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TOWARDS DIGITALISATION AND THE MITIGATION OF SUPPLY CHAIN RISKS IN THE PHARMACEUTICAL INDUSTRY IN ZIMBABWE.

RESEARCH BY

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Dedication

This dissertation is a tribute to my Lord and Saviour, Jesus Christ, for granting me the gift of life and the opportunity to complete my studies. Secondly, I dedicate this dissertation to my family, who provided me with encouragement and support throughout my academic journey.

Declaration

I, Nkulumandla Mathe, student registration number B241493A, hereby declare that the work presented here is entirely original with the exception of the citations that I have made, and that I have not submitted it to any university for the purpose of receiving a degree.

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Abstract

This study was driven by the limited digitalisation of the pharmaceutical sector in Zimbabwe that is characterised by its inclination towards legacy systems. The study was structured around four objectives that aimed at exploring the effect of artificial intelligence systems, machine learning systems, blockchain technology and dynamic pricing on the ability of the pharmaceutical sector in Zimbabwe to lower supply chain risks. The study applied the diffusion of innovations and the UTAUT theory in framing the theoretical focus relating to the intensity of technology infusion in organisations. The research methodology was premised on a quantitative approach culminating in the survey method in data collection through a closed-ended and standardised questionnaire distributed across supply chain partners in the pharmaceutical sector in Zimbabwe. Research results suggested that emphasis was being placed on legacy systems in reducing supply chain risks in the pharmaceutical sector in Zimbabwe. Resultantly, the pharmaceutical sector in Zimbabwe is failing to deal with the threats to supply chain sustainability posed by the proliferation of contraband and counterfeit drugs that are disrupting the sustainability of the local pharmaceutical supply chain. The weak integration of artificial intelligence systems in the pharmaceutical sector in Zimbabwe reduces its conceptual appeal towards limiting supply chain risks in the sector. Otherwise, leveraging machine learning systems, blockchain technology, and automated dynamic pricing has been associated with a reduction in the supply chain risks. The main conclusion was that the pharmaceutical sector in Zimbabwe has to leverage digitalisation to counter the disruptions caused by counterfeit drugs along the supply chain.

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List of Acronyms and Abbreviations

API	Application Programming Interface
AI	Artificial Intelligence (AI),
COVID-19	Coronavirus disease of 2019
ERP	Enterprise Resources Planning
EGP	Electronic Government Procurement system,
Industry 4.0	Fourth Industrial Revolution
IoT	Internet of things
UTAUT	Unified Theory of Acceptance and Use of Technology

CHAPTER 1

INTRODUCTION

Introduction

This chapter focuses on the study's background, specifically examining the extent to which the pharmaceutical industry can leverage digitalisation through artificial intelligence systems to mitigate supply chain risk and optimise its performance. It incorporates the introduction, specifying the information relating to the link between digitalisation and supply chain risks, the problem statement, the formation of the research objectives, and the research hypothesis. These create the platform and parameters for the operationalisation of subsequent chapters in the dissertation.

1.2 Background of the study

Digitalisation in manufacturing is confined to adopting Industry 4.0 to improve supply chain resilience and visibility (Jerome, Sonwaney & Arunkumar, 2023). Digitalising supply chains using artificial intelligence systems involves simulating human intelligence through the application of technology and machines to carry out routine tasks, such as machine learning-based decision-making, speech recognition, and autonomous problem-solving with little to no human intervention (AL-Dosari Fetais, & Kucukvar, 2024). Supply chain risks are finding, assessing, and choosing suppliers anticipated to maximise cooperation, quality, and cost to support a company’s strategic success (Mirzajani, Nikoofal & Zolfaghari, 2024). This research aims to create a framework for utilising artificial intelligence to enhance the capacity of companies in the pharmaceutical sector to optimise the quality, direction, and supplier collaboration of their products. The pharmaceutical industry faces capacity constraints of less than 50% in 2024, less than 8% of Zimbabwe's national gross domestic product (Confederation of Zimbabwe Industry, 2024).

Digitalising supply chains is moving along with trends in sustainability. Several industries are aligning their operations through digitalisation, which involves adopting and applying requisite technologies to optimise functional performance. Digitalisation, which integrates digital technologies like the Internet of Things (Iot), blockchain, and Artificial Intelligence (AI), can enhance supply chain visibility, traceability, and efficiency (Zhou, Wang & Yang, 2023).

Digitalising the supply chain and its influence on promoting its resilience has been debated within the academic community. Incorporating technology in business in general and along supply chains in particular has presented significant paradigm shifts in mitigating supply chain risks. The disruptions caused by geopolitical and public health incidents, such as the COVID-19 pandemic, have contributed to the need to enhance the performance of the supply chain by limiting the adverse effects associated with supply chain risks.

Silva, Araujo and Marques (2020) has proven that the pharmaceutical supply chain is vulnerable to supply chain risks due to stringent regulations, expectations to maintain high levels of product integrity, and the industry's global focus. Senna et al. (2024) highlighted that key supply chain risks facing the pharmaceutical industry relate to geopolitical instability, which includes tariffs and trade wars. These disruptions affect the supply and procurement of raw materials, and natural disasters and pandemics, such as the COVID-19 pandemic, which resulted in lockdowns that disrupted global logistics (Ivanov, Dolgui, Blackhurst & Cho, 2023).

Wang, Wang, Zhang and Zhu (2022) indicates that dependence on a limited number of suppliers has affected the efficacy of global pharmaceutical supply chains. Statistics indicate that 80% of API productions are mainly concentrated in China and India, which creates a sensitive dependency that can disrupt the pharmaceutical supply chain if there are constraints in the production in these two economies (Ramori, Cudney, Elrod & Antony *et al.*, 2021). It has been proven that the global pharmaceutical supply chain must also contend with some standard medicines and counterfeit drugs, mainly in developing nations with relatively weaker quality control mechanisms (Fang & Chen, 2022). Adhikari, Joshi and Bas (2023) indicates the presence of falsified oncology drugs that are penetrating the global supply chain, creating division and illegal packaging. Furthermore, the challenges prominently reported in literature on logistics and code supply chain constraints, especially in delivering temperature-sensitive products like vaccines, require strict temperature control between 2°C and 8°C. Constraints in remote areas affect the operationalisation of effective logistics (Neboh and Mbhele, 2021).

The focus on supply chain risks in the pharmaceutical supply chain is essential, given the strategic nature and contribution that the pharmaceutical industry makes towards public health (Neboh & Mbhele, 2021). There is a risk to patient safety if supply chain risks in the industry are not adequately managed. Hence, the failure to manage the disruptions along the pharmaceutical supply chain effectively can be life-threatening and harmful (Tseng, Ha, Lim, Wu & Iranmanesh, 2022). Moreover, the inability to put the mechanism of technology and digitalisation within the pharmaceutical supply chain can expose the industry to harmful counterfeit drugs that might impair public health (Ergun, Hopp & Keskinocak, 2023). The works of Al-Banna, Yaqot and Menezes (2023) stress that the pharmaceutical industry is subject to higher regulatory scrutiny, sensitivity, and risk when non-compliance attracts fines, drug recalls, and even pharmaceutical shutdowns. Moreover, the complexity of pharmaceutical global supply chain networks has significantly reduced the need to rely on single-source suppliers, which can expose the global pharmaceutical supply chain to fragility.

The pharmaceutical industry's supply chain risks are complex and globalised. However, the threat to public health has been more defined in developing economies that have yet to digitalise their pharmaceutical supply chains fully (Sawik & Sawik, 2024). These native economies are battling counterfeit drugs; the World Health Organisation estimates that 10% of the medicines distributed in low—to medium-income countries are fake (World Health Organisation, 2024). Reliance on traditional supply chains to resolve these challenges has proven ineffective and has more often contributed to inefficiency, exposing patient safety and leading to financial losses (Yang, Xie, Liu & Wang, 2023). From this perspective, African economies are exploring possibly incorporating digitalisation as a mitigation strategy in pharmaceutical supply chain disruptions.

Various digital technologies are incorporated into the pharmaceutical supply chain, such as using blockchain technology for transparency and ensuring that no counterfeit products pass through the supply chains (Shamsuzzoha, Marttila & Helo, 2023). However, these initiatives have been affected by the investments in adopting blockchain technology. Other challenges relate to the lack of competitiveness in applying blockchain technology in tracking drugs across the supply chain (Thakker, Rane & Narwane, 2024). In addition, artificial intelligence systems and the internet of things are being applied through smart sensors to track sensitive products like vaccines' temperature, location and humidity (Gligor, Davis-Sramek, Tan, Vitale, A., Russo, Golgeci & Wan*et*, 2022). Big data analytics and cloud computing are also used to improve supply chain visibility, regulatory compliance, and reporting through real-time collaboration with regulatory authorities. Machine learning and efficient intelligence have also proven effective in forecasting demand fluctuations, optimising logistics and reducing strategies (Okanlawon, Oyewobi & Jimoh, 2024).

Despite these benefits, current literature is focused on the operationalisation of digital technology within the Zimbabwean pharmaceutical sector. This leaves a knowledge gap on the possibility that digitalising the supply chain has mitigated supply chain risks within the Zimbabwean context.

Statement of the problem

The pharmaceutical industry in Zimbabwe faces several significant challenges that compromise medicines' quality, availability, storage and safety. Supply chain risks in the pharmaceutical industry have overwhelming consequences on public health. Despite the potential benefits of digitalisation, many pharmaceutical companies in Zimbabwe have been slow to adopt modern technologies. The reluctance may emanate from a lack of understanding of digital tools, fear of costs or inadequate infrastructure. As a result, the pharmaceutical industry continuously faces risks, including delays in the delivery of medicines and pharmaceuticals, a lack of transparency, poor inventory management, and being highly vulnerable to counterfeit drugs. Traditional supply chain management strategies have struggled to address such risks effectively. While more developed economies have adopted digitalisation, its implementation in Zimbabwe has remained limited. The study investigates how digitalisation can mitigate supply chain risks in the Zimbabwean pharmaceutical sector.

Research Objectives

The following objectives guided the study:

- To analyse the impact of artificial intelligence systems in reducing supply chain risks in the pharmaceuticals sector in Zimbabwe.
- To evaluate the impact of blockchain technology on reducing supply chain risks in the pharmaceutical sector in Zimbabwe.
- To assess the impact of machine learning-based decision-making on reducing supply chain risks in the pharmaceuticals sector in Zimbabwe.
- To analyse the impact of automated dynamic pricing on reducing supply chain risks in the pharmaceuticals sector in Zimbabwe.

Research questions

The following questions guided this study

- What is the impact of artificial intelligence systems on reducing supply chain risks in the pharmaceuticals sector in Zimbabwe?
- What is the impact of blockchain technology on reducing supply chain risks in the pharmaceutical sector in Zimbabwe?
- What is the impact of machine learning-based decision-making on reducing chain risks in the pharmaceuticals sector in Zimbabwe?
- How impact is automated dynamic pricing on reducing supply chain risks in the pharmaceuticals sector in Zimbabwe?

Statement of hypothesis

The following hypothesis oriented the study

H_1 Artificial intelligence systems have a positive impact on reducing supply chain risks in the pharmaceuticals sector in Zimbabwe

H_2 Blockchain technology has a positive impact on reducing the quality of supply chain risks in the pharmaceutical sector in Zimbabwe.

H_3 Machine learning-based decision-making positively reduces the efficiency of supply chain risks in the pharmaceutical sector in Zimbabwe.

H_4 Automated dynamic pricing has a positive impact on reducing supply chain risks in the pharmaceutical sector in Zimbabwe.

Significance of the study

This study contributes to the existing body of knowledge on supply chain management by providing insights into the benefits of digitalisation in Zimbabwe's pharmaceutical sector. The findings are helpful to various stakeholders, including:

Contribution to the body of knowledge

The research findings consolidate existing literature regarding digitalising supply chains to mitigate supply chain risks. These contributions emanate from the perspective of the pharmaceutical sector in Zimbabwe, which is distinguished by its regulation of minimum requirements.

