the number of bots deployment had a positive impact on the process delivery and the supply chain was observed to be more efficient, effective, sustainable, and progressive. With the integration of bots in the supply chain stages, the beef capacity also increased along with the shelf-life due to less human intervention and error. This enhanced the supply chain processes, lowered human error and reduced chances of beef contamination and wastage thus adding value to the business processes. To summarise, the adoption of RPA provided process excellence, work-based accuracy, improved operational efficiency of business processes thus creating sustainability as observed through the simulation findings of scenario 3. Xu et al (2023), who studied meat industry's challenging working environments and strenuous workload, report that novel automation strategies are required to meet sustainability challenges in meat production. Moreover, as reported by OECD-FAO (2023), the global meat production will see a rise of 14% in the next ten years' time span. In this context, there is an urgent need to implement process automation considering efficiency, reliability, safety, and accuracy concerns in red meat supply chains (Rose *et al*., 2021). Mason et al (2023) study further highlights that beef sector has a complex business environment; however, the industry is a large contributor to the food supply chain and thus inclusion of RPA can greatly resolve issues related to productivity, labour shortages, health and safety standards, socio-environmental concerns, and capital costs. Jacxsens *et al* (2010) research paper adopted a simulation-based approach to test scenarios based on climate change and globalisation challenges that the fresh produce supply chain faces. A knowledge-based modelling system was proposed in the study which offered solutions and monitored or alleviate any microbiological food risks during the production and supply stages. Similarly, another study conducted by Paape et al (2022) focused on improving the meat sector-poultry processing system and used discrete-event simulation to form a model in Anylogic software. The study developed two scenarios to assess the performance level of production systems using the simulation model built. To conclude, several studies have focused on the need to automate business processes and meet sustainability goals, however, existing literature lacks attention and assessment of the potential risks in the adoption of RPA in beef supply chains (Åkerberg *et al.*, 2021). The findings of this research in scenario 3 provided a comparative analysis of scenarios with and without the adoption of RPA in beef supply chains. It was evident from the findings of scenario 3 that RPA implementation improved supply chain efficiency and ensured high quality, safe and sustainable beef with greater shelf-life, whereas, manually driven beef supply chain faced reduced operational efficiency, poor performance and production of low-quality, unsafe, and reduced shelf-life beef. Also, scenario 3 findings depict that lesser bottlenecks were observed in beef supply chain where RPA was deployed.

5.10 Critical assessment on scenarios 4 and 5 findings – consideration of financial or cost-related aspects as parameters

5.10.1 Scenario 4

The scenario 4 was simulated and assessed considering financial or cost-related parameters using the business process model in Simul8 software. Financial aspects comprising of all the significant costs related to the supply chain processes are important for simulation analysis and evaluation to depict supply chain financial and operational efficiency levels, productivity, and business viability from the sustainability lens. The scenario 4 was tested considering the financial aspects to evaluate supply chain productivity, economic conditions, production levels and main bottlenecks or financial risks in beef processing and manufacturing. The scenario 4 used human workforce as labour at different workstations in the beef supply chain. The scenario was tested to evaluate the manual-centric supply chain considering the cost-related factors. The simulation results or findings in scenario 4 depict that the supply chain observed low beef capacity, poor financial and operational performance, and increased bottlenecks at different supply chain stages. The findings also highlight that supply chain processes were time taking in terms of task completion and increased queuing times were observed in beef processing and packaging phase. The supply chain was manually driven due to which task delivery was poor and inefficient because of high human error. As the supply chain was highly reliant on human workforce, the beef capacity reduced at each progressing stage of the supply chain; initially the beef capacity was observed to be 40 at the stunning and slaughtering phase and reached to 10 in the final retailer or distribution centre phase as shown in the simulated model in Figure 5.11 respectively. Due to increased bottlenecks and errors in supply chain stages, reduced beef capacity and shelf-life were observed in scenario 4. Simulation analysis in this scenario also depict that the supply chain faced loss, poor financial performance and low stability as the operational costs exceeded the revenue which led to an inefficient supply chain system as shown in the income statement report generated by the software in Figure 5.12. The findings of the scenario also observed an income statement report which represented that the supply chain had high operational costs due to increased energy and time-taken for task delivery. This was because the business processes heavily relied on human workforce for beef processing and manufacturing in the given scenario; human handling caused increased human error which resulted in poor financial efficiency. Moreover, the scenario 4 also experienced high environmental impact in beef production leading to hazardous work environment which is risky for both workers and beef manufacturing. The carbon emission report in Figure 5.13 depicted that scenario 4 also produced high amount of carbon emissions in beef supply chain stages and low carbon offset was detected in the working environment that resulted in increased air pollution which caused health and safety risks for the human workers. Also, air pollution due to high amount of carbon emissions at each stage of the supply chain also increased chances of beef contamination leading to low-quality and unhealthy beef production for human consumption with reduced nutritious value. Therefore, the supply chain in this scenario was unable to comply with the quality and safety standards in beef production. To conclude, the simulation results and findings in scenario 4 assessed that the supply chain experienced increased human error and bottlenecks at various stages which reduced the beef capacity, quality, safety, and shelf-life. The supply chain processes were time-consuming, complex, and risky resulting in poor financial and operational performance. The business processes experienced increased time taken, high operational costs and energy which led to poor financial efficiency and economic loss as shown through the income statement report. Additionally, the working environment was polluted and hazardous for the human workforce due to high amounts of carbon emissions and air pollution causing high environmental impact. Increased human intervention and handling and high environmental impact increased chances of contaminated beef production. According to the research findings, the supply chain in this scenario failed to achieve sustainable value in the three dimensions of sustainability and experienced low production levels at high operational costs as the supply chain experienced loss and poor financial performance.

Cosenz et al (2020) study examined and suggested a system dynamics approach for sustainable business modelling. The system dynamics modelling technique was adopted to bridge the methodological gaps in literature. Based on the findings, a systemic design tool was introduced that combines environmental, economic, and social drivers into a dynamic model structure, thereby overcoming methodological limitations of current business modelling tools. As simulation is considered a powerful technique to evaluate business processes, another study revealed significant findings in the relevant domain. Mourtzis (2020) evaluated the major milestones in manufacturing systems with respect to simulation technologies. The study findings reviewed and examined the recent research and industry approaches in the domain of digitalised manufacturing from the context of 4th industrial revolution and how technological developments have shaped simulation in the operation and design of manufacturing systems. With respect to the same perspective, Pattar *et al* (2020) claims that in recent times simulation approach and technological adoptions has been strategically used by the manufacturing industry to enhance decision-making concerning productivity, viability, process reengineering, design, and costs. Dalmarco et al (2019) poses an argument and highlights that there are challenges with regards to adopting industry 4.0 technologies and some the main challenges are evaluation of data generated, new technologies integration with workforce and equipment and computational errors or limitations. The findings of this simulation study are distinctive and unique in the domain of beef sector with regards to RPA adoption. The scenario 4 findings evaluated the bottlenecks in manual centric supply chains and observed high operational costs at different stages. The results also produced a carbon emissions report which highlight increased air pollution due to increased use of energy, fuel, and time.

5.10.2 Scenario 5

The scenario 5 was evaluated considering the financial or cost-related aspects that influence the adoption process of RPA. It is crucial to analyse scenario using financial parameters or factors to allow identification of financial risks and main bottlenecks at different supply chain stages. Scenario 5 was assessed from a sustainability perspective through simulation of process model to evaluate RPA potential, accuracy, and benefits in beef supply chain processes. In broader sense, the results or simulation findings show that Scenario 5 experienced healthier, safer, and more nutritious beef production than Scenario 4. Scenario 5 used RPA technology along with human workforce for task completion at different workstations in beef supply chain.

Scenario 5 showed a greater production, higher beef capacity and efficiency during each progressing stage of the supply chain, as the initial capacity at the start of the supply chain was observed to be 15 and it reached to 35 in its final stage, i.e., the retailer or distribution centre phase. The financial and operational performance of Scenario 5 was also evaluated through process testing and it was better than Scenario 4. This is because Scenario 5 obtained profit due to task automation and reduced human error, thus facilitating the beef supply chain, and resulting in lower operational costs and generating higher revenue, as depicted in Figure 5.15 in the income statement report. As a result of the low operational costs due to less reliance on the human workforce, better productivity levels, and fast-paced supply chain, Scenario 5 resulted in profitable business processes in comparison with Scenario 4. On the other hand, scenario 4 findings depict that the supply chains faced low financial performance and suffered loss due to human-centric task delivery with resulted in increased human error, greater operational costs, and low revenue in the final stage. Therefore, Scenario 5 experienced a profitable supply chain due to good financial and operational performance. Moreover, the findings from the scenario analysis in the Simul8 software also depict that Scenario 5 experienced less environmental threats and lower impact than Scenario 4, as observed in the carbon emission report in Figure 5.16. Scenario 5 had an eco-friendly and safe environment because of RPA integration and less reliability on human workforce throughout the supply chain which reduced the time taken, as well as the fuel and energy consumption in process delivery. The environmental impact in scenario 4 was high and double to that in scenario 5 as shown in Figure 5.13. To summarise the simulation findings, Scenario 5 used process automation along with the human workforce to perform tasks, whereas Scenario 4 only used the human workforce as labour for process delivery. Scenario 5 exhibited efficient financial and operational efficiency and high productivity levels with low processing costs, and created social, economic, and environmental value in the beef supply chain. Scenario 5 experienced less reliance of human workforce and utilised RPA as a business solution to gain profitable supply chain with higher productivity levels. Scenario 5 was less prone to risks because of reduced human error, shorter queuing times for beef processing, and production of hygienic and nutritious beef, as shown in simulation results. According to the findings of scenario 5, as the work environment was less challenging due to integration of bots with human workforce, the beef supply chain achieved sustainable value.