Contribution to practitioners

Research results will enable pharmaceutical supply chain practitioners to appreciate the role of digitisation in reducing supply chain risk and improving supply chain transparency and information sharing.

Contributions to public procurement policy

This study is relevant because it consolidates the existing digitalisation of procurement in public sector organisations, which is characterised by implementing the eGP platform by the Procurement Regulatory Authority of Zimbabwe. The research results aim to contribute to the existing digitalisation framework in public procurements, which can be contextualised within the pharmaceutical supply chain in Zimbabwe.

Contributions to the pharmaceutical industry

The research on digitalising supply chains provides insightful information about how digitalisation can optimise the sourcing procedure, resulting in reduced costs, increased effectiveness, and better decision-making. The research benefits healthcare providers by ensuring improved access to quality medicines and minimising supply chain disruptions and counterfeit pharmaceuticals and medicines. The study assists industry stakeholders by helping them understand how digitalisation can enhance supply chain efficiency and minimise risks along the supply chain.

Contributions to the research fraternity

The study advances using digitalisation in supply chain risks, creating opportunities for further study. Businesses, procurement specialists, digitalisation developers, and academic institutions are important stakeholders. This research provides a foundation for understanding how digital technologies can enhance supply chain resilience and contribute to the existing literature on digitalisation in supply chain management.

Contributions to the university

The results can potentially yield significant benefits for multiple stakeholders by stimulating innovation, optimising operational effectiveness, and influencing strategic choices regarding sourcing procedures.

Assumptions of the study

This study is premised on the following assumptions:

i. Pharmaceutical companies in Zimbabwe have access to basic digital technologies, and stakeholders recognise the need for digitalisation.
ii. Implementation of digitalisation in Zimbabwe is feasible, and stakeholders are willing to adopt new digital solutions.
iii. The economic environment remains stable enough to allow for investment in digitalisation.
iv. The respondents provide accurate and honest information on the intersection between digitalisation and the mitigation of supply chain risk in the pharmaceutical industry in Zimbabwe.

Delimitations of the study

This research is focused on digitalising supply chains to lower supply chain risks.

Geographical delimitations

The study was geographically delimited to the pharmaceutical industry in Zimbabwe and not on other sectors, with particular emphasis on pharmaceutical firms located in Bulawayo Province, near the researcher.

Time delimitations

The study is focused on the supply chain risk that were encountered in the pharmaceutical industry as from the year 2020 to 2025. This presents the time frame as from the disruptions faced by the pharmaceutical industry during the COVID-19 period and the post-COVID-19 era.

Literature delimitations

Literature sources are delimited to peer-reviewed academic journals published over 5 years from January 2021 to June 2025. The study examined the role of digitalisation in mitigating supply chain risks, excluding other industries (examples of digitalisation tools are ERP systems, EGP system, data analytics, and supply chain management software) and their impact on supply chain risks. The study will consider key technologies, including blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI).

Limitations of the study

The primary drawback of this research is its quantitative methodological approach. This approach is based on the application of quantitative techniques in collecting and analysing data to generate valid and reliable research outcomes. The recruitment of research participants is done using probability sampling techniques. Despite these benefits, using the quantitative approach fails to gather the qualitative and subjective elements associated with the relief experiences of people who potentially use technology across the pharmaceutical supply chain. To counter this methodological anomaly, this research looked forward to increasing the size of the sample to enhance the representativeness of people from the diverse pharmaceutical sector in Zimbabwe.

Definition of terms

Blockchain technology: Decentralised digital ledger technology that records and stores transactions across a network of computers in a secure, transparent and tamper-proof manner (Ghobakhloo, Iranmanesh, Foroughi, Tseng, Nikbin & Khanfar, 2023).

Digitalisation: this involves the incorporation of digital technologies such as blockchain technologies, artificial intelligence systems, and big data analytics into everyday life to improve business processes (Brintrup, Kosasih, Schaffer, Zheng, Demirel & MacCarthy, 2024).

Internet of Things (IoT): A Network of interconnected devices that collect and exchange data (Rayes and Salam, 2019).

Pharmaceutical Industry: The sector involved in the research, development, production, and marketing of drugs and pharmaceuticals (Hong, Song, Lau & Zhao, 2025).

Pharmaceutical supply chain: The system that involves the production, procurement, storage and distribution of medicines and pharmaceuticals (Ivanov *et al.*, 2023).

Supply Chain Risks: Potential threats that can disrupt or negatively impact the flow of goods, services and information across the supply chain (Dolgui and Ivanov, 2021).

Organisation of the study

The research is structured into five chapters. The chair of the first chapter articulates the study's central problem; it is justified by a review of literature undertaken in a global, regional and local context. This literature provides the best information on the key variables specified in the study. Is there a hypothesis to reduce the extent of supply chain release in the pharmaceutical sector.

The second chapter articulates the theoretical, conceptual and empirical literature perspectives, which is essential in outlining the knowledge and research gaps that exist between the current study and existing literature.

Chapter 3 sets the tone for developing an appropriate research methodological framework that guides data collection and analysis. The chapter also specifies the research population, sampling strategy, and mechanisms for collecting and analysing data within the framework of acceptable research ethics.

Chapter 4 assumes the responsibility of presenting and analysing research findings related to the study's objectives. These findings are then compared with related existing studies on a similar topic.

Chapter 5 provides a comprehensive summary of the entire research, articulating the answers to research questions and new ideas that emerged from pursuing the research. It also proposes areas of future study which arose from undertaking this research.

Chapter Summary

The outgoing chapter justified the need to conduct research focusing on digitalisation and its influence on reducing supply chain risk within the pharmaceutical sector in Zimbabwe. This background to the study validates the proposition of the research problem, which determined the nature of research objectives and questions in the hypothesis statement. Other key elements in this chapter included the focus of the research through its geographical, time and literature delimitations, the significance of the study to different stakeholders and special interest groups, and research assumptions and limitations. The next chapter, which focuses on the literature review, is guided by the study's objectives.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review provides a detailed analysis of existing literature related to the concept of digitalisation of supply chains, aiming to appreciate the historical development of the concept and its reception within the pharmaceutical supply chains. The theory of diffusion of innovations and the unified theory of acceptance and use of technology guide the literature review. This review focuses on the application of artificial intelligence systems, the infusion of blockchain technology, machine learning systems, and supply chain automated dynamic pricing, which helps reduce the prevalence of supply chain risks. The chapter then presents the conceptual framework guiding the study and outlines the interrelationships among the variables under consideration. Finally, the empirical literature specifies previous studies on a related line of study to identify points of difference and areas of similarity.

2.2 Theoretical framework

The purpose of a theoretical framework is to explain existing theories that seek to articulate the relationship among research variables under consideration. Since this study is focused on digitalising the pharmaceutical supply chain, it was considered essential to incorporate the diffusion of innovations model and the unified theory of acceptance and use of technology. These are the most appropriate theoretical foundations that can help explain the extent of digitalisation of the pharmaceutical supply chain and mitigate supply chain disruptions. These two theories were selected to address the complementary elements related to technology adoption and use in a high-stakes and highly regulated sector.

Diffusion of innovations model

The diffusion of innovations model is credited to the works of Rogers (1962); the theory focuses on an industry-wide adoption of technology, explaining how digital technologies that incorporate the Internet of Things, artificial intelligence systems, machine learning systems, and blockchain technologies, amongst others, can be spread across different categories of supply chain partners (Bressler, Plumhoff, Hoey & Blesh, 2021). Literature indicates that adopting technologies rarely relies on the relative advantage, such as reduced counterfeit risks and enhanced traceability of supply chains (Nyama, Attatsi, Nyamah & Opoku, 2022). Other perspectives also highlight that the essence of the efficiency of technology is a result of the compatibility of technologies with existing legacy systems (Okanlawon, Oyewobi and Jimoh, 2024). Moreover, diffusion theories have also focused on the complexity of new technologies relating to their ease of integration with existing systems. Another point of view focuses on the trialability of technologies and the observability of measurable risk reduction (Singh & Chan, 2022)

The diffusion of innovations model depicts five adopted categories: innovators, early adopters, late early majority, late majority, and laggards (McHugh & Perrault, 2022). These can represent different partners across the supply chain concerning the ease with which they are prepared to adopt digitalisation of supply chains, which can help mitigate separation disruptions.

The key construct behind the diffusion of innovations model is the realisation that whenever a new invention is introduced in the market, only 2.5% of innovators are prepared to accept it readily (Burritt, Herzig, Schaltegger & Viere, 2019). Afterwards, about 13.5% of early adopters look forward to innovators showing them how technology can contribute to their organisational performance. (Leeuwis and Aarts, 2020). In this context, they look forward to realising digitalisation's contribution to mitigating supply chain risks so they can adopt the same technology. The adopter categories increase by 34% from the early majority until a peak is reached. When the technology is saturated in the market, the late majority and laggards adopt it (Okanlawon, Oyewobi and Jimoh, 2024).

The logical progression of adopter categories is indicative of the risk-averse contexts and the conservative nature of supply chain participants in accepting new technologies, where the rest of the market is looking forward to leading firms to adopt technology and identify demonstrable success before they can embrace the technology themselves. The essence of the diffusion of innovations model is its emphasis on communication channels that should align with the need for supply chain collaboration across fragmented supply chains (Zhou et al., 2024).

Despite the apparent benefits of adopting the diffusion of innovations model, some limitations are industrial relations and organisational contextual factors that incorporate employee resistance. The model assumes that technology adoption is equivalent to practical application, which might not be true in practice.

Unified theory of acceptance and use of technology.

This research also considered the potential contribution that can be attained by applying the concepts of the Unified Theory of Acceptance and Use of Technology, a user-centric adoption model centred on constructs such as performance expectancy, effort expectancy, social influence, and facilitating conditions (Johnson, 2020).

The essence of performance expectancy from the lens of the theory is that supply chain partners are prepared to digitalise their supply chain activities if they anticipate improvements in supply chain performance. These recognised benefits might include sharing information and reducing supply chain disruptions. The ability of a technology to demonstrate benefits relating to improved performance is one of the key driving forces behind adopting technologies across the Supply chain. Effort expectancy looks at the ease with which supply chain activities can be done due to adopting technology. For instance, blockchain technology applications across the supply chain have helped to increase supply chain transparency relating to sharing of information, which has expedited the quality of decision making by supply chain partners.