There are existing studies which have focused on the future of business organisations and the opportunities with the implementation of RPA. As process automation plays a vital role in the food sector, Jagtap et al (2020) research focused and explored the emerging technologies, such as RPA, simulation, artificial intelligence etc., and their role in enhancing and revolutionising food logistics to obtain low operational costs, improved flexibility, and enhanced supply chain performance. The findings observed that novel solutions and technologies like RPA and simulation, play a crucial role in food logistics with respect to sustainable development. Moreover, another study by Lezoche et al (2020) emphasised on agri-food domain and conducted a survey where more than hundred papers were reviewed on emerging technologies like RPA, and the findings revealed that implementation of new technologies allows Agri-based supply chains to address important objectives such as soil conservation, reduce carbon emission, efficient production, and minimised waste. However, the findings also suggested that though the industry 4.0 technologies have a positive impact, there are certain challenges in terms of management. Previous studies lack knowledge and assessment on financial risks through RPA implementation in beef supply chains (Flechsig *et al*., 2022). The scenario 5 findings provide insights regarding the cost analysis at different beef supply chain stages through RPA integration. The findings revealed reduced financial and operational risks, less environmental impact, and a profitable supply chain system. Therefore, the simulation results observed positive RPA financial and operational potential along with sustainable, profitable, and viable supply chain system in scenario 5.

5.11 The sustainability assessment of 'what-if' scenario analysis considering social, economic, and environmental dimensions

The adoption of RPA had been seen as a value addition to the process model which depicts the beef supply chain stages. In this study, the scenarios were analysed from the aspect of operational efficiency, beef capacity, shelf-life, safety, and costs. The simulation findings of this research and observations made through process analysis are significantly important as the main bottlenecks were detected, and simulation allowed assessment of supply chain performance. Broom (2021) study findings presented a scoring method to test sustainability in production systems and the study took beef production systems as an example for review. It was found that land degradation caused by extensive grazing and indoor housing or feedlots with grain feeding are the least sustainable beef production method. In this context, the factors or parameters of sustainable beef production are important and valuable for consideration. Sustainably produced beef brings opportunities and benefits to the organisations and enhance consumer satisfaction level. Achieving sustainability in beef processing also allows higher production levels at lower costs, which is one of the challenges faced by beef manufacturers at present, other than maintaining high quality standards. Therefore, the simulations findings in this study were also observed and evaluated from sustainability perspective.

Charry et al (2019) claims that the ethics in beef production systems are important to be analysed and evaluated as quality standards are directly associated to that. A system or process is sustainable if it brings social, economic, and environmental value to the supply chain system (Charry *et al*., 2019). Therefore, it is crucial for beef supply chains to be sustainable and progressive in beef production as long-terms benefits are associated with it. The advancements and adoption of technologies such as the RPA can help reduce human error, efforts and automate tasks that were performed manually otherwise. Hence, as per the results and findings, the adoption of RPA in beef supply chains reduced risks and errors while improving performance at various stages. The simulated process model assessed scenarios with varying operational efficiency, capacity, and shelf-life.

The findings of scenarios 1, 2 and 3 were observed and examined from social and environmental dimensions of sustainability based on beef shelf-life, safety, and quality used as research parameters. The scenarios 4 and 5 considered financial aspects in the adoption of RPA in beef supply chains and are discussed and explained from the perspective of social, environmental, and economic value based on the simulation findings in previous chapter. The approach towards ***sustainable beef production*** is discussed as per the simulation results in different scenarios.

5.11.1 Social Value

The **scenario 1** was simulated to observe the supply chain performance with respect to efficiency, capacity, and shelf-life. The scenario 1 used only human workforce as resource input to perform tasks at different stages of the beef supply chain. The scenario 1 observed main bottlenecks in the slaughtering, cutting and boning stage and packaging and storage stage as depicted in the data analysis and results section. The scenario 1 experienced lower operational efficiency, beef capacity and shelf-life due to human workforce working on the processing line. In this respective scenario analysis, employee-level efficiency and operational efficiency was at the lower side due to repetitive, strenuous, and boring tasks. Major bottlenecks were observed at different stages of the process model which depicted increased human error. Due to the lower efficiency and process delivery, more time taken was observed to complete and perform tasks and this lowered the pace of beef processing and manufacturing. High human error also posed health and safety risks in beef production and there were high chances of beef contamination. Thus scenario 1 did not have an approach towards social value as process delivery was slower, riskier with major threats to beef quality standards and safety.

The **scenarios 2** and **3** were analysed to evaluate the risk factors and supply chain performance with respect to operational efficiency, shelf-life, and capacity. The scenarios used RPA technology and human workforce / labour as resource input to produce simulation results after several runs. As RPA automates rule-based, repetitive tasks, the scenarios observed higher operational efficiency levels which also relieved the employees, and they could potentially work with enhanced accuracy due to less pressure. The beef capacity also enhanced which increased shelf-life of beef. The processing of tasks was more fast paced with less time taken and reduced human error. The beef production was observed to be healthier and safer with high-quality standards because of lower risk factor. Hence, the social value or goal was achieved in the scenarios 2 and 3 as there was enhanced employee-level efficiency and satisfaction due to less pressure, reduced human error and quality beef production. The health and safety standards were also observed and met in the respective scenarios thus benefitting the business processes in social aspects.

Scenarios 4 and 5 were simulated and both the scenarios used financial parameters for scenario testing. The cost-related parameters or factors were considered in **scenarios 4 and 5** to evaluate the supply chain efficiency with and without the adoption of RPA in beef supply chains.

The **scenario 4** used human workforce as labour to perform tasks at different stations or phases of the beef supply chain. The findings in scenario 4 highlight that the supply chain was unable to create social value in business processes. Scenario 4 had a manual-centric supply chain which resulted in a low beef production capacity as time passes through different phases of the supply chain. The simulated model showed a result of 40 beef capacity or shelf life at the initial phase of the supply chain, and it constantly reduced at every level; it was observed to be 10 when processed beef reached the retailer or distribution centre. As shown in Table 5.4, the working% of the beef processing and packaging stage was 37.15 and the average time taken for the carcass to reach the final customer was 1428.76 min–23.81 h, which was extensive in comparison with Scenario 5. Increased time taken to produce beef, higher queue size, and increased human error due to manual handling of the processes led to low-quality beef production with a reduced shelf life. As the working% of beef processing was also lower and was half the value observed in Scenario 5, this indicated lower operational and employee-level efficiency in scenario 4 according to the simulation findings.

Scenario 5 used RPA technology and the human workforce as a resource input. Beef supply chain tasks were automated, and humans worked with bots in beef processing. The integration of RPA enhances supply chain operations, and the supply chain observed a consistent and higher beef capacity throughout the supply chain workstations. The initial beef capacity or shelf life observed during the stunning and slaughtering stage is 15, and as the carcass progressed, the capacity increased to 18 and then reached 19 in the beef processing and packaging phase. Finally, it increased to 35 when it reached the retailer or distribution centre. The average time taken for the carcass processing was 705.91 min–11.76 h, which was much less than Scenario 4. The simulation analyses showed high-quality beef production and safer beef for consumption due to the automation of tasks, which saved energy, time, and money. The working% was 90.87, as depicted in Table 5.5, for Scenario 5, which was double the percentage seen in Scenario 4; hence, a higher operational and employee-level efficiency was observed. The simulation findings depicted that Scenario 5 had a greater shelf life and higher quality of beef production. The working% during the beef processing and packaging stage was also double, and so a greater employee-level efficiency and operational performance was observed in Scenario 5. Scenario 5 also demonstrated social value and improvement in terms of sustainability due to a profitable and cost-effective supply chain system in comparison with Scenario 4.

There are studies which have focused on the benefits of industry 4.0 technologies to create social value in business environments. Tang et al (2019) study focused on the role and potential of emerging technologies like RPA, artificial intelligence, robotics blockchain etc., in transforming and shaping logistics in supply chains. The findings of the study state the application of these game changing technologies like automation brings social value for both businesses and consumers through automating mundane tasks, however, such technological advancements also might create social unrest and social inequality for workers who might lose their jobs due to automation facilities in every industry. Sharing a similar perspective on automation opportunities, Mason et al (2021) study provides a comprehensive outlook on the meat factory cell and focuses on improving sustainability with meat sector. The study highlights and discusses health risks, job nature, work environment, education and industrial development as sustainability gaols which are in accordance with United Nations Sustainable Development Goals (SDG). The findings observed that technology such as process automation can undoubtedly enhance business processes and activities on a societal level. On the contrary, Krings et al (2021) argues and points out future automation adoptions might lead to a high impact in the US labour market with special reference to human-based jobs at risks. The authors stress that future work models should reinterpret new societal expectations and demands. Previous studies lack information related to social dimensions of RPA adoption in beef supply chains and the risks to its implementation. The findings of this research advance to present knowledge as the study identified the main bottlenecks in RPA adoption using simulation and highlight the social value generated by implementation of RPA in sustainable beef production. The study findings revealed that scenarios 2, 3 and 5 successfully created social value by obtaining improved employee, financial and operational efficiency through RPA integration and were also successful in meeting quality, safety, and shelf-life in beef production in social dimension. The findings also highlight that due to poor performance, high human error and human workforce as labour, scenarios 1 and 4 were unable to achieve social value in beef supply chain.

5.11.2 Environmental value

The **scenario 1** observed human workforce as the only resource input to perform strenuous, repetitive, and exhausting tasks across the beef supply chain stages. As discussed above, the supply chain performance was less due to lower operational efficiency, reduced beef capacity and shelf-life. Due to lower efficiency, capacity and quality in the production system, there were higher chances of beef contamination because of major risks and human error. Due to human handling and intervention in the scenario 1, the chances of transmission of diseases were more which posed a threat to hygienic beef production and human well-being. The efficiency and capacity were also observed to be lower, and the processing line was slow as it took substantial time to perform tasks due to human handling. As there were major bottlenecks and human error during beef processing, hence, there was increased chance of beef wastage. Therefore, scenario 1 was unable to achieve environmental value due to slow process delivery with high human error, increased time-taken for task completion and poor operational performance along the supply chain processes.

The findings of **scenarios 2 and 3** highlighted that increased operational efficiency, beef capacity and shelf-life was observed in the scenarios. The scenarios 2 and 3 used human workforce along with RPA technology adopt to automate tasks in the beef supply chain stages. Efficiency and productivity in supply chain performance and process delivery at different stages of the beef supply chain was observed in simulated process models. The processing of beef was faster with reduced human error and risks. Due to less human intervention and handling in processing tasks, there were lesser chances of beef contamination. This greatly benefitted the beef production as less percentage or chances of beef contamination ensure production of high-quality, safer beef with great nutritional value. Less human handling also prevented the transmission of diseases and assured human well-being and hygienic beef production and processing. As the supply chain efficiency was higher and sustainable, this helped to prevent pollution in terms of less beef wastage across the supply chain during processing. Scenarios 2 and 3 observed enhanced progression, performance, and sustainability with gaining environmental value. The supply chain processes were observed to be more efficient, productive, and environmentally friendly.

Scenario 4, from the perspective of environmental value, had a high environmental impact, as shown in the carbon emission report in Simul8. The carbon emissions in Scenario 4, which was human-centric, were very high due to increased usage of fuel, energy, resources, raw materials, costs, packaging, and distribution during beef processing and manufacturing. The carbon emissions were also higher, which led to a high environmental impact due to the increased human error, costs, supply chain risks, and supply chain disruptions. Reduced operational and employee efficiency contributed to increased time and energy consumption, which led to high carbon emissions and less carbon offset. The supply chain in this scenario experienced more environmental risks, health and hygiene challenges, air pollution, and threats to beef contamination and the transmission of diseases due to human handling and intervention. There was an increased risk of beef waste in the processing line due to high human error. The environmental impact was 278, 961.49 CO2e, which indicated greater environmental threats, as depicted in the Carbon Emission Report in Figure 5.13 in scenario 4.

Scenario 5 simulation results depicted a lower environmental impact of 141,082.49 CO2e, as displayed in Figure 5.16, compared with Scenario 4, which was double this amount. The carbon emission report in the scenario showed less carbon emissions throughout different stages of the supply chain. Lower carbon emissions contributed to a decreased environmental impact, as the supply chain used RPA technology alongside humans on the processing line. The tasks were automated, thus reducing the time, energy, and costs needed, which led to lower carbon emissions. RPA integration with humans allowed for better utilisation of resources, fuel, and financial performance, as well as enhanced production and distribution systems. This resulted in less environmental threats and increased the likelihood of high-quality and hygienic beef production. A lower environmental impact also indicated the prevention of pollution and reduced beef waste. Automation also reduced the risk of disease transmission. Beef production involves industrial processes that contribute to air pollution due to carbon dioxide emissions at different supply chain stages, thus resulting in an environmental impact that could be threating and hazardous to the atmosphere and to humans. Scenarios 4 and 5 were investigated through process simulation and scenario testing and were considered from the perspective of environmental impact. To further emphasise on this concept, Scenario 5 had a lower environmental impact on the environment according to the carbon emission report presented in Figure 5.16. Scenario 5 had two resource inputs, RPA technology and human workforce, which were used for handling complex tasks at different workstations of the beef supply chain. Beef processing and production result in significant greenhouse gas emissions due to the complex nature of the supply chain processes. Beef supply chains emit carbon dioxide emissions during beef processing and manufacturing due to the complex procedures involved, such as slaughtering, cutting, deboning, and packaging, which cause environmental hazards and threaten the environment and atmosphere. Scenario 5 included process automation through RPA adoption and relied on less human handling, which resulted in less fuel and energy consumption during beef production. As less energy, time, and fuel are used for beef processing at each progressing stage of the supply chain, less operational costs are involved, as seen in Scenario 5. Automating tasks reduced human error and speeded up supply chain operations, which reduced carbon dioxide emissions at different stages of the supply chain as observed in the carbon emission report in scenario 5. Reduced environmental concerns and pollution related to the atmosphere depicted that Scenario 5 was a safer and eco-friendlier alternative in beef processing in comparison with Scenario 4, where the emissions were equal to 278,961.49 CO_2e. The carbon emission report represented the statistical data for both scenarios, as observed in Figures 5.13 and 5.16, and illustrated the emissions at each phase of the beef supply chain. The comparison of the two scenarios indicated that Scenario 5 had increased environmental value as there were more chances for high quality and nutritious beef production than Scenario 4, which had a high environmental impact. The supply chain in Scenario 5 was also considered to be safer and more environmentally friendly as the sustainability goals were met.

There are academic works that have emphasised on automation opportunities with respect to environmental gains. Ojo et al (2018) studied and examined the industry 4.0 challenges and opportunities on sustainable food supply chain environments. The study findings proposed a model which represented the influence of industry 4.0 technologies like automation and robotics on food supply chain environment. The study recommended future works to form a generalised model which can enhance sustainable food supply chain management. Similarly, in another study Hao et al (2020) examined the logistics industry and the emergence of automatic warehousing systems in the sector. The study developed a TOE conceptual model which investigated different factors that influence the adoption of green technology in logistics industry. The findings of the study suggested decision-makers to consider the environmental sustainability issues in new technology adoption and stated that costs, firm size, technological turbulence, operational performance, and partner organisations influence are some of the significant factors that impact technological application in small organisations. Moreover, Ahmed and Vij (2020) research provided insights regarding industrial potential with the implementation of industry 4.0 technologies and eco-friendly manufacturing. The study findings revealed that environmental management in adopting emerging technologies leads to effective present and smarter and sustainable future therefore, laws and collective awareness should be imposed for quality manufacturing. However, Aly et al (2023) shared a different view on technological adoptions like robotic automation and the study pointed out that there are complexities and challenges with regards to robotic technology implementation in red meat processing. The study findings stated that as red meat sector has harsh working environments, therefore, adaptive control having real-time perception and preoperative scanning are recommended for task automation in red meat cutting. Moreover, it was also recommended to fully automate cutting activities by having a gradual shift in abattoirs through utilisations of virtual reality, cobot, and exoskeletons augmented reality. Literature in the past has not focused on assessing the role of RPA and its implementation in beef supply chains with respect to environmental aspects. The findings of this simulation study contribute to existing literature by providing scenario analysis on beef supply chain specifically, and simulation analysis has provided results in the form of carbon emissions report to depict the environmental impact of beef production through RPA adoption and without its implementation based on different parameters. The findings also detect the main bottlenecks in RPA adoption in beef supply chain.

5.11.3 Economic value

Scenarios 4 and 5 were tested, assessed, and evaluated considering the financial parameters which were used as a basis for scenario development and testing. The process simulation assessed both the scenarios from economic aspect.