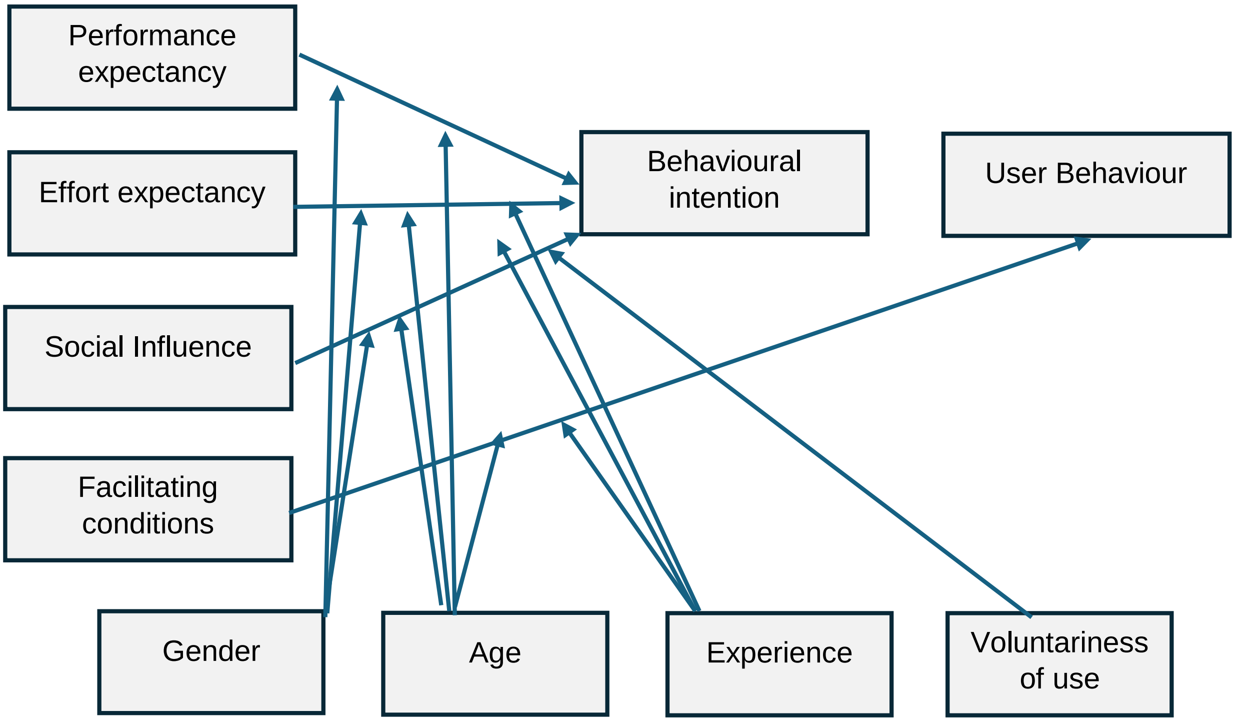


Figure 2.1: The UTAUT framework

Source: Abu-Al-Aish & Love (2013)

Social influence focus is on the acceptance of Technology across the supply chain is a function of its applications by other supply chain partners (Venkatesh, Morris, Davis & Davis, 2003; Johnson, 2020). In essence, the idea is that partners across the supply chain are prepared to adopt new technologies that might enhance their performance or reduce supply chain risks based on the benefits that other partners across the same supply chain have realised (Dangaiso, Jaravaza and Mukucha, 2024).This is particularly true when we consider adopting blockchain technologies for information sharing, which benefits if all partners across the supply chain have a similar platform for sharing information (Bhatnagr and Rajesh, 2023). Social influence, therefore, looks at the holistic benefits of technology adoption and digitalisation across supply chains, which can enhance the supply chain's competitiveness (Ashaduzzaman Jebarajakirthy, Das & Shankar, 2021).

Facilitating conditions look at organisational support, resource availability, and other enabling conditions that make it possible for supply chain partners to adopt technology and realise the benefits associated with technology adoption (Abbad, 2021). These might include the technology's user friendliness and its ability to expedite integration in collaboration across supply chain partners (Marhadi, Fathoni, Setiawan, Pratiwi, Hayati, Boros & Sudibyo, 2024).

Ultimately, the unified theory of acceptance and use of technology answers the operational effectiveness of supply chains relating to applying predictive analytics and identifying potential barriers that might undermine supply chain risk reduction (Kaur, Saini, Behl & Poonia 2024). However, the main limitation associated with the model is its predominant focus on the behaviour of individuals and not on the industry-level diffusion (McKinnon, 2024). Moreover, the model may undervalue external pressure like regulatory requirements that override individual perceptions.

In the final analysis, both models provided an indispensable holistic focus on the link between digitalising supply chains and the reduction of supply chain risk. The diffusion of innovations model articulates the approach to one digital solution diffused across the supply chain to create systemic risk reduction (Rinaldi, Di Bernardino, Cram-Martos & Pisan, 2022) On the other hand, the unified theory of technology acceptance and use provides assurance that technologies are embraced effectively and used by individuals within the organisation to realise the benefits of Technology adoption.

2.3 Digitalisation of supply chains

Digitalising supply chains has taken centre stage in the research literature. This comes from realising the potential benefits of incorporating technology with legacy systems to enhance supply chain efficiency performance. Several options have been proposed as potential solutions to digitalising supply chains. However, there appears to be a diversity of technological possibilities at the disposal of supply chain performance, which can be potentially incorporated to enhance the overall performance of supply chains. Literature indicates the proclivity of supply chains in adopting digitalisation and the options at the disposal of supply chains for the application of technology.

From the perspective of this research, the focus of digitalising supply chains is on applying artificial intelligence systems to reduce supply chain risks within the pharmaceutical supply chain. Attention is also given to the application and relevance of blockchain technologies, mission learning systems and automated dynamic pricing as they play a pivotal role in reducing the disruptions of the pharmaceutical supply chains. These technological aspects are discussed at length in the following section.

2.4 Supply chain risks

Supply chain risks focus on the disruptions that might potentially affect the smooth flow of supply chain activities (Hsu, Wu, Zhang & Chen, 2024). The trailer to put in place sound mechanisms of supply chain resilience if often exposed supply chains to vulnerabilities as a result of interconnected entities and processes that might potentially affect the production, distribution and consumption of pharmaceutical products (Zheng, Kong and Brintrup, 2023). The existence of salvation disruptions if an effect on threatening the quality commercial safety, availability and affordability of medicines which might obviously effect on public health and business continuity (Brintrup *et al.*, 2024). Supply chain risks look at the disruptions that might affect the smooth flow of information, goods and finances across the supply chain. These disruptions contribute to increased costs of goods, deteriorating quality, and failure to meet demands, leading to delays. Supply chain risks contribute to an increase in supply chain inefficiency. the inability to be resilient to environmental dynamics that include geopolitical factors, supplier rigidities, or even natural disasters.

Fatorachian & Pawar (2025) indicates that there are several categories of supply chain risks in migrating this sustainability to pharmaceutical supply chains. Some of these supply chain risks incorporate raw material shortages as a result of geopolitical instability in social regions. Logistical challenges to transportation delays which have affected the last mile logistical requirements (Risberg, 2023). Regulatory and compliance risks often affect the integrity of pharmaceutical supply chains. It has also been highlighted that the pharmaceuticals industry is a highly regulated sector which requires strict compliance with medical standards (Vakulenko Shams, Hellström & Hjort, 2019). Any disruptions from the effect of creating demand shocks that potentially disrupted a smooth flow of supply chain activities.

Zaid, Farooqi and Azmi (2025) indicates that the potential disruptions across medical supply chains are more defined, especially within the context of systems that do not make efficient use of advanced technologies in demand management. It has also been indicated that quality and safety risks oppose the special regard for the production and the marketing of counterfeit drugs that, in the future, the pharmaceutical supply chain will pull the public health threat (Shahsavari, Hussain and Sharma, 2025). These risks are prominently featured in supply chains that do not make use of blockchain technology to trace the origin of drugs.

Cybersecurity risks have also been noted in supply chains that do not have robust mechanisms of security, which have resulted in data breaches and tampering of clinical data (Sheehan, Murphy Kia & Kiely, 2021). Moreover, Brintrup *et al.* (2024) indicates that the prevalence of economic and geopolitical risks associated with trade restrictions and fluctuations of currencies negatively affects the procurement course in global pharmaceutical supply chains.

Hsu *et al.* (2024) stress that incorporating technology along the pharmaceutical supply chains has played the people's role in mitigating supply chain disruptions. Heim (2022) highlighted that digital transformation through using blockchain technology has helped pharmaceutical supply chains to become more transparent through demonstrating the traceability of drugs. Tiwari, Bidanda, Geunes, Fernandes & Dolgui (2024) agree that this has proven to be instrumental in combating this trade in counterfeit drugs. Moreover, the application of Internet of Things sensors has been instrumental in real-time temperature monitoring, especially for the cold supply chain (Fatorachian and Pawar, 2025).

Zaid, Farooqi and Azmi (2025) indicates that the application of artificial intelligence systems is significant in predicting supply chain disruptions due to demand spikes and climate risks. Ivanov *et al.* (2023) stress that machine learning approaches have promoted adopting flexible manufacturing through modular facilities for rapid scalability. Xiong, Wu and Yeung (2024) stress that ultimately, pharmaceutical supply chain risks are a complex phenomenon in a globalized world characterised by a strange mix of regulations and the provision of life-critical drugs. The most prominent threat to the sustainability of the pharmaceutical supply chain has been the prevalence of counterfeit drugs, especially in contexts that do not make prominent use of technology to detect and flag these drugs across the supply chain (Gruchmann, Elgazzar and Ali, 2023). This demands the implementation of proactive pharmaceutical supply chain risk management through technology adoption, diversification, and collaboration. These positives are proven to be essential in promoting supply chain resilience.

2.4.1 Artificial intelligence and supply chain risk mitigation

Artificial intelligence systems are technological innovations that reduce reliance on human interfaces by imitating human intelligence (Eaton, 2021). Artificial intelligence is popular mainly because of its precision and minimal errors when handling repetitive tasks. The notion of supply chain risks is attracting the research community's attention because of its disruptive effects on supply chain performance (Sundarakani, Manikas and Gunasekaran, 2024). This has sparked the need to develop a predictive approach to mitigate these supply chain risks through artificial intelligence algorithms that effectively expedite and efficiently monitor supply chain activities in real time to enhance performance (Shahidzadeh and Shokouhyar, 2022).

The popularity of artificial intelligence systems across the supply chain results from their ability to sift through vast amounts of data and make real-time decisions to produce original and accurate conclusions (Mandania and Oliveira, 2023). Intelligence systems are effectively applied in the pharmaceutical sector as they have proven evidence of the capacity to reduce the burden of human reasoning, imperatively managing supply chain risks. Related sentiments expressed by Karttunen, Lintukangas and Hallikas, (2023) highlight the predictive power of artificial intelligence in detecting fraudulent payments across the financial sector and leveraging artificial big data analytics.

The disruptions across the pharmaceutical supply chain caused at the height of the COVID-19 pandemic have also raised the need to develop an adaptive and predictive model of averting such disruptions through artificial intelligence-based systems (Rinaldi *et al.*, 2022). Enhance the responsiveness of the supply chains through leveraging algorithms to identify patterns in data sets and make appropriate decisions with minimum human intervention (Guida *et al.*, 2023a). Leveraging artificial intelligence systems is permanently featured in using machine learning capabilities to allow pharmaceutical supply chains to leverage historical data sets and make predictive analyses based on that data (Balasubramanian, Shukla, Islam, Upadhyay & Duong, 2023). The essence of artificial intelligence systems within the pharmaceutical sector has been the focus of attention regarding their capacity to predict consequences from a complex data set (Merhi & Harfouche, 2024). These systems' ability to leverage historical data has made them more favourable, especially in development supply chain contracts (Hirsch, Niemann and Swart, 2024).

Current research suggests that adopting artificial intelligence systems within the pharmaceutical sector is more prominent within developed economies than in developing economies (Oosthuizen, Botha, Robertson & Montecchi, 2021; Dauvergne, 2022; Guler, Kirshner and Vidgen, 2024). This can be explained by the diffusion of innovations model, where developed economy contexts and supply chains are more adaptive to new technologies and new inventions since they are used to them. Another dimension looks at the level of technological sophistication between developed and developing economies, which makes developed economies more suitable for adopting advanced technological innovations.

Kantasaard, Bekrar, Aitelcadi and Saliez (2019) works look at the context of technology integration and stipulate that it is more cost-effective to introduce artificial intelligence systems in an already technologically advanced supply chain than one that is less technologically advanced. This perspective points to the required level of investments needed for developing economies to keep pace with technological and capacity advancements (Culot, Podrecca & Nassimbeni, 2024). There are pharmaceutical supply chains for optimum performance.

The works of Brintrup et al. (2024) highlight that the complexity of algorithms required to keep additional intelligence for operations has reduced their conceptual appeal, especially in developing economic contexts, where there is a lack of expertise, which makes the benefits associated with artificial intelligence from reality. Related sentiments are expressed by the works of Allal-Chérif, Simón-Moya and Ballester (2021), who highlight that the failure to develop pharmaceutical supply chains and realise the benefits associated with the application of artificial intelligence systems has led them to rely more on legacy systems.