Scenario 4 simulation findings provided the income statement generated in Simul8, where the costs of production and manufacturing surpassed the revenue at the final stage, resulting in supply chain losses. The loss experienced in Scenario 4 was −284,498.59 GBP because of the high operational costs, and thus the supply chain experienced a poor financial performance and lack of efficiency regarding business activities during the different stages of the beef supply chain (depicted in Figure 5.12). The revenue in Scenario 4 was less than the costs because the supply chain activities were manually completed, which increased the time-taken, energy, and human error. The supply chain was manually driven, which resulted in time consuming tasks, miscommunication, poor resource utilisation, and a lack of security, that led to costly procedures throughout all levels of beef manufacturing. Thus, Scenario 4 had a low and poor financial efficiency, which reduced its business viability and stability, increased operational costs, and minimised the profit margins which resulted in economic instability and loss.

Scenario 5 adopted RPA to automate strenuous, repetitive tasks and uses human labour for performing complex procedures. The alliance of RPA and humans helped to improve supply chain processes and reduce costs and energy at different phases of the supply chain. According to the study findings, scenario 5 displayed a good financial performance as the cost of beef processing and manufacturing was reduced and more revenue was generated at the end customer phase which resulted in a profitable supply chain that amounts to 221,300.39 GBP, as seen in Figure 5.15. The lower consumption of time and energy, as well as improved business viability and stability, helped to reduce operational costs, thus ensuring an efficient financial performance for the supply chain. Scenario 5 experienced higher financial efficiency and increased performance due to profit generation and a reduction in operational costs, as indicated by the income statement report in Simul8. On the contrary, Scenario 4 suffered loss due to increased operational costs, which negatively impacted business stability and viability. Hence, according to the simulation assessment based on sustainability criterions, Scenario 5 gained economic value as the processing line was fast-paced and successfully produced good quality, hygienic beef at low operational costs resulting in a stable and profitable supply chain.

Process automation transforms business processes and acts as a catalyst for economic development and progress with respect to sustainability (Hitzmann and Ahmad, 2017; Borowski, 2021; Heema *et al*., 2022). Duong et al (2020) explored the integration of robotics and autonomous systems in food sector from the context of supply chain operations to enhance productivity and lower costs. The study conducted a systematic review and came across five themes in food supply chains which were food waste, food safety, food quality, supply chain analysis and supply chain efficiency. The role of robotics and autonomous systems (RAS) have been discussed from different perspectives – financial costs, cyber security, data availability, and skill capability. As digitalisation has also impacted the agri-food sector, Abbate et al (2023) study provided a comprehensive analysis and reviewed last decade research related to agri-food sustainability and the industry 4.0. The study provided implications for agri-food supply chains and suggested organisations to re-design business models in accordance with perspective that prioritises value-creation, long-term business viability, profitability, and sustainability. It was also highlighted that adoption of digital technologies like automation can improving farming activities, save costs and provide long-term economic gains. Previous works have not considered or paid attention to the beef supply chains and there is no thorough evaluation on the cost benefits analysis with respect to RPA adoption in beef sector. The simulation findings through scenario testing provided cost-related information and knowledge in RPA application and the results generated income statement reports to depict the financial performance with respect to each scenario in beef supply chain.

The Table 5.7 further summarises the findings with respect to sustainability assessment conducted in ***scenarios 1, 2 and 3*** from the perspective of social and environmental value. The ***scenarios 1, 2 and 3*** were simulated and analysed based on respective parameters: ***beef quality, safety, and shelf-life***.

Table 5.7: Sustainable Value – Social and Environmental value evaluated through simulation results in Scenarios 1, 2 and 3

	Social Value	**Environmental Value**
Scenario 1	▪ Low employee-level efficiency ▪ Low operational and functional efficiency ▪ Higher risks and increased human error. ▪ Health and safety standards were not met. ▪ Low quality beef production ▪ Reduced shelf-life ▪ Lower production of beef	▪ Higher chances of beef wastage ▪ Higher pollution with regards to beef waste across supply chain stages ▪ Higher chances of beef contamination due to human intervention ▪ Higher chances of transmission of diseases due to human handling and labour working to perform tasks. ▪ Threat to human well-being and safety

		▪ Low quality beef production due to higher risks, errors, and major bottlenecks ▪ Less production and increased time taken resulted in poor supply chain performance. ▪ Less beef production – high risks of not meeting consumer demand. ▪ Consumer and retailer dissatisfaction and discontent
Scenario 2	▪ Increased employee-level efficiency ▪ Employees could potentially focus on judge-based or skilled jobs. ▪ Reduced human error. ▪ Increased operational and functional efficiency thus relieving business owners or decision-makers in real-life scenarios. ▪ Health and safety standards achieved. ▪ Quality beef production ▪ Increased beef production and shelf-life	▪ Reduced beef waste due to faster production and higher efficiency ▪ Pollution prevention due to less beef wastage across the supply chain stages. ▪ Less transmission of diseases due to less human intervention and handling ▪ Less beef contamination – quality/ hygienic beef production ▪ Human well-being and safety as bots performed tasks alongside humans. ▪ Increased beef capacity and production with higher chances of meeting customer demand. ▪ Consumer and retailer satisfaction due to high-quality, longer shelf-life beef

Scenario 3	▪ Enhanced employee-level competency and efficiency ▪ Efficient supply chain performance with bots' integration and increase in adoption. ▪ Less supply chain or process delivery risks ▪ Adoption of bots and less reliance on human labour working on processing line, reduced chances of accidents or errors. ▪ Human less prone to accidents or injuries – enhancing human well-being and safety. ▪ Lower human error or risk elements / bottlenecks ▪ Quality beef production in accordance with the quality standards ▪ Fast-paced production system resulted in higher production levels / output	▪ Less beef wasted during processing. ▪ Effective waste management ▪ Environmental pollution prevention due to reduced chances of beef wastage. ▪ Sustainable supply chain processes ▪ Lower transmission of diseases due to less human intervention and more bots deployed for performing tasks. ▪ High chances of meeting consumer demands and enhanced consumer satisfaction levels ▪ Hygienic and safer beef production which has high nutritional value due to less contamination, increased shelf-life, and faster production systems

The Table 5.8 provides a further overview of the sustainability assessment conducted through simulation analysis results in ***scenarios 4 and 5***. The two scenarios were evaluated and observed from the perspective of social, environmental, and economic value. To re-emphasise, the scenarios 4 and 5 were analysed, and simulated using ***financial or cost-related parameters***

or factors which served as a basis for scenario development. The scenarios 4 and 5 findings were also assessed from sustainability perspective.

Table 5.8: Social, environmental, and economic value assessed through simulation results in Scenarios 4 and 5

	Social	**Environmental**	**Economic**
Scenario 4	• Low beef quality – the beef production was not according to quality standards due to inefficient supply chains. • Increased human error – supply chain was manually driven, and business processes were conducted using humans as workforce. • Low operational efficiency achieved. • Increased queuing time in beef processing and manufacturing – low beef capacity and shelf-life	• Increased chances of beef contamination – production of low-quality, unhealthy beef not complying with quality standards • Increased beef waste along the processing line – this was due to high human error, inefficient and ineffective human handling at the processing line. • High environmental impact – increased air pollution due to CO_2 emissions	• Reduced business stability and viability – highly vulnerable and risky supply chain processes resulting in short-term business survival and poor supply chain performance. • Loss experienced – the operational costs exceeded the revenue generated which led to poor financial performance. The supply chain was slow, risky, inefficient with high operational costs due to human workforce as only resource input.

	• Low production levels due to increased bottlenecks and high risks along the supply chain stages. • Reduced employee efficiency due complex business procedures and heavy reliance on human workforce only as the resource input	making the environment and surroundings risky and threating for humans to work. Unsafe and hazardous working environment; production of low-quality and contaminated beef. • High chances of disease transmission due to human handling and intervention in beef processing and manufacturing line.	• High operational costs resulting in low revenue generation at the ending stage of the supply chain. • Higher chances of short-term business survival due to extremely vulnerable and risk-prone supply chain processes with heavy reliance on human workforce.
Scenario 5	• Quality and safety standards were met – RPA served as a strategic catalyst to automate rigorous tasks and work with humans to	• Hygienic beef production – quality and health standards were met due to reduced human error, fast-paced	• Increased business stability and viability experienced due to task automation

	produce high-quality, nutritious beef that is safe for human consumption. • Reduced human error and resilient supply chain – RPA integration with human workforce reduced bottlenecks and resulted in a less risky supply chain. Less human handling and intervention and task automation ensured lower human error. • High operational and employee efficiency – smooth running of operations, fast-paced supply chain, efficient processes and reduced bottlenecks experienced.	and efficient supply chain processes through task automation. • Less environmental impact – pollution prevention in sustainable beef production. Eco-friendly and safe working environment due to less CO_2 emissions at different stages of the supply chain. Less air pollution and reduced chances of beef contamination. Safer and eco-friendly environment for the workers on the processing line.	• Cost-effective supply chain. Good financial performance and efficiency observed – the supply chain was fast-paced and used less energy, time and costs for task completion. Low operational costs experienced due to fast, automated, efficient, and less-complex supply chain system. • Profitable supply chain – revenue exceeded the operational costs resulting in a sustainable and cost-effective supply chain. • Long-term business viability: reduced human error, less risky and more resilient supply chain

	• High productivity levels – increased beef capacity, shelf-life, and production to satisfy demand through production of high-quality beef.	• Less chances of disease transmission; reduced human handling and intervention due to automation of tasks. Production of quality and safe beef for human consumption. • Reduced beef waste alongside the processing line due to enhanced operational and employee-level efficiency. Supply chain processes were effectively handled and monitored due to RPA services and adoption. • Reduced fuel and energy consumption – lower queuing	system which led to sustainable beef production at reduced costs.

		times in beef processing were observed. Task automation ensured less usage of fuel and energy which resulted in less environmental impact.	