Artificial intelligence systems do not provide the required scalability necessary to optimise pharmaceutical supply chains' performance in a dynamic operating environment (Jackson, Ivanov, Dolgui & Namdar, 2024). As a result of the poor integration of artificial intelligence systems, most developing pharmaceutical sectors appear to be lagging in leveraging dynamic capabilities and the required agility to respond to threats to their head health sectors by developing responsive mechanisms supported by predictive analytics (Kosasih, Papadakis, Baryannis and Brintrup, 2024).

Spreitzenbarth, Bode and Stuckenschmidt (2024) suggests that the conceptual appeal of artificial intelligence systems is more readily welcomed in developed pharmaceutical supply chains than in developing pharmaceutical supply chains. This difference determines the competitiveness of these supply chains relating to their ability to mitigate supply chain risks (Olan, Spanaki, Ahmed and Zhao, 2024). It has been realised that developing pharmaceutical supply chains are at a higher risk of suffering from disruptions than developed supply chains that use big data analytics systems to even out supply chain disruptions through predictive analytics (Kehayov, Holder and Koch, 2022).

The failure to leverage your nutrition intelligence systems in developing supply chains has led to an increase in reliance on traditional and legacy systems with weaker predictions and more often resulted in inaccuracies and failure to perform deep analytics in future predictive abilities (Helo and Hao, 2022). Within this context, this research is meant to ascertain the extent to which adopting artificial intelligence systems within the pharmaceutical supply chain in Zimbabwe has been effective in mitigating supply chain destruction especially considering the threats that we presented by the covid-19 pandemic that's a page to threaten the sustainability of the pharmaceutical sector and the health centre which depends on it (Cannas, Ciano, Saltalamacchia and Secchi, 2024).

In light of the above, the researcher hypothesises that:

H_1 Artificial intelligence systems positively affect the reduction of supply chain risks in the pharmaceuticals sector in Zimbabwe.

2.4.2 Blockchain technology and supply chain risk mitigation

Increasing competition and the need to enhance competitiveness across supply chains have resulted in adopting blockchain technologies (Sunny, Undralla and Madhusudanan Pillai, 2020). These information systems are essential in facilitating real-time data exchange, and they promote the visibility of supply chains on different platforms and reduce supply chain risks. The essence of blockchain technology is to store transactional data across supply chains, which can be leveraged in the creation of supply engagements, building trust and promoting authentication (Gligor *et al.*, 2022). The works of Gordon and Catalini (2018) stress that blockchain technology is essential in real-time monitoring of supply chain activities, enhancing the accessibility and safety of data across supply chains. Leveraging blockchain technology is key in promoting transparency across pharmaceutical supply chains.

Insights from Bischoff & Seuring (2021) highlight that leveraging blockchain technology has been instrumental in promoting the traceability and transparency of product-related information across supply chains and reducing supply chain risks. Blockchain technologies are of utmost importance, especially in pharmaceutical supply chains, given the threat of imitative brands (Sunny, Undralla and Madhusudanan Pillai, 2020). Having a blockchain platform is essential for supply chain partners to appreciate product-related information, such as the product origin and authenticity of the product, which is instrumental in mitigating threats brought about by counterfeit products whose quality cannot be guaranteed (Gligor *et al.*, 2022). The essence of leveraging blockchain technologies has also been realised relating to the promotion of disability of transactions and creation of an audit ledger across the pharmaceutical supply chains.

Song, Fisher, de Sousa Jabbour and Santibañez Gonzalez (2022) highlights that leveraging blockchain technology effectively promotes transparency and generates a platform where different supply chain partners can integrate and share information and reduced supply chain risks. This sharing of information has been found to enhance the competitiveness of the supply chain and the quality of decision-making. Moreover, Gelsomino, Sardesai, Pirttilä and Henke (2023) emphasise that sharing product-related information is also instrumental in protecting public health and mitigating the negative environmental impact associated with counterfeit products. Ultimately, Heim (2022) indicates that leveraging blockchain technology helps supply chains align with the sustainability agenda, particularly for public health protection and environmental preservation. At the same time, supply chains generate sustainability profits.

Like any other disruptive technological innovation, adopting blockchain technologies has proven to be more prominent in developed economies with the required expertise and financial resources to support it (Burgess, Sunmola and Wertheim-Heck, 2024). This is distinguished from developing economies and health systems that are yet to embrace using blockchain technology fully and to optimise their performance through the sharing of information (Roeck, Sternberg and Hofmann, 2020). This comes against the backdrop of potential benefits associated with the utilisation of blockchain technology relating to enhanced commodity monitoring, which has been associated with the ability to encourage the recycling of material and the reduction of waste (Gruchmann, Elgazzar and Ali, 2023).

Thakker et al (2024) have focused on reinforcing the effect that despite the apparent initial investments required to set up blockchain technological systems, there are significant benefits relating to long-term association through exploring integrations across supply chain participants and reduced supply chain risks. Some of these benefits have also been linked to environmental management in lowering ecological degradation, which helps improve supply chain sustainability (Gligor *et al.*, 2022).

However, alternative perspectives suggest that developing economies are not placing so much emphasis on sustainability issues, especially regarding the health impacts of their pharmaceutical systems (Shamsuzzoha, Marttila and Helo, 2023). The emphasis on the sustainability of pharmaceutical systems in developing economies is not as prominent as that of developed economies due to the dependency of the developing pharmaceutical sector on developed pharmacies (Gruchmann, Elgazzar and Ali, 2023). Issues that come into play revolve around the failure to capacitate local product innovation within developing economies, affecting the traceability of information across the local pharmaceutical sector (Burgess, Sunmola and Wertheim-Heck, 2024).

In light of the above, the researcher hypothesises that:

H_2 Blockchain technology positively affects the reduction of supply chain risks in the pharmaceutical sector in Zimbabwe.

2.4.3 Machine learning systems and supply chain risk mitigation

Machine learning algorithms are increasingly being applied across the supply chain, enabling machines to learn from historical transactions and develop a deep learning appreciation of user behaviour (Alexander, Kumar, Walker and Gosling, 2024). The relevance of machine learning algorithms lies in their ability to leverage deep learning and determine techniques through integrating neural network analysis in the prediction of user behaviour (Theodosiou and Read, 2023). Applying machine learning techniques across supply chains has helped to even out supply chain disruptions. The work of Hejazi and Habani (2024) highlights that machine learning algorithms can promote the effectiveness of supply chain performance through maintaining effective differentiation between legitimate and fraudulent transactions.

Machine learning capabilities have helped supply chains predict and mitigate supply chain disruptions by applying predictive analytics, adaptively optimising supply chain complexities, and reducing supply chain risks. O’Connor & Booth (2022) highlights that machine learning algorithms have been in high demand for forecasting and optimising inventory across supply chains. Applying machine learning capabilities across pharmaceutical supply chains has effectively leveraged historical sales data and external factors to predict demand with high precision (Zheng, Kong and Brintrup, 2023). This has effectively limited the bullwhip effects of stockouts and adjusted the inventory accordingly (Mukucha and Chari, 2023). Machine learning algorithms have been practical in predictive maintenance of supply chains to predict equipment failures prior to their occurrence and optimise sustainable supply chains (Adhikari, Joshi and Basu, 2023). Delivery history and logistical challenges that might potentially disrupt sustainable sourcing.

Poursoltan, Seyedhosseini and Jabbarzadeh (2021) highlights that machine learning systems optimise logistics and routes, helping to moderate transportation routes in real time and mitigate supply chain risks. Research stipulates that the leveraging of machine learning is found in its ability to operationalise scenario modelling and risk prediction tomorrow. Hemmati, Ghomi and Sajadieh (2023) stressed that machine learning can be used to predict anomalies in transactions, such as fraud detection and using pharmaceutical drugs across pharmaceutical supply chains, which might potentially disrupt the integrity of pharmaceutical supply chains.

The essence of machine learning in supply chain risk mitigation is its ability to promote real-time visibility across supply chain activities by leveraging Internet of Things and blockchain technology through end-to-end transparency and security (Wichmann, Brintrup, Baker, Woodall and McFarlane, 2020; Zheng, Kong and Brintrup, 2023). Moreover, this promoted a response to supply chain disruptions and continuous improvement by learning from the new dataset. Fang & Chen (2022) highlights the scalability of pharmaceutical supply chains due to gathering information from patients from different sources. It also reiterates the cost efficiency associated with leveraging machine learning algorithms.

Despite the potential benefits associated with leveraging machine learning the potential limitations concerning data quality and integration, given that the effective operation of machine learning algorithms requires the presence of unified data from different sources, such as the Internet of Things. Duan & Zhao (2023) reiterate that organisations that rely on legacy systems and soft ways often lack the scalability to integrate appropriately with machine learning systems, resulting in their failure to recognise benefits. Martinez-Millana, Saez-Saez, A., Tornero-Costa, Azzopardi-Muscat, Traver and Novillo-Ortiz (2022) highlights that the complexity of supply chains within the group of frameworks, which comprises a diversity of stakeholders, is often complex. This complicates the machine learning algorithms, requiring experts to program the system to benefit all stakeholders (Sharma, Antony, Sharma & Daim, 2024).

Yin, Chu Dolgui, Cheng and Zhou (2022) have specified that an overreliance on historical data is one of the most significant shortcomings of machine learning systems. These systems fail to predict other pre-crisis data, such as the COVID-19 pandemic, which increased supply chain risks. Perano, Cammarano, Varriale, Del Regno, Michelino and Caputo (2023) confirmed that the crisis almost paralysed the global pharmaceutical sector. In addition, concerns have been raised regarding privacy and ethical issues associated with sharing sensitive data, which exposes supply chains to cybersecurity risks. Ultimately, Mhlanga (2021) also highlights the skills gaps in the competence necessary to maintain capacity building and interpretations.

In light of the above, the researcher hypothesises that:

H$_3$ *Machine learning-based decision-making positively reduces supply chain risks in the pharmaceutical sector in Zimbabwe*

2.4.4 Automated dynamic pricing and supply chain risk

Automated dynamic pricing is a mechanism for real-time price adjustment based on demand fluctuations, market conditions, and supply chain constraints (Wang, Zhi, Liu and Yang, 2023). Automated dynamic pricing can alternatively be viewed as a technique for using artificial intelligence systems to optimise prices based on demand conditions. This automated mechanism ensures that the pharmaceutical supply chain does not overstock or understock its inventory to generate value for money in inventory management.

The automated dynamic pricing approach leverages information technologies to reduce supply chain risks and advance agility by promoting resilience (Mandania and Oliveira, 2023). Automated dynamic pricing is applied in pharmaceutical supply chains, as it has been proven to reduce supply chain disruptions through mitigating stockouts and overstocking (Malasevska Haugom, Hinterhuber, Lien and Mydland, 2020). The automatic operation of raising prices during periods of high demand, such as in pandemics, has managed to reduce excessive demand and prevent shortages while also containing pressure on supply chains. On the other hand, pricing adjustments during depression minimised warehouse costs and lowered the risk of obsolescence (Tuncay, Kaya, Yılmaz, Yaslan & Öğüdücü, 2024).

Luo, Zhou and Xu (2023) highlighted the inventory management mechanism to reduce the bullwhip effect across the supply chain. This arises from the real-time adjustment of prices due to erratic demand conditions, enabling supply chain partners to align production with inventory levels. This is to even out the demand conditions to avoid the situation where small changes in demand can amplify upstream shocks (Malasevska *et al.*, 2020).

Tuncay et al. (2024) highlights that dynamic prices have promoted the stabilisation of cash flow conditions across the supply chain by promoting higher margins while offsetting the financial impact of disruptions. Israel and Siwandeti (2024) adds that surplus liquidity is being found to mitigate potential disruptions across pharmaceutical supply chains. Moreover, automated dynamic pricing is also associated with pharmaceutical supply chains' capacity to respond to disruptions by providing demand shifts for available products.