5.12 Chapter Summary

The simulation study provided new results that haven't been explored previously. The findings of the study indicated that RPA implementation improved beef safety, quality, shelf-life which is a growing concern for beef supply chains at present times. RPA integration in beef supply chain also reduced operational costs and ensured higher output levels. Moreover, the findings depicted that RPA adoption served as sustainability tool to improve supply chain processes through task automation and reduced human error. The emerging technology plays a vital role in attaining operational and financial efficiency in beef supply chains whilst boosting output levels at low operational costs. RPA successful adoption also allows firms to achieve their strategic and economic goals and the powerful innovation serves a business solution to achieve competitive advantage and fulfil corporate social responsibility in complex supply chains such as the beef industry. In this study, different scenarios were developed and simulated based on various research parameters that influence the adoption process of RPA in beef supply chains.

Based on the simulation analysis, new insights and findings were obtained in this domain that haven't been explored previously. This is the first study focusing on the safety, quality, shelf-life, and financial parameters in the adoption process of RPA, and it explored the pitch towards sustainability through RPA integration and implementation in the beef sector. The results of the simulation study provide an improved and more strategic approach for adopting RPA by considering the significant parameters – beef safety, quality, shelf-life, and costs. This emerging technology is not only considered in terms of its adoption process, but also from the perspective of creating sustainable value in beef supply chains. RPA acts as a sustainability tool to enhance supply chain business operations and improve financial and operational performance through cost reduction, reduced human error, autonomous beef supply chain processes, less complex work-flow management systems and enhanced process integration and synchronisation. The simulation-based study not only identifies the main bottlenecks at different stages of the beef supply chain in various scenarios testing but also critically evaluates RPA adding value and dimensions to sustainability in the beef supply chain. The simulation approach through development and assessment of different scenarios allows enhanced risk assessment and evaluation from business users perspective; it also further provides the opportunity to conduct a thorough cost analysis for successful adoption of RPA in beef supply chains.

The study simulated the business process model using different scenarios. The simulation findings provide an opportunity to businesses in beef sector to decrease financial and operational risks in the adoption of RPA by eliminating risks beforehand. The study also introduces sustainability assessment criteria to analyse the scenarios from social, economic, and environmental aspects, considering the significant parameters or factors that play an important role in RPA adoption process in beef supply chain. The important parameters considered in this simulation study were ***beef quality, safety, shelf-life, and cost-related or financial aspects*** respectively and these were used for scenario analysis to observe operational, financial, and employee-level efficiency, beef quality, production levels, capacity, and shelf-life at different stages of the beef supply chain. The study also encourages decision-makers to pay attention to the operational and financial procedures in beef processing and helps them improve their decision-making abilities by providing insights on the main bottlenecks, and risks in various supply chain stages. Simulation results gave a clear comparison of the efficiency levels achieved with and without the adoption of RPA in beef supply chains. The simulation analysis enables business users or stakeholders to adopt a systematic approach in RPA implementation and provides clear understanding on how the innovative technology can potentially enhance cost-effectiveness, quality, production, shelf-life, and capacity in beef supply chain. The research project provides a generic business process model which can be utilised for the successful adoption of RPA by potential beef manufacturers in the beef business. The process model is easy to adapt and modify as it is not complex in nature and design. The process model can be used as a basis to understand and observe the operational and financial aspects of adopting RPA in beef supply chains; the proposed model can be modified by decision-makers or managers according to their own business requirements or circumstances. The successful and robust adoption of RPA can assist organisations with sustainable beef production at reduced operational costs and help attain higher productivity levels. Smooth adoption process of RPA also improves operational, employee, and economic performance of beef supply chains in social, economic, and environmental capacity. Additionally, RPA robust adoption can be a cost-effective solution to beef supply chains to add value to their business processes and achieve social, environmental, and economic value (Quille *et al*., 2023).

The simulation study only assessed five scenarios to provide solution to the research problem and address the quality, safety, shelf-life, and financial concerns faced by beef manufacturers at present times. The next chapter discusses the conclusion, responses to the research questions and aims and objectives fulfilment. The commencing chapter also explains the contribution to academic knowledge and professional practice, limitations to research, recommendations, or future scope for potential works in the domain. It also includes the reflections and motivation of study and concludes with a chapter summary.

CHAPTER SIX: CONCLUSION, RESEARCH LIMITATIONS AND FUTURE DIRECTIONS

6.1 Conclusion

Sustainable beef production, maintenance of quality standards, meeting health and safety guidelines in beef processing are some of the significant challenges faced by beef manufacturers at present times. This study is in a focused domain of RPA adoption in beef supply chains to evaluate operational, employee-level, and financial efficiency levels through task automation in supply chain processes. Simulation is a technique and method which determines and evaluates process changes, tests innovative procedures and predict performance levels in a business system. Simulation allows exploration of 'what-if' scenarios and questions using a virtual environment and helps to detect bottlenecks in information, material, and product flows. It further provides an insight on process delivery and performance levels and allows testing of complex business system such as the beef supply chains to address issues or challenges (E-Fatima *et al*., 2022; E-Fatima *et al*., 2023). In this respective research, simulation method was used as a scenario testing tool or technique for investigation and identification of the potential risks in RPA adoption. Moreover, this research also evaluated the impact of RPA adoption and integration in beef supply chains. The study adopted DES simulation technique to map the significant beef supply chain stages and model real-life business scenarios to observe the performance levels and progression with passing time. The discrete-event simulation method allowed to observe and assess the behaviours and performance of business processes in a business set up. Change of variables and resources allowed flexibility in this technique and helped to observe efficiency levels of business process at each event or stage. The DES method provides the opportunity to model dynamic behaviour and uncertainties of a real business system (E-Fatima *et al*., 2023; Ma *et al*., 2023).

The beef supply chain strategy in this simulation study aimed to assess both operational and financial efficiency across predefined scenarios. The process model developed for this research included various supply chain stages, closely replicating the phases encountered in real-life beef supply chains. To achieve this, the study employed a 'what-if' scenario analysis approach, leveraging process simulations to yield robust results and insights regarding the efficiency of the beef supply chain. The process model was designed to reflect the actual stages of the beef supply chain, from farm feeding to retail distribution to the end consumer stage. The study used 'what-if' scenario analysis to explore different conditions and configurations within the beef supply chain. This method allowed the researcher to predict the outcomes of various strategic decisions and operational changes. The simulations incorporated stochastic variables to account for the inherent uncertainties and variability within the supply chain. Each simulation run evaluated the efficiency of the beef supply chain using a set of predefined scenarios. The simulations provided detailed insights into how different configurations and resource allocations affected performance and efficiency of the beef supply chain. The results from the simulations were measured against specific KPIs. These KPIs served as crucial metrics for assessing the operational and financial efficiency of the beef supply chain. Moreover, the simulations highlighted how different strategies impacted the speed and reliability of the supply chain. For instance, the integration of RPA was shown to enhance efficiency by reducing processing times and error rates in some scenarios. Furthermore, financial implications were also examined, demonstrating how different resource allocations (e.g., human labour versus automation) affected overall costs in scenarios which used cost-related aspects as parameter. The comprehensive simulation study, with its robust process model and detailed scenario analysis, offered a clear understanding of the efficiency levels across various beef supply chain configurations. By evaluating KPIs in each scenario, the study provided actionable insights for enhancing the operational and financial efficiency of the beef supply chain. The scenario analysis also highlighted how RPA integration proved to be beneficial to produce sustainable beef.