Karabağ and Gökgür (2023) has proven to be a predictive analytical risk diversification strategy to analyse historical sales data in computer actions to forecast risks and leverage supply chain performance. (Lu, Gao, Kuroki and Ge, 2022) stress that the potential shortcomings associated with automated dynamic pricing relate to its perceived fairness, given that frequent pricing variations erode customer trust and negatively affect corporate reputation and customer loyalty. Kool, Westerlaken and Suleri, (2022) indicates that the implementation costs associated with automated dynamic pricing are relatively higher, as advanced analytical tools for real-time data monitoring and integration, such as the Internet of Things and enterprise resource planning systems, are required. Jalas & Numminen (2022) confirm that these technological inventions can be prohibitive for emerging supply chains.

Kumar et al. (2022) focused on the ethical and regulatory implications associated with automated dynamic pricing. Guillen et al. (2021) indicates that aggressive pricing during shortages has more often attracted regulatory attention, leading to scrutiny and fines. Research also indicates that automated dynamic pricing does not address the root causes of supply chain disruptions. Explain the challenges associated with the automated dynamic pricing approach. Its conceptual appeal within the pharmaceutical supply chain is a result of its ability to mitigate overstocking of perishable products.

Kumar et al. (2022) reiterate that the ability to adjust prices, especially of generic drugs, during strategy periods prioritises critical markets. Within the spectrum of this research, automated dynamic pricing is considered, particularly regarding the preparedness of the Zimbabwean pharmaceutical supply chain to even out shortages and surpluses by applying a novel pricing approach to leverage supply chain performance while simultaneously reducing supply chain risks. In light of the above, the researcher hypothesises that:

H_4 Automated dynamic pricing positively affects the reduction of supply chain risks in the pharmaceutical sector in Zimbabwe.

2.5 Conceptual framework

The conceptual framework reflects the relationships that exist between digitalisation of pharmaceutical supply chains through using artificial intelligence systems, blockchain technologies, machine learning capabilities and automated dynamic pricing is the influence the reduction of supply chain from the perspective of this research, it is hypothesised that is the direct relationships between the leveraging of digitalising the pharmaceutical supply chain and reduction supply chain risks. The conceptual framework is presented in Figure 2.2

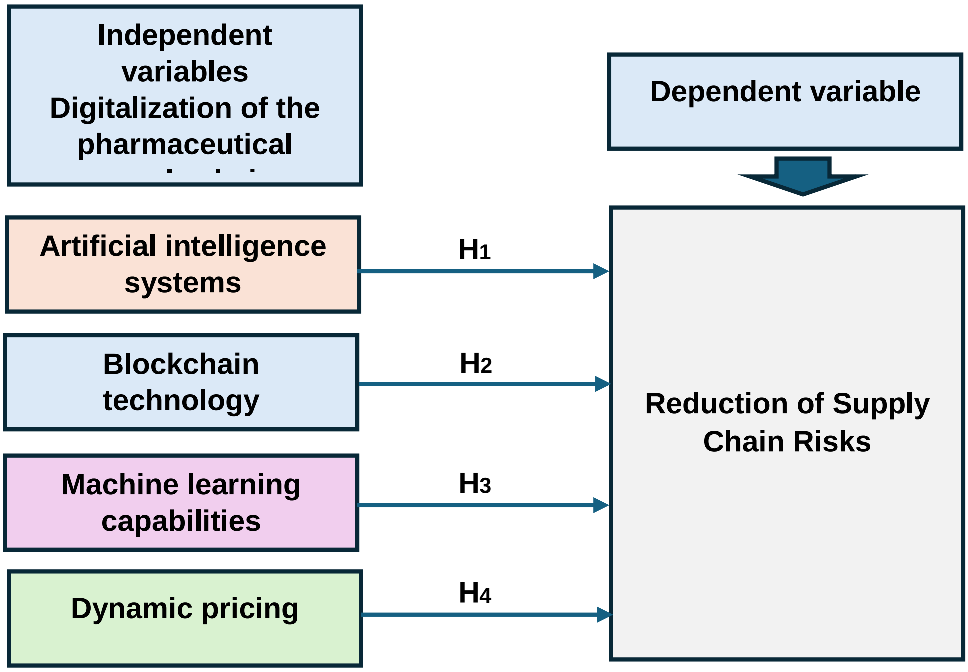


Figure 2.2: The Conceptual Framework

Source: Designed by researcher

The conceptual framework in this study is developed based on the hypothesis that there is a direct relationship between the predictor variables and the ability of the pharmaceutical supply chain to mitigate risks. It is hypothesised that leveraging artificial intelligence systems will result in real-time interventions across the pharmaceutical supply chain in a matter of minutes, enabling participants in the supply chain to share information that will lower the risk.

The conceptual framework also depicts that adopting blockchain technology will promote transparency across Zimbabwe's pharmaceutical supply chain. This will enhance information sharing and mitigate the prevalence of imitative and counterfeit brands, potentially heightening supply chain risks in the pharmaceutical sector. It is also presented by the hypothesis that using machine learning algorithms directly lowers the prevalence of risks across the pharmaceutical supply chain. This emanates from the remote learning capabilities of machines through both supervised and unsupervised learning approaches to flag questionable transactions and activities that potentially expose the pharmaceutical supply chain to risk.

Finally, the conceptual framework also shows that leveraging and feature intelligence-driven Automated dynamic pricing strategy can manage demand conditions by evening out overstocking conditions. It is an equilibrium mechanism to ensure the supply chain operates at optimal stock levels.

Empirical studies

The link between the digitalisation of supply chains and the reduction in supply chain risk is not only synonymous with this research; previous studies have focused on a related line of study.

Global context

Research focused on the digitisation of supply chains is prominent in developed economies, which has permanently emphasised the need to digitalise supply chains to improve the ability to absorb shocks and remain resilient. The focus of attention in existing research in developed economies of blockchain technology is the application of big data analytics through artificial intelligence systems to promote the transparency of supply chains, reducing supply chain risks well. Research in the United Kingdom specified that efforts to digitalize supply chains have improved the transparency and surveillance of pharmaceutical supply chains (Brintrup *et al.*, 2024).

Similar outcomes have been highlighted in a UK study, where using machine learning techniques has been instrumental in promoting automated dynamic pricing and supply chain resilience (Mandania and Oliveira, 2023). Related study in Finland confirmed that digitalising the supply chain was associated with significant cost savings (Karttunen, Lintukangas and Hallikas, 2023). Digitalisation of supply chains by leveraging machine learning technologies improves the quality of decision-making across the pharmaceutical supply chain (Allal-Chérif, Simón-Moya and Ballester, 2021).

Outcomes from the study in Germany reiterated that the essence of supply chain digitalisation through blockchain technology is predicting the actions of supply chain partners through advanced information sharing. Related insights from a study in Italy confirmed that digitalising supply chains transformed the transparency of the pharmaceutical sector and reduced risks (Cannas *et al.*, 2024). Research in France confirmed that artificial intelligence systems leveraging big data analytics were instrumental in building relationships across supply chain partners (Centobelli, Cerchione, Cricelli & Strazzullo, 2021).

Insights from the Australian pharmaceutical sector highlighted that machine learning algorithms enhance automated dynamic pricing and promote operational transparency (Lau et al., 2023). A related Australian study by Ghobakhloo *et al. (*2023b) confirmed that leveraging Industry 4.0 technologies was instrumental in optimising the performance of supply chains relating to their agility, transparency, and flexibility.

The benefits of automated dynamic pricing are associated with improved customer relationship building and improved competitive advantage (Kool, Westerlaken and Suleri, 2022). Research in Asia confirmed that leveraging digitalisation of supply chains was associated with an improvement in the performance of supply chains (Cai, Sharkawi & Taasim, 2024). The innovations associated with using blockchain technologies are associated with the overall improvements in salvation performance and reduction in distractions in China (Liu, Liu, Lee, Yuan, Long and Cheng, 2024).

A study in India confirmed that digitalising the supply chain through incorporating artificial intelligence systems, the Internet of Things, and blockchain technology was instrumental in promoting supply chain visibility (Tiwari *et al.*, 2024). It was also highlighted that leveraging these advanced technologies could promote supply chain resilience to external shocks.

The african context

Scant literature focuses on the digitalization of the pharmaceutical supply chains within the African context. This is likely a result of the poor application of blockchain technology to improve the transparency of pharmaceutical supply chains. Research indicates that the poor adoption of these disruptive technologies across the pharmaceutical supply chains exposes most separations within the African context to disruptions and poses the public health system to peril, given the glorification of counterfeit drugs (Guida, Caniato, Moretto & Ronchi, 2023). A South African study by Namweseza, Ndandiko, Obanda and Mugurusi (2024) confirmed that leveraging information systems across the pharmaceutical sector effectively managed reverse logistics by sharing information across participants, reducing risks associated with environmental degradation.

A Nigerian study confirmed that weak implementation of digitalisation, artificial intelligence systems, and the scalability of the pharmaceutical sector (Okpeke, Ogugua & Eyo-Udo, 2024). A study in Uganda confirmed that leveraging digitally driven procurement internal controls was effective for immediate information integration and the programming performance of humanitarian organisations in the health sector (Muhwezi, Mutebi, Mayanja, Tukamuhabwa, Namagembe & Kalema, 2023). The outcomes of this research appear to suggest that leveraging internet digital technologies is effective in promoting the sustainability of organisations relating to promoting supply chain transparency.

Weak technological infrastructure appears to be affecting the scalability of the pharmaceutical sector in Africa (Ek, Wakunuma & Akintoyeal, 2023). Risks across the supply chain if also be noted within the South African pharmaceutical sector due to the lack of robust responsiveness to the application of Technology (Hirsch, Niemann & Swartet, 2024).

The zimbabwean context

The sustainability of the pharmaceutical supply chain in Zimbabwe was threatened during the covid-19 pandemic when the failure to implement a robust blockchain technology mechanism exposed the pharmaceutical sector to corruption. At the height of efforts by the national pharmaceutical industry to procure protective equipment in Zimbabwe, there were allegations of fraudulent transactions involving shelf companies that could not handle pharmaceutical deliveries. This demonstrates the weakness of the Zimbabwean pharmaceutical sector to supply chain disruptions, as it does not have a sound mechanism of blockchain technology to trace the transparency of transactions and activities that supply chain partners perform along the supply chain (Office of the Auditor-General, 2023).

2.6 Research gaps

The most prominent knowledge gaps identified in literature relate to the scant application of digitalisation, particularly adopting artificial intelligence systems, machine learning capabilities, blockchain technology and automated dynamic pricing within the Zimbabwean context. This scenario is exposed to the local pharmaceutical sector, which is exposed to corrupt tendencies given the failure to promote transparency in the traceability of transactions across the supply chain.

The situation is synonymous not only with the context of the local pharmaceutical sector. Research indicates that the failure to implement robust investments in digitalising supply chains has exposed pharmaceutical supply chains in Africa to being contaminated with counterfeit drugs that further impair the sustainability of their fragile health delivery systems. The same cannot be said of developed economies' pharmaceutical supply chains; they leverage blockchain technologies to promote information sharing and transparency across the supply chains.

In this context, the gaps identified with respect to the extent to which leveraging blockchain technology, artificial intelligence systems, and machine learning capabilities can help pharmaceutical supply chains characterised by resource-constrained economic contexts like Zimbabwe improve their resilience against supply chain disruptions. Moreover, it is a gift regarding the operationalisation of digitalisation within the context of a highly regulated pharmaceutical sector in a resource-constrained economic context, given that the most prominent participants across the supply chain, such as public hospitals, are yet to fully digitalise their information needs with other partners across the supply chain. Universalisation across the place in partners might potentially disrupt the benefits associated with digitalisation.

2.7 Chapter summary

The chapter outlined the existing literature on regulating digitalisation of pharmaceutical supply chains and the benefits realised in mitigating supply chain disruptions. The diffusion of innovations model, as outlined in the Unified Theory of Acceptance and Use of Technology, guided the chapter. Literature has highlighted that the adverse effects associated with investments in digitalisation and across the pharmaceutical supply chains have been disproportionately filtered within developing economies, rather than developed countries. There is an apparent keeping of knowledge, but now the best the pharmaceutical supply chains can be digitalised within resource limitations, which characterises most developing economies. The next chapter specifies the methodology that guides the study in data collection and analysis.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodology, which illustrates the process of collecting, analysing, and measuring logical data. It is premised on applying a quantitative approach founded on positivist research philosophy and using cross-sectional survey research design. The chapter also specifies the research instruments, data collection and analysis approach, and ethical issues.

3.2 Research philosophy

The research subscribes to a positivist philosophy based on positive verification and confirmation. (Bougie and Sekaran, 2019). Applying positivism in research, digitalisation of the pharmaceutical supply chain, and chain risk mitigation aims to yield objective outcomes that justify its benefits. A quantitative approach, rooted in positivist philosophy, employs statistical techniques to select a representative sample, serving as the unit of analysis for statistical inferences. This research focuses on Zimbabwe's pharmaceutical supply chain, which comprises various facilities, including rural clinics and hospitals. Due to its diversity, not all elements can be included. Nonetheless, positivism allows for selecting specific parts from which data can be collected and analysed, enabling generalisation regarding supply chain risk mitigation in Zimbabwe. Adopting a positivist research philosophy in this study aims to explore the link between digitalisation the pharmaceutical supply chain and risk mitigation in the Zimbabwean pharmaceutical supply chain. Positivism stresses the importance of objective and measurable data, aligning to analyse quantifiable outcomes (Saunders, Lewis and Thornhill, 2019).

Research methodology

This study uses a quantitative research methodology that leverages empirical methods in data collection, measurement scales, and analysis (Mexon and Amanda, 2020). A quantitative approach to research methodology uses objective methods to validate data based on objective reality. This research methodology employs statistics, which provide numbers that can generalise research outcomes to a larger population based on sampling data. A quantitative research methodology is suitable for this study because it collects numerical data to analyse relationships and trends. Quantitative methods provided valuable, measurable evidence since the study aims to quantify the impact of leveraging digitalisation in the pharmaceutical supply chain.

Research strategy

The survey method is well-founded as it helps researchers efficiently collect data from a large participant pool. Since this study aimed to assess digitalising the pharmaceutical supply chain in Zimbabwe, a survey was conducted to engage various professionals effectively. It offers an in-depth view of their knowledge, experiences, and perspectives regarding digitalisation in the pharmaceutical supply chain risk management. An explanatory research design was suitable for this investigation as it explores the cause-and-effect dynamics between employing artificial intelligence systems and creating supply chain risk mitigation. This approach permitted the study to discern whether digitalising the pharmaceutical supply chain application directly influences the supply chain risk mitigation.

Research approach

Deductive reasoning is appropriate for this study as it involves developing hypotheses based on existing theories or empirical evidence, which can be tested through data analysis. (Saunders, Lewis & Thornhill, 2019). In this case, researchers can formulate hypotheses about the relationship between leveraging digitalisation in the pharmaceutical supply chain and risk mitigation and test them using the collected data.

Target population

The research population consists of all medical personnel employed in the pharmaceutical supply chain in Zimbabwe. The estimated population size of key participants across the pharmaceutical supply chain is 230.

Sample size

The sample size was determined through the mathematical formula, which resulted in the adjudication of a sample of 146 participants.

Sampling methods

Sampling was incorporated using a stratified random sampling approach.

Sampling Procedure

A study employed a stratified random sampling approach to engage with participants across the pharmaceutical supply chain. This approach provided A proportional representation of different participants along the pharmaceutical supply chain. This was necessary since different categories of participants included pharmaceutical firms and downstream participants, such as hospitals, pharmacies, and other healthcare centres. It was therefore imperative to incorporate these different participants in the pharmaceutical supply chain to develop a holistic appreciation of how digitalising the supply chain has been critical in mitigating some of the disruptions encountered in the supply chain.

Data sources

The research centres on utilising both secondary and primary data sources. Secondary sources are the initial step for data collection, as the information they provide is easily accessible from various published materials (Bougie & Sekaran, 2019). This category of secondary data includes insights on the level of implementation of supply chain risk mitigation in developing economies, with a specific focus on Zimbabwe. Such data can be readily obtained from online resources and peer-reviewed academic journals examining technology's role in health delivery systems.

Secondary data sources

The utilisation of secondary data approaches is pivotal, as it offers a framework to guide this research in identifying the areas that have been explored and those that remain under investigation concerning the digitalisation the pharmaceutical supply chain in enhancing supply chain risk mitigation in Zimbabwe. From this perspective, this research employed secondary data sources acquired from various platforms, including electronic libraries, peer-reviewed academic journals, and publicly available industry materials, focusing on advancements within the health delivery system.

Primary data sources

To contextualise current research findings, primary data sources were utilised to gather relevant and precise data that directly addresses and fulfils the objectives of the present study. A structured questionnaire was used to collect primary data. This research instrument was meticulously designed to include two principal sections. The first section was dedicated to collecting demographic information about the respondents. The current study's demographic information is significant because it can profile respondents' biodata, potentially elucidating their propensity to adopt supply chain risk mitigation strategies within Zimbabwe's public health delivery system.

The second section of the questionnaire collected research-specific data that aligned with the study's objectives. The measurement scale used to rate the responses provided by respondents was based on applying the 5-point Likert scale (Mirahmadizadeh, Delam, Seif & Bahrami, 2020). This scale was chosen for its prominence in information technology research. It offers five options for individuals to select an answer that closely reflects their opinions regarding a particular research question. These options range from strongly agree to strongly disagree. Additionally, it includes an option for respondents to express neutrality or indifference when they do not have a strong opinion about a statement. Furthermore, using this measurement scale expedites data coding and analysis with statistical tools such as the Statistical Package for the Social Sciences (SPSS).

Data collection procedure

The process of collecting data begins with obtaining informed consent from potential respondents. This study employed a mix of physical and electronic questionnaires distributed to chosen participants within the public health delivery system. Utilising both methods offered the necessary convenience for respondents to choose options that matched their preferences. Furthermore, the electronically generated questionnaires sent via the Google Forms platform significantly improved the ease of responding in real time and allowed for seamless electronic submission.

This electronic approach to distributing the questions was also beneficial to the researcher because the researcher could easily combine all the collected and completed questionnaires and export the results to a Microsoft Excel package. Electronically generated questionnaires were sent through a Google Forms link conveyed on preferred platforms, such as social media platforms like Meta, WhatsApp, and X, or through email. The main drawback behind using electronically generated questionnaires was that they could only be responded to online. This area is where physical questionnaires have an advantage since, they can be responded to anytime and do not require internet access. However, physical questions do not provide the convenience of receiving a response instantly.

Overall, using the administered questionnaire implies that respondents answer it at their own convenience. There was a challenge that the person who eventually responds to the question might not fall within the limits of the unit of analysis. This threatens the quality of the data collected from such questionnaires since the views and opinions of actual respondents are not reflected in the responses received.

Data analysis and presentation

This research uses descriptive and inferential statistics for data analysis. Descriptive statistics summarise respondent patterns and characteristics based on demographics. Various statistics will be generated using the Statistical Package for Social Sciences, including measures of central tendency (mean, mode, median) and measures of dispersion (range, standard deviation). Additionally, cross tabulations and bar charts illustrate relationships between variables. Descriptive statistics describe scenarios involving artificial intelligence systems and supply chain risk mitigation without making inferences.

Inferential statistics analysed associations among research variables, primarily using multiple regression analysis. This facilitated predictions regarding the relationship between utilising digitalisation in the pharmaceutical supply chain and supply chain risk mitigation in Zimbabwe's pharmaceutical supply chain. The benefits of multiple regression include identifying the significance of individual variables in supply chain risk mitigation and employing correlation statistics to assess relationships between the examined variables. Ultimately, inferential statistics were essential for hypothesis testing regarding the significance of digitalisation in the pharmaceutical supply chain and risk mitigation. Results are presented in correlation test tables and regression statistics, including analysis of variance, model summaries, and regression coefficients, which ultimately support hypothesis testing.

Validity and reliability

Conducting data quality checks for a study on an artificial intelligence framework for a digital health mobile application in Zimbabwe’s health sector requires careful consideration of both reliability and validity.

Reliability tests

The study employed a combination of statistical and traditional methods to enhance the reliability of the research findings. The Cronbach Alpha method of testing for the internal consistency of research instruments. This approach to determining reliability is measured on a scale of 0 to 1. The ideal reliability score is 0.7, which depicts a relatively high level of reliability relating to the internal consistency of respondents in responding similarly to a given construct. In addition to this approach, other methods to promote reliability included implementing a standardised data collection process to ensure that areas were minimised and promote consistency.

Validity tests

The researcher performed thorough data cleaning to identify and correct any errors, missing values, outliers, or inconsistencies (Mohammed, 2019). This included verifying the accuracy of the data entries and ensuring they aligned with the research objectives. In addition, the researcher conducted a peer review of the methodology, data collection instruments, and analysis techniques used in the study. This assisted in identifying any potential biases or flaws in the research design, ensuring the study's validity. Moreover, the researcher sought external validation of the study findings from experts in the field or stakeholders in Zimbabwe’s pharmaceutical supply chain. This provides additional credibility and enhances the validity of the results. Moreover, validating the collected data by cross-referencing it with other reliable sources, such as official health records or databases, helps to identify any discrepancies or inaccuracies and ensure the integrity of the dataset.

Ethical considerations

Research ethics encompass moral principles guiding researchers in social research, focusing on informed consent, beneficence, non-maleficence, respect for individuals, and justice. Informed consent ensures voluntary participation, with researchers clarifying study objectives, benefits, and limitations. Participants may withdraw without cost or sanctions (Gutierrez et al., 2020). Beneficence emphasises the importance of creating a platform for voices in the health delivery system to address artificial intelligence in supply chain risk mitigation, while highlighting the benefits of mobile digital health applications for operational efficiency in the pharmaceutical supply chain.

Non-maleficence dictates minimising physical or psychological harm. This was achieved through designing convenient data collection instruments. Questionnaires focused on identifying literature gaps, avoiding overburdening participants with excessive requests. The researcher also implemented measures to protect participants from psychological harm, respecting the sensitivity of health-related issues, privacy, and confidentiality. Moreover, to promote justice, the study avoided overwhelming participants with requests and used respectful language to minimise bias and discrimination. Standardised questionnaires preserved respondents' privacy, ensuring that only relevant individuals were questioned. Participants were assured that no social or financial disadvantage would arise from their involvement.

Furthermore, researchers informed participants of study objectives, supporting voluntary engagement and the right to withdraw without punishment (Chivanga & Monyai, 2021). Honesty and transparency in research were crucial, along with research participants and to specify the quality of the data that the study collected (Pruzan, 2016). It was also essential to specify another week to study and clarify responsibilities. Guarding shared personal information and employing pseudonyms upheld confidentiality. Group analysis, rather than individual analysis, also helped maintain privacy.

Chapter summary

The chapter highlights the research methodology relating to the processes used in data collection, measurement, and analysis. The research philosophy, design, strategy, and approach were articulated, and they provided a road map for applying empirical approaches in data collection and analysis. The target population, sampling technique, research methods, reliability and validity considerations, and research ethics were also outlined. The next chapter involves a detailed presentation, analysis, and discussion of the research findings.