To provide an overview on the simulation results, the 'what-if' scenarios were assessed from a sustainability perspective to evaluate the potential of RPA in task automation and process excellence. A business process model comprising of significant stages of beef supply chain was formed in this research. The process model used different scenarios based on various parameters that influence RPA adoption in beef supply chains. Simulation to the process model allowed testing of five scenarios which used different research parameters such as beef quality, safety, shelf-life and financial or cost-related aspects, as a basis for simulation using the Simul8 software. Process simulation allowed identification of main bottlenecks in the adoption of RPA. The scenarios were tested and assessed from sustainability lenses to observe the operational, employee, and financial performance of business processes. The scenarios were tested to evaluate the supply chain efficiency with and without the integration of RPA in beef supply chains. Scenario testing and process simulation allowed risk detection and identification in advance using a virtual environment. Simulation approach provides opportunities for beef manufacturers to adopt RPA using the best approach and achieve sustainability in beef production. The scenarios were primarily designed based on different research parameters to test, evaluate and assess best approach and practice in RPA adoption within beef supply chains. Risk assessment and identification in advance further allows decision-makers to alleviate or reduce risks in real-world situations. The research not only tested the scenarios to depict the best route to RPA adoption but also assessed these from sustainability dimensions i.e., social, economic, and environmental in beef processing and manufacturing.

Through process simulation and optimisation, ***scenarios 1, 2 and 3*** were observed and analysed with respect to operational efficiency, quality, safety, and shelf-life, to make supply chains more sustainable through value-addition with successful adoption of RPA in beef supply chains. The scenarios 1, 2 and 3 were observed with respect to social and environmental value as discussed and tabulated in previous chapter in Table 5.7 through simulation analysis and results. The Table 5.7 depicts the sustainability assessment of scenarios 1, 2 and 3 using simulation results. According to the results, scenarios 2 and 3 successfully gained social and environmental value whereas scenario 1 faced supply chain complexities, bottlenecks, increased human error and high risks making is unable to meet sustainability goals. The ***scenarios 4 and 5*** were simulated and assessed to observe financial or economic performance along with evaluation on beef productivity and capacity in beef supply chain. Scenarios 4 and 5 provided insights on the costs associated at each supply chain stage with respect to resource inputs (human workforce and RPA) being used. The scenarios were simulated to evaluate the business viability, costs, productivity levels and financial efficiency through process testing in beef supply chain. The scenarios 4 and 5 testing and simulation analysis also provide income statement report generated by Simul8 software to observe profit or loss account experienced through process simulation in beef supply chain. The respective scenarios were also tested to observe environmental impact with and without the adoption of RPA considering the financial aspects in beef supply chains. The scenarios 4 and 5 were observed and assessed with regards to social, economic, and environmental value as explained in detail in Table 5.8 in the previous chapter. The scenarios were assessed from sustainability perspective to examine the impact of RPA and determine its potential to speed up supply chain processes. The Table 5.8 depict and illustrate that scenario 5 successfully met sustainability goals and standards and achieved social, economic, and environmental value in comparison to scenario 4. In scenario 4, the supply chain was unable to achieve sustainability criterions due to manual-centric processes and therefore, it experienced poor financial and operational performance and high environmental impact on the surroundings. It is significant to highlight that RPA has brought visible changes to the work environment as it replaces the human workforce with software bots to do repetitive and boring tasks. However, this motivates employees to concentrate on skilled-based, talent-oriented jobs which require managerial and decision-making skills. This opens new job opportunities for the human workforce who can enjoy and focus on meaningful tasks in beef supply chains. RPA accuracy and full adoption in beef supply chains can also resolve problems such as a shortage of the workforce and create sustainable value to achieve competitive advantage (Kosonen and Lappi, 2020; Zhu and Kanjanamekanant, 2023).

Digital transformation such as RPA paves way for green and sustainable production systems, value addition and meeting sustainability dimensions in beef sector. RPA promising advantages create sustainable value in beef supply chains and makes the business processes more viable, profitable, and resilient. RPA facilitates beef processing and manufacturing and allows higher production levels, enhanced system performance and smooth work-flow management system. The emerging technology has proved to be a sustainability driver and tool within the beef sector and provides opportunity to solve complex business problems through automating processes. RPA work potential streamlines business processes, reduces human error and intervention, and allows beef supply chains to achieve sustainability goals and agendas through robust adoption process.

The study has offered insights related to RPA positive impact on beef supply chains and its potential to improve supply chain processes. The simulation findings identified the main hinderances and risks in RPA adoption. The commencing sections shed light on how the research questions are answered and the objectives are met. The contributions to academic knowledge and professional practice are also discussed in further sections. The limitations to research and future scope in the domain are also discussed and explained in this chapter. Lastly, the chapter is concluded with a summary.

6.2 The responses to the research questions

The research used various parameters extracted from secondary data and information relevant to RPA adoption in beef supply chains. Availability of secondary data and information allowed selection of significant parameters that influence RPA implementation in beef supply chains. The research parameters for scenario analysis were beef quality, safety, shelf-life and financial or cost-related aspects. These parameters play a vital role in the effective functioning of beef supply chains and in RPA adoption process. Therefore, the parameters or factors were used in the development and testing of 'what-if' scenarios for simulation and optimisation of beef supply chain. The study adopted a simulation method and tested various scenarios using a business process model for the detection of main bottlenecks in RPA adoption and for evaluation of supply chain performance through process automation. Using a simulation-based approach and through scenario analysis, the researcher provide practical solutions to the stakeholders and decision-makers in beef industry who strive to adopt RPA successfully in their business environments. Considering the research questions of this study, the following are the responses to them:

1. What is the role and impact of RPA adoption in UK beef supply chains from sustainability aspect?

To investigate the role and impact of RPA in beef processing and manufacturing, the study developed five scenarios which used different research parameters for simulation analysis. The research used a simulation-based approach to examine and observe the influence of RPA within beef supply chains. Through process simulation and scenario analysis it was observed that the supply chain performance was poor and increased queuing time and bottlenecks were detected in scenarios which used humans as the only resource input. The simulation results evaluated that in scenarios where RPA was integrated and worked alongside humans, the supply chain had operational, employee and financial efficiency. Therefore, scenarios which used RPA adoption to automate tasks observed a more resilient and fast-paced supply chain system with less bottlenecks and reduces risks. The beef productivity, quality, safety, and shelf-life were improved with RPA adoption and supply chain gained social, economic and environmental value in scenarios which implemented RPA for process excellence. Therefore, through analysation of different scenarios it was observed that RPA had a positive impact on beef supply chains and task automation also resulted in sustainable beef production at low operational costs. It was also found through scenario analysis that implementation of RPA had less environmental impact due to sustainable beef production, whereas, scenarios where supply chains were manually driven, the environmental impact was very high which led to low quality and reduced shelf-life in beef production.

2. What are the potential risks in the adoption of RPA and how can these be avoided or eliminated within the UK beef supply chains to create sustainable value?

This research tested and analysed 'what-if' scenarios based on different research parameters for the identification of risks and bottlenecks in RPA adoption. Simulation approach was employed to test the scenarios and the simulation to the process model detected the main bottlenecks or risks in different scenarios. The simulation results observed the potential risks through simulated models, KPI values, Measure of Risk and Error Plots, Income Statement Reports and Carbon Emissions Reports. Process simulation allowed detection of risks and main bottlenecks at different supply chain stages in predefined scenarios. According to the scenario analysis, scenarios that relied exclusively on human labour to perform tasks experienced a range of issues that significantly impacted both operational and financial efficiency. These challenges led to a sluggish supply chain and introduced various risks including high queuing size and times, low beef capacity and productivity, reduced shelf-life, high processing costs, and high environmental impact. Human labour tends to be slower and more prone to variability compared to automated processes. Tasks that require precision and consistency often experience delays due to the limited pace at which humans can work. Therefore, in manual centric supply chain where humans were the only resource input, the scenario experienced increased risks. This also resulted in long queues at various stages of the supply chain. High queuing sizes and times led to bottlenecks, where the flow of products was hindered, causing further delays down the line in manually driven scenarios. Moreover, human workers are constrained by physical and cognitive limitations, which can lead to reduced throughput and productivity. Tasks that could be performed more efficiently by machines take longer and are subject to errors. Hence, in scenarios which only employed human workforce, the overall capacity of the supply chain to process beef was lower. Reduced productivity translated to fewer units of beef being processed and prepared for market, which impacted supply levels and led to missed opportunities for sales. The slower pace and increased error rate of human labour also resulted in delays that affected the freshness of the beef. Extended handling times and potential contamination risks associated with human involvement reduced the shelf-life of beef products in scenarios which were solely reliant on human workers. Also, in scenarios where humans performed tasks without the integration of RPA, the supply chain utilised more time, energy and efforts leading to low financial efficiency. By identifying these risks, the scenario analysis underscores the need for strategic interventions, such as the adoption of automation, to enhance the efficiency and resilience of the supply chain. Scenarios which were human-intensive required more human handling, which increased the consumption of time, costs, and energy leading to larger carbon footprint and greater environmental impact in beef production. On the contrary, the simulation results predict that scenarios which implemented RPA for process automation had lesser risks and errors due to fast-paced and resilient supply chain, and higher efficiency levels. RPA adoption in scenarios proved to be beneficial as automation not only improved work-flow management system but also produced quality and sustainable beef for human consumption. Automation also ensured a resilient supply chain system with higher capacity and productivity, improved shelf-life, and low operational costs. To summarise, the simulation approach used a virtual environment to determine and identify the potential risks in RPA adoption. The study provides critical insights on the sustainability advantages of RPA implementation and supports decision-makers in the beef business to adopt RPA efficiently and effectively. The study's findings offer substantial support for beef manufacturers in adopting RPA by identifying and addressing potential risks in advance, ensuring a robust and successful implementation process. Automated processes are typically more precise, leading to less waste of raw materials and finished products. This contributes to sustainability goals by minimising the amount of waste generated. The study outlines best practices for RPA implementation, helping beef manufacturers to follow a structured and strategic approach. This includes planning, risk assessment, integration, and continuous monitoring. The scenario analysis offers valuable guidance to managers and stakeholders in the beef sector, helping them to take the best route towards RPA implementation and realise its sustainability and efficiency benefits.