CHAPTER 4

DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Introduction

The contribution of this chapter is to handle the presentation, analysis and discussions of research findings. This research aimed to establish the influence of digitalisation on enabling the pharmaceutical supply chain in Zimbabwe to mitigate risks. The research was designed along four objectives that include leveraging artificial intelligence systems, blockchain technology, machine learning systems and automated dynamic pricing, as they help the pharmaceutical supply chain to lower supply chain risks. The starting point of this chapter is an analysis of the overall response rate received from the survey method that she incorporated, the distribution of a closed-ended questionnaire to a cross-section of respondents. Organisation was a characteristic analysed relating to organisational size. In the pharmaceutical sector, it played a role in the pharmaceutical industry. Findings in this research are then analysed relating to descriptive and influential statistics. Ultimately, research results in this study are compared to empirical literature through discussions.

4.2 Analysis of response rate

The study incorporated data collection from a cross-section of participants in the pharmaceutical industry in Zimbabwe.

Table 4.1: Response rate

Questionnaire sent	Valid responses received	Response rate
146	99	67.81

Source: Research (2025)

The targeted sample size in this research stood at 146, from which a total number of valid responses of 99 were received, giving an overall response rate of 67.81%. This response rate indicates that the results generated in this research can be a valid account of the extent of digitalisation in the pharmaceutical sector. Methodology stipulates that if a response rate received in a social study surpasses 50%, then the outcomes reflected in that research were a true reflection of the opinions of most participants. Outcomes expressed in this research demonstrated the external validity of the state of digitalisation within the pharmaceutical industry in Zimbabwe, relating to the contribution they make in reducing supply chain risks.

Organisational characteristics

The study considered three organisational characteristics that included the number of employees in an organisation, the period of experience within the pharmaceutical sector and the role that the respondents play within the pharmaceutical sector in Zimbabwe. This information was considered essential to profile representatives relating to their level of understanding of supply chain activities in the pharmaceutical sector and how technology can be incorporated to enhance the ability of the participants along the pharmaceutical supply chain to mitigate supply chain disruptions.

Organisational size

Research results relating to the size of the organisation relative to the number of employees are presented in Figure 4.1.

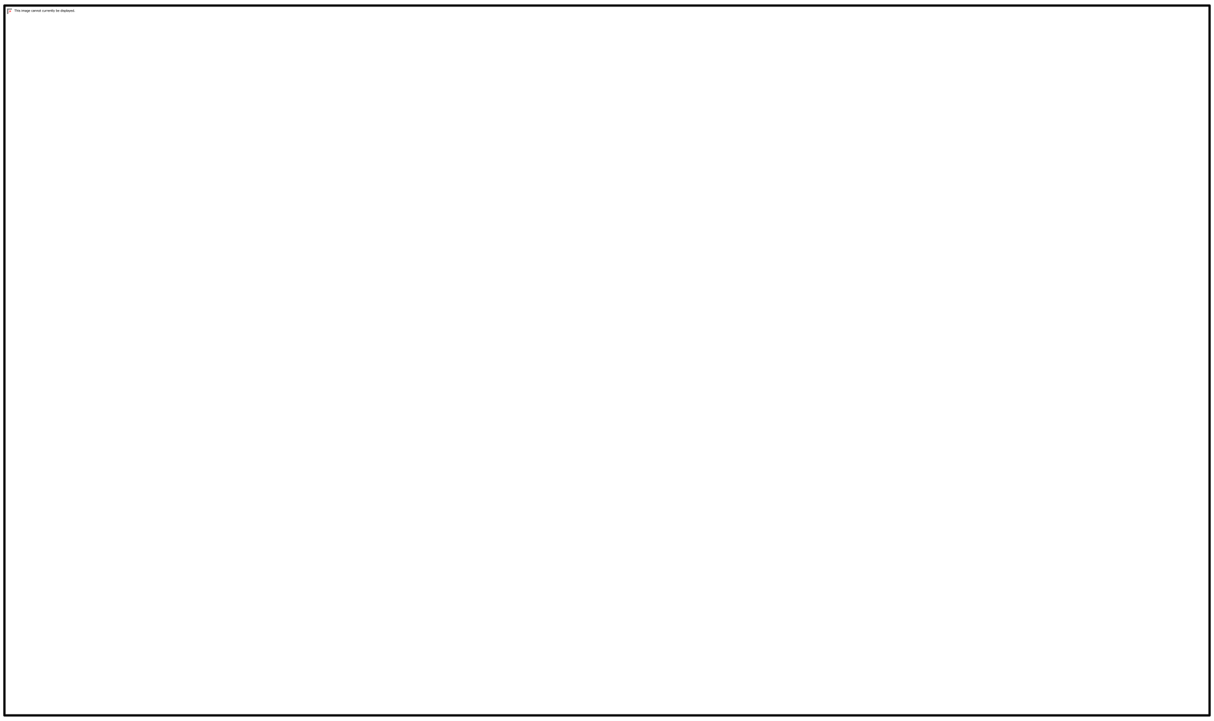


Figure 4.1: Employee size

Source: Research (2025)

The size of an organisation is a key determinant of the complexity of its operations. Results indicate that most of the pharmaceutical sector in Zimbabwe has over 21 employees. The number of employees is a key determinant of the ability of an organisation to navigate through supply chain disruptions. This is because employees are the only resource that have the adaptability and flexibility to adapt to a changing environment. Therefore, the ability of an organisation to have a sizeable number of employees implies that such an organisation has a large pool of employees who are used to help in navigating through supply chain disruptions.

Period in the pharmaceutical sector

The period of working in the pharmaceutical sector in Zimbabwe s presented in Figure 4.2.

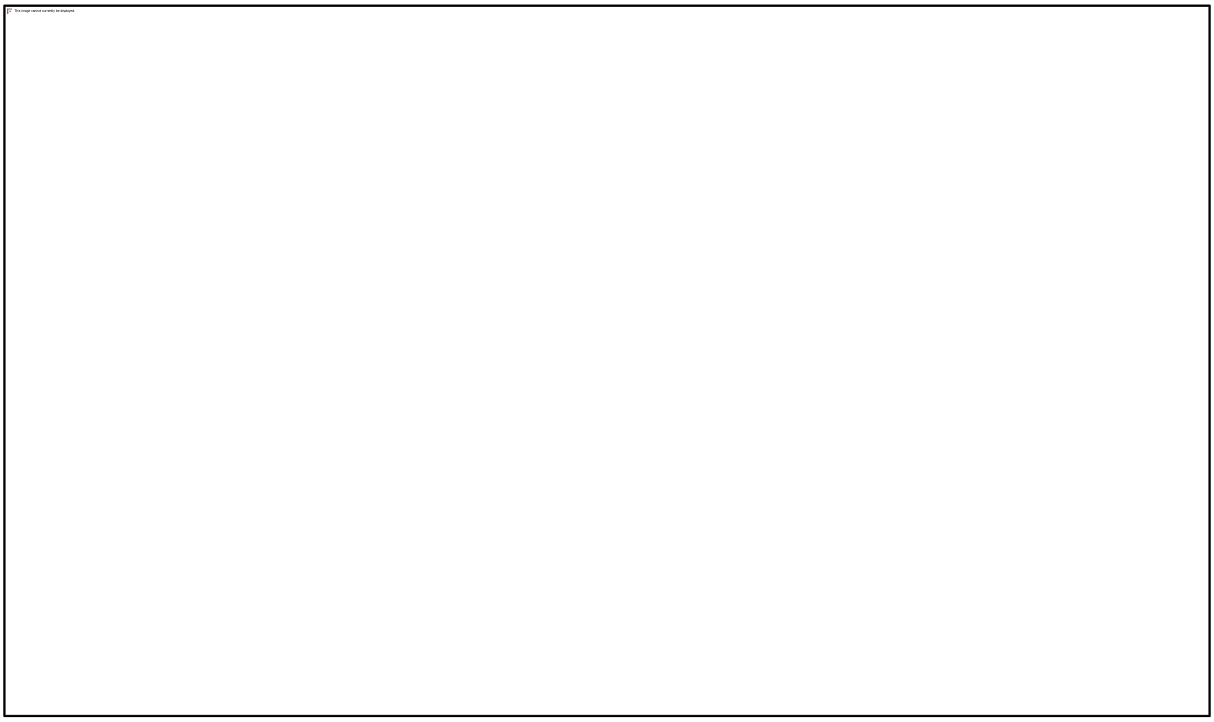


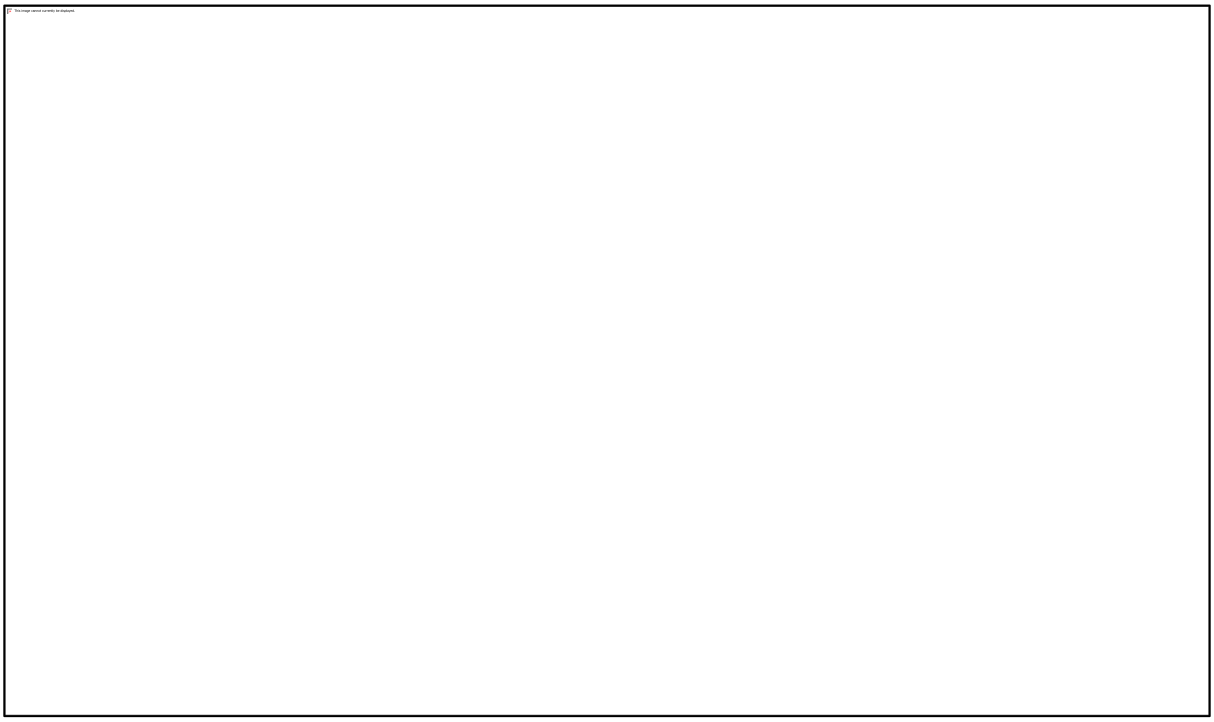
Figure 4.2: Period in the pharmaceutical sector in Zimbabwe

Source: Research (2025)

Results indicate that most participants in the pharmaceutical supply chain ahead between 11- and 15-years' experience in the sector is represented by 33.33%. while are those with more than 15 years' experience in the pharmaceutical sector making up 30.30% of the total participants. These results indicate that these participants have been in the pharmaceutical supply chain for over a decade, which helps to validate outcomes of this research relating to exposure to various supply chain disruptions. The pharmaceutical supply chain's first significant disruptions during the COVID-19 pandemic were 5 years ago, where measures to contain the virus through the distribution of vaccines and other essential medicines to keep the spirit of the coronavirus with paramount importance. The COVID-19 pandemic caused severe supply chain disruptions that the pharmaceutical sector has had to contend with over the past decade. Therefore, having an extended period of experience in the pharmaceutical sector can help to shape the context of digitalisation within the sector, as it helps to even out the supply chain disruptions and risks that have affected the pharmaceutical industry.

Role in the pharmaceutical sector

The study also considered the role of participants within the pharmaceutical sector is presented in Figure 4.3.