6.3 Achievement of research aim and objectives

The following research objectives have been met in relation to the study aim which focused on the investigation and identification of potential risks in RPA adoption within beef supply chains.

a. The role of RPA within UK beef supply chains from sustainability aspects

The simulation-based study used various parameters that influenced the implementation of RPA in beef supply chains. The research used simulation method and discrete-event simulation technique to form a business process model for ‘what-if’ scenario analysis. The parameters were used as a basis for scenario development and analysation. The role of RPA was evaluated through simulation approach where scenarios were tested and evaluated to observe supply chain efficiency and performance. RPA was integrated and adopted in different 'what-if' scenarios as a resource input and the simulation results to these scenarios depicted that RPA adoption improved operational, employee and financial efficiency of beef supply chain. It was also observed that RPA played a significant and important role in improving process delivery, beef quality, safety, shelf-life. It was also assessed that RPA had a positive role in reducing costs resulting in profitable supply chain systems. RPA implementation also led to reduced human error and risks and low environmental impact was observed through automation. The simulation results for 'what-if' scenario analysis were discussed in detail in previous chapters from the aspect of RPA's positive role in value addition and meeting sustainability goals in beef production.

b. The impact of RPA adoption in UK beef supply chains, focusing on its role from a sustainability perspective and broader environmental aspects

For this study, the impact of RPA adoption was determined from the aspect of sustainability through simulation of different pre-defined scenarios where RPA was integrated for task automation. The scenarios were simulated and run to evaluate and observe RPA's potential for process excellence and value addition. The testing of 'what-if' scenarios provided simulation results which were also assessed from the lens of sustainability. The simulation findings for each scenario were examined to observe how each scenario performed in gaining social, environmental, and economic value. The simulation results also generated income statement reports, carbon emissions reports, KPI values, MORE plots which showed the performance of beef supply chain in each simulated scenario. A sustainability assessment of the scenarios evaluated that those scenarios where RPA was implemented had achieved sustainable value, while scenarios where supply chain was manual-centric did not.

c. The potential risks in the adoption process of RPA within UK beef supply chains

The findings of the study investigated and highlighted the potential risks in RPA adoption through application of simulation method. 'What-if' scenario analysis provided simulation results for the scenarios and the main bottlenecks, queuing times and risks were observed through process simulation. The potential risks to RPA adoption were also evident in the simulation results which produced simulated or optimised process model, Measure of Risk and Error Plots, KPI values. These results depicted the risks in the supply chain, queuing times, delays, average time taken for beef processing and reaching the end consumer. Therefore, this research critically analysed the potential risks in RPA adoption through simulation of different scenarios.

d. Providing recommendations to the UK beef sector to effectively adopt RPA to achieve sustainability objectives

This objective was fulfilled by critical investigation and testing of assumed scenarios which were assessed to highlight the risks or potential risks in RPA adoption. The simulation results provided in previous chapters illustrated and discussed the simulation results where scenarios were tested, and main bottlenecks were identified in the beef supply chain. Moreover, identification of potential risks to RPA adoption using a virtual environment, provides solution to beef manufacturers who aim to adopt RPA successfully. Additionally, this research proposes a standard business process model to the UK beef sector; the business model is generalised for use in practical or real-life scenarios and can be utilised by practitioners according to their working environments and process needs. Using the study findings, managers gain insight into RPA adoption costs and can conduct an in-depth cost analysis, plan effectively, remove or alleviate risks in advance, and use the best approach for RPA deployment to achieve sustainability.

6.4 Contributions to academic knowledge and professional practice

This research provides understanding of the role and impact of RPA in beef supply chains. The study also investigated and identified the main risks in RPA adoption. Prior studies have addressed the popularity, need for and importance of RPA in business processes (Axmann and Harmoko, 2020). However, the existing literature lacks knowledge and information regarding the role and impact of RPA in beef sector. Also, present studies lack attention and assessment of the potential risks in the adoption of RPA within beef supply chains. The study contributes to academic knowledge by providing an enhanced understanding of the role and impact of RPA in beef processing and manufacturing through simulation-based approach and scenario testing. The study tested different scenarios based on various important parameters to produce new information and knowledge related to RPA implementation in beef supply chains. The research findings add to scientific knowledge and literature by investigation and identification of the potential risks in the adoption process of RPA in beef supply chains. The study findings also contribute to theoretical aspects and provide decision-makers with knowledge to eliminate or prevent potential risks in advance, therefore accelerating the adoption of RPA. Previous research also lacks information and literature related to the sustainability perspective of RPA implementation in beef supply chains. In this research, supply chain performance was analysed in each scenario from social, environmental, and economic aspect. Hence, the study findings add to scientific knowledge by highlighting RPA's social, economic, and environmental advantages and potential for profitability and long-term business viability by emphasising its potential for process improvement.

The research contributes to professional practice as the findings provide practical solutions to beef manufacturers who struggle to adopt RPA with full potential and gain its maximised services. The study proposes a generic business process model to the beef supply chains and beef manufacturers for adoption and this model can be standardised for use within business organisations in real-life scenarios. The business process model is not complex thus making its implementation easier and simpler for beef supply chains as per their own circumstances. The generic process model can be modified or utilised according to the individual business needs and requirements of organisations. The process model is a standard model which can be adopted by beef supply chains to enhance their operational, employee, and financial efficiency through efficient and smooth RPA adoption. The simulation to the process model also highlights and detects the potential risks in RPA adoption and the risks can be potentially avoided in real-life situations. RPA successful adoption aids beef supply chains to achieve operational, financial, and strategic goals whilst reducing cost and quality concerns regarding beef production. The process model further provides insights on the costs associated with supply chain processes and RPA adoption and provides the opportunity to decision-makers and managers, who constantly face financial challenges, to conduct a thorough cost-benefit analysis. Moreover, the use and implementation of process model provides a strategic approach to implement RPA with greater ease and accuracy. Systematic adoption of the revolutionary technology increases quality beef production and improves beef safety and shelf-life through automation of repetitive tasks. Therefore, the utilisation of the process model can help and aid in resolving practical business problems associated with the implementation of RPA in beef supply chains and support stakeholders in beef sector to plan more efficiently for effective RPA adoption process. The process model can be used by business owners to adopt RPA efficiently and overcome financial and operational challenges through identification of potential risks in advance. RPA successful adoption through removal of risks allows organisations to add value to their business processes, achieve sustainability and gain competitive advantage through sustainable beef production. RPA robust adoption also allows beef supply chains to gain social, economic, and environmental value. The findings of the study are significant as it helps managers and stakeholders in practical scenarios to implement RPA positively and successfully and reduce social, economic, and environmental challenges concerning beef production.

6.5 The limitations to present research

This study was in a specific domain and therefore had some limitations. The study was limited to RPA application in beef supply chains; other food supply chains need to be investigated separately to assess the use of RPA for process excellence. This research was limited to and focused only on the application of RPA as a tool for process excellence in beef supply chains; integration of other technologies with RPA needs critical evaluation in future for intelligent process automation in beef sector. This research was limited to the use of one simulation software i.e., Simul8 for scenario analysis and works in future could focus on other simulation software for producing results. The study used only one modelling type or technique which is discrete-event simulation for conducting this research; other modelling techniques could be used in future works to generate simulation results. Moreover, this study concentrated on four research parameters as the basis for scenario development, testing and analysation that are beef quality, beef safety, shelf-life, and financial aspects. Research in the future could potentially use other simulation modelling tools or techniques to explore more scenarios based on other research parameters that have not been explored in this study. Another research limitation was the availability of less data for simulation of the process model for different scenarios as the study is in a specific domain and direction; hence, this was also seen as a limitation to this respective research. However, this limitation was addressed amicably and promptly through development, analysation and testing of various scenarios based on different research parameters to gain simulation results for each scenario and this has been discussed and explained before in detail in the previous chapters. Simulation studies entail inherent risks, including concerns about the model's adaptability to rapidly evolving work environments, challenges in implementation, accurately assessing work speeds, and ensuring organisational-level adoption. Resistance from managers or stakeholders further compounds these risks. These potential risks can introduce biases, as observed in this study's limitations. However, to address these challenges, the researcher prioritised rigor and transparency throughout the simulation process. The study also developed a simplistic, generic model, facilitating easier adoption for beef manufacturers in the business. The methodology and limitations of this research were clearly documented for robustness of the simulation study. The study relied on secondary data for simulation purposes using discrete event modelling, which posed a limitation as it did not involve primary data collection. This absence of real-data collection may have impacted result generation within the domain. Validation of results was also constrained due to the utilisation of single modelling technique; however, this limitation was addressed by testing various assumed scenarios for simulation purpose. Furthermore, the study was constrained by its focus on only four significant parameters for simulating scenarios, potentially limiting the generalisability of findings within the UK beef sector. Future research could address this limitation by exploring additional parameters to better understand and tackle sustainability challenges within the sector.

6.6 Future Scope in Research

There is significant scope for future research in this field of study. Future works in the field could potentially focus on the development of other simulation models based on other factors or parameters, such as logistics, RPA assistance, technical expertise, RPA architecture and design, RPA governance and monitoring etc., that influence the adoption of RPA in business environments. Future orientations could consider developing more scenarios for process simulation based on other factors or parameters to improve adoption process of RPA. This study contributes to a specific field and focuses on beef supply chains, and advancements in work could also consider other food or meat supply chains that could also benefit from sustainability-oriented innovations such as the RPA technology for process acceleration and accuracy. Future studies could also potentially evaluate other socio-economic benefits through advanced simulation testing and analysation considering the organisational factors impacting the adoption of RPA. Future studies could concentrate on simulation models to provide further insight and additional methods to tackle the environmental hazards and emissions resulting from beef production using RPA facilitations and opportunities. Other modelling techniques and simulation software such as AnyLogic, MATLAB, and SimScale could be used for model development, scenario analysis and sustainability assessment to observe different approaches to RPA adoption and to create sustainable value. Currently, there are no thorough evaluations on the integration of RPA with AI assessing intelligent process automation in beef supply chains, and future works could focus on this domain to improve supply chain processes. Moreover, future approaches in this field could explore contextual factors, such as managerial, individual, and organisational parameters, in the adoption of RPA. There are also no extensive studies on suitable processes for automation; hence, future works could critically analyse automation suitability according to organisational set up and explore ways to achieve sustainable value and a competitive advantage.

6.7 Reflections and motivation in conducting this research

This PhD research has been conducted out of sheer interest and curiosity in the domain of business management and technological advancements like RPA that has emerged as a sustainable business solution to complex business systems such as the beef supply chains. The exploration towards how technology plays a vital role in bringing sustainability to challenging business systems, began after completion of my master's degree in science – Project Management. The idea of technological innovations such as the emerging RPA technology occurred to me because of the business attention, focus and need to adopt such solutions in supply chain systems to create sustainability. Businesses require technological adoptions and innovative business solutions in this era of digitalisation and modernization due to competitive and fast-paced markets with sustainability agendas. The inspiration towards this research project was to critically assess and understand the impact of technological advancements such as RPA and the opportunities it brings to supply chain systems with respect to sustainability. The research also focused on the potential risks to RPA adoption in beef supply chains and simulation method was adopted to identify the potential risks in RPA implementation in beef supply chains. The research was also explored and investigated from the perspective of sustainability criterions and how innovations like RPA could create sustainable value in beef supply chains. The researcher was motivated to explore and assess the role and impact of RPA on beef supply chains and identify the potential risks in its adoption process so that beef manufacturers can enjoy its maximised potential and benefits. As a result, the researcher explored and studied secondary data and information relevant to beef supply chains, dynamics and challenges of beef sector, RPA adoption process, sustainability criterions and RPA promising advantages to complex business systems. The doctoral journey comprised on the thorough development and working on the literature review, collection of statistical data and information relevant to RPA and beef supply chains using secondary sources, formation of a business process model and analysation of data using 'what-if' scenarios for process simulation to generate simulation results. The data analysis and simulation results were then assessed from a sustainability perspective to observe the operational, financial, and employee efficiency with and without the adoption of RPA in beef supply chains.

Reflecting on the PhD journey, it was an incredible experience though it had some challenges as well. During the PhD, the researcher also published two journal articles as part of the PhD work in the ***"Journal of Logistics"*** and ***"Journal of Sustainability"*** at the MDPI and the peer-review process of the submissions gave a sense of confidence on the scientific research done in the specific domain. The researcher also felt excited about the contribution to academic research and science in the field of sustainability and automation within beef supply chains through the publishing of two journal articles. To further emphasise on the research journey, the data collection phase had been complicated and challenging due to the less availability of data in this specific field; however, development and analysation of different scenarios based on various research parameters helped in generating simulation-based results through 'what-if' scenario analysis using Simul8 software. The researcher really appreciates and values the overall PhD journey as a significant learning process which has enhanced the overall vision and broaden the knowledge horizon in the domain of research and literature. The researcher aimed to provide real-life, practical solution to the beef sector for robust RPA adoption through researching in this domain and has proposed a business process model which can be generalised for use within beef supply chains according to businesses own desires and needs. The proposed process model can support managerial decision-making related to best RPA adoption approach, cost analysis and risk identification in various beef supply chain stages. This is a significantly important study in the domain of process automation as it investigated how software bots' integration with human workforce speeds up supply chain processes and help beef supply chains to meet sustainability standards in beef production.

6.8 Chapter summary

This study thoroughly explores the implications of RPA on sustainability within the UK beef supply chains, identifying risks to its adoption. Utilising a simulation-based approach, the research conducts 'what-if' scenario analyses grounded in significant parameters. These parameters serve as the foundation for scenario development and process simulation, facilitated by a standard and generic business process model. Implemented with Simul8 simulation software, this model offers a practical solution for beef manufacturers, adaptable to their specific needs and circumstances. Key parameters such as beef quality, safety, shelf-life, and cost considerations are central to the simulation research. By examining these parameters, different scenarios are constructed and evaluated to understand RPA's potential impact on the beef supply chain. The assessment extends beyond operational and financial performance to include sustainability dimensions, encompassing social, economic, and environmental factors. Simulation results allow for a comprehensive evaluation of the supply chain, highlighting operational efficiencies, beef quality, safety measures, production levels, and shelf-life improvements. By simulating various scenarios, the research identifies bottlenecks and risks across different stages of the beef supply chain, aiding in risk mitigation strategies and decision-making processes. Through scenario analyses, KPI values, MORE Plots, Income Statement Reports, Carbon Emissions Reports, and other metrics are generated to assess the financial performance, environmental impact, and operational efficiency of the beef supply chain under different conditions. The study offers a generic business process model tailored to the beef sector, empowering stakeholders, and decision-makers to navigate RPA adoption with confidence. This model provides a roadmap for RPA implementation, allowing for customisation according to individual business requirements. Importantly, the research underscores the significance of RPA adoption in enhancing sustainability within beef production. By integrating social, economic, and environmental considerations, decision-makers can align RPA implementation with broader sustainability goals, gaining a competitive advantage in the process. In conclusion, this research contributes valuable insights to academia and practitioners in the beef industry, offering a holistic perspective on RPA adoption and its implications for sustainability. By leveraging simulation methods and a robust business process model, stakeholders can conduct thorough cost analyses and plan effectively for RPA implementation. Ultimately, successful RPA adoption promises to enhance financial, operational, and employee efficiency within beef supply chains while enabling the fulfilment of sustainability objectives and corporate social responsibility mandates.

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APPENDIX

RESEARCH DISSEMINATION

The following papers are based on the doctoral research presented in this respective thesis. These two papers were published as part of the PhD work undertaken during the doctoral journey. The research papers went through a rigorous peer reviewing process after which these were published online. The research papers have been published in "***Sustainability MDPI"*** and "***Logistics MDPI"***.

Published Journal Articles

- E-Fatima, K., Khandan, R., Hosseinian-Far, A. and Sarwar, D. (2023) The Adoption of Robotic Process Automation Considering Financial Aspects in Beef Supply Chains: An Approach towards Sustainability, *Sustainability*. **15**(9), p.7236.

- E-Fatima, K., Khandan, R., Hosseinian-Far, A., Sarwar, D. and Ahmed, H.F. (2022) Adoption and Influence of Robotic Process Automation in Beef Supply Chains, *Logistics*. **6**(3), p. 48.

Poster Presentation

- E-Fatima, K. (2021) 'Impact of technological advancements on food supply chains.' Poster competition, The University of Northampton.