Source: Research (2025)

Results indicate that most of the participants in this research were retailers, represented by 50.51%. These are key participants in the pharmaceutical supply chain in the form of pharmacies that have a direct interface with the end users through the distribution of various drugs. Raw material suppliers made a minute 1.01%, while those in the manufacturing sector were composed of 20%. Transporting logistics was composed of 16.16%. In the final analysis, participants in this research were drawn from diverse specialisations, which can help to validate the relevance of technology incorporation, as it helps to even out the disruptions across the pharmaceutical supply chain.

Descriptive statistics

The scope of descriptive statistics was focused on using measures of central tendency and dispersion in explaining the set of a situation regarding digitalising the pharmaceutical supply chain. The interpretation of the descriptive statistics is based on the 7-point Likert scale of measurement, which measures the level of relevance of regarding the state of artificial intelligence.

Table 4.2: Measurement Scale

Scale	Interpretation
1 to 1.44	Not at all
1.45 – 2.44	Very slightly
2.45 to 3.44	Slightly
3.45 to 4.44	Moderately
4.45 to 5.44	Significantly
5.45 to 6.44	Very significantly
6.45to 7	Extremely

Source: Research (2025)

Table 4.2 shows the scales used and their associated interpretations regarding the descriptive statistics applied in this section.

Artificial intelligence systems

Table 4.3 shows descriptive results on the prospects of integrating artificial intelligence systems in the pharmaceutical sector in Zimbabwe are shown in Table 4.3.

Table 4.3: Prospects of artificial intelligence systems integration

	Mean	Std. Dev
How has your organisation adopted AI systems into its core business strategy?	3.18	1.593
How have employees across different departments adopted AI systems in their daily workflows?	3.00	1.355
How are customers/users adopting AI-powered products or services offered by your organisation?	3.55	1.163
How has your organisation invested in training and development programs to support adopting AI systems?	3.45	1.837
How has adopting AI systems led to changes in organisational structure or processes?	3.73	1.823
How has adopting AI systems impacted the overall productivity of your organisation?	3.36	1.729
How has adopting AI systems influenced innovation within your organisation?	3.73	1.719
Valid N (listwise)		

The average score for the prospects of integrating artificial intelligence systems ranged from 3 to 3.73. This implies that views expressed by respondents ranged between a slight to moderate level of adopting artificial intelligence systems in the pharmaceutical sector in Zimbabwe. The strategic implications of these results suggest that there have not been any significant investments in artificial intelligence systems within the pharmaceutical sector that could help to lower the level of supply chain risks. It appears that a significant number of participants in the pharmaceutical sector are relying on legacy systems for detecting and resolving disruptions across the supply chain. This has reduced the efficiency levels across the supply chain relating to information sharing. These results contradict existing literature, which has established that digitalising the pharmaceutical supply chains in the United Kingdom has improved transparency and surveillance, leading to improved integration among supply chain participants (Brintrup *et al.*, 2024).

Blockchain technology

Blockchain technologies are applied the world over to enhance the transparency across the supply chain through improved information sharing. The descriptive results relating to the prospects of integrating blockchain technology in the pharmaceutical supply chain are presented in Table 4.4.

Table 4.4: Prospects of integrating blockchain in the pharmaceutical supply chain

	Mean	Std. Dev
How has your organisation adopted Blockchain technology into its core business strategy?	3.91	1.938
How have employees across different departments adopted Blockchain technology in their daily workflows?	3.73	1.823
How are customers/users adopting Blockchain-based products or services offered by your organisation?	3.91	1.629
How has your organisation invested in training and development programs to support adopting Blockchain technology?	3.82	1.410
How has adopting Blockchain technology led to changes in organisational structure or processes?	4.27	1.551
How has adopting Blockchain technology impacted the overall efficiency of your organisation?	4.18	1.955
How has adopting Blockchain technology influenced innovation within your organisation?	3.73	1.823
Valid N (listwise)		

The main statistics on the prospects of integrating blockchain technology didn't the pharmaceutical supply chain arranged between 3.73 and 4.27. These statistics imply that there is a slight to significant application of blockchain technology across the pharmaceutical supply chain. This demonstrates A relatively favourable level of integration relating to information sharing across participants in the pharmaceutical supply chain. The pharmaceutical supply chain is highly regulated by the MCAZ which enforces minimum standards that are essential to help preserve supply chain disruptions. The MCAZ has been struggling to trace the origins of illegal contraband relating to counterfeit drugs on the other hand drugs that are being used for substance abuse in the country. This appears to reduce the conceptual appeal of leveraging artificial intelligence and blockchain technology to enhance the transparency and traceability of activities taking place across the pharmaceutical supply chain. These research results contradict results by Bischoff and Seuring (2021), which have shown that leveraging blockchain technology has been instrumental in promoting traceability and transparency across supply chains.

Machine learning systems

Machine learning technologies are essential in unsupervised learning of activities that take place across the supply chain, allowing machines to remotely optimise supply chain performance and reduce disruptions without the direct intervention of people. Results relating to the prospects of integrating machine learning systems across the pharmaceutical supply chain are presented in Table 4.5.

Table 4.5: Prospects of integrating machine learning in the pharmaceutical supply chain

	Mean	Std. Dev
How has machine learning-based demand forecasting significantly reduced inventory shortages and surpluses?	4.55	.659
How has machine learning-driven projective risk analytics improved organisational performance?	4.18	1.119
How have machine learning algorithms for anomaly detection in procurement reduced the risk of counterfeit drugs?	4.00	1.604
How can machine learning minimise delays across the supply chain?	4.27	1.292
How has integrating machine learning improved the reliability and quality of pharmaceutical raw material sourcing?	4.45	1.239
How has adopting machine learning impacted employee productivity?	4.36	1.439
How has adopting machine learning influenced innovation?	4.64	1.675
Valid N (listwise)		

Descriptive statistics relating to the prospects of integrating machine learning systems in the pharmaceutical supply chain indicated a mean ranging between 4.00 and 4.64, suggesting moderate to significant relevance. This statistic suggests that the pharmaceutical sector in Zimbabwe is making significant inroads relating to investing in automated systems that require minimal human intervention in making decisions. Some of the most exceptional contributions that machine learning has made to the pharmaceutical sector include promoting innovation through automated customer relationship management building, given a mean of 4.64. However, machine learning is largely ineffective in anomaly detection, especially associated with the risk of counterfeit drugs, given a mean of 4.0. Otherwise, there is a general appreciation of the automated contribution that leveraging machine learning technologies can make to the readiness of the pharmaceutical industry in reducing supply chain disruptions relating to employee productivity (mean of 4.36), minimising delay (mean of 4.27), and forecasting demand conditions (mean of 4.5).

These descriptive statistical outcomes corroborate related insights that were shared by the works of Liu *et al.* (2024), who stated that the innovations associated with using blockchain technologies are associated with the overall improvements in salvation performance and reduction in distractions in China. Current research findings support research in Asia which confirmed that leveraging digitalisation of supply chains through machine learning systems integration was associated with an improvement in the performance of the pharmaceutical supply chains (Cai, Sharkawi & Taasim, 2024). Despite the positive sentiments that have been expressed regarding the favourable application of machine learning technologies in optimising the performance of the pharmaceutical supply chain in Zimbabwe, the difference is related to the intensity and level of investments in using machine learning technologies that differ between the local context and the developed economic context. These differences determine the extent to which machine learning Technologies can automatically resolve supply chain disruptions.

Automated dynamic pricing

The emphasis of the fourth research objective was on the essence of applying automated dynamic pricing as a mechanism for reducing supply chain disruptions in the pharmaceutical sector. Descriptive outcomes with respect to this objective are presented in Table 4.6.

Table 4.6: Prospects of integrating dynamic pricing in the pharmaceutical supply chain

	Mean	Std. Dev
How has automated dynamic pricing optimised inventory levels?	4.18	1.410
How have real-time price adjustments improved the stability drug supply?	4.36	1.675
How has automated dynamic pricing enhanced revenue management?	4.55	1.163
How has using demand-sensitive pricing reduced financial risks associated with the expired pharmaceutical products?	4.73	1.719
How has automated dynamic pricing improved the accessibility of essential medicines?	4.45	1.311
How has automated dynamic pricing impacted the overall efficiency?	4.18	.941
How has adopting automated dynamic pricing influenced innovation?	4.36	1.073
Valid N (listwise)		

The descriptive mean for dynamic pricing ranged between 4.18 and 4.73, signifying a significant relevance in the pharmaceutical sector in Zimbabwe. Dynamic pricing is an instrumental management strategy to avoid stockouts or overstocking by ensuring that prices are adjusted in line with the demand conditions prevailing at a particular time. In this research, using dynamic pricing has been identified as a key strategy to avoid supply chain risks relating to financial loss, given the rapid evaluation of the Zimbabwean currency in the foreign exchange market. Dynamic pricing has helped to save again the financial interest of players in the pharmaceutical industry, especially regarding drugs that are not manufactured locally and must be imported.

Research shows that using a relatively stable currency such as the US dollar as the point of reference has also helped the pharmaceutical participants to avoid disruptions across the supply chain relating to restocking initiatives. The Reserve Bank of Zimbabwe's liberalising of the foreign exchange markets has also been a step in the right direction to lower the prevalence of disruptions across the pharmaceutical supply chain, where the procurements of drugs outside the country are concerned. These results support the benefits of automated dynamic pricing, which are associated with improved customer relationship building and improved competitive advantage (Kool, Westerlaken and Suleri, 2022).

Advanced statistical analysis

While the emphasis of the descriptive statistical presentation of results was on describing the state of a phase regarding digitalising the pharmaceutical supply chain in Zimbabwe, it did not extend to relating digitalisation of the supply chain to its ability to mitigate supply chain disruptions. This was achieved using advanced statistical analysis incorporating regression statistics.

Regression tests results

A multiple regression approach was selected due to its simplicity, while maintaining substantial predictive value. This was essential to infer the relationship existing between digitalising the pharmaceutical supply chain and its ability to reduce risks and disruptions. A multiple regression approach was considered essential, given the various variables being tested in this research, which incorporated artificial intelligence systems, machine learning technologies, blockchain technologies, and automated dynamic pricing systems, as they influence the pharmaceutical supply chain's ability to reduce disruptions.

Model summary statistics

The starting point in executing a multiple regression analysis was testing the model summary, whose results are shown in Table 4.8.

Table 4.7: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.705[a]	.555	.523	2.29154

a. Predictors: (Constant), Dynamic Pricing, Artificial Intelligence, Blockchain, Machine Learning

The model summary indicated a combined linear correlation of 0.705, indicating a strong positive correlation between elements determining digitalising the pharmaceutical sector in Zimbabwe (dynamic pricing, artificial intelligence, blockchain, machine learning) and supply chain risk mitigation. The R-squared value of 0.555 and the adjusted R-squared of 0.523 suggest that almost half of the variations in supply chain risk management mitigation in the pharmaceutical sector, which is accurately composed of 55.5%, were attributed to the predictor variables used in the compilation of the multiple regression model. This leaves around 44.5% of changes in supply chain risk mitigation to be attributed to other variables that have nothing to do with digitalisation in terms of dynamic pricing, artificial intelligence learning and blockchain technology. Nevertheless, the regression model demonstrates a relatively favourable goodness of fit given the lower extended weight of the estimate of 2.29154. The relevance of the model summary if analysed in conjunction with the regression coefficients.

Regression coefficient statistics

The regression coefficient statistics are outlined in Table 4.8.

Table 4.8: Regression Coefficients

Model		Unstandardised Coefficients		Standardised Coefficients		
		β	Std. Error	β	t	Sig.
1	(Constant)	26.185	3.317		7.893	.000
	Period (Control)	.732	.405	.159	1.807	.074
	Employee Size (Control)	-1.414	.430	-.376	-3.289	.001
	Role played (Control)	-.498	.426	-.104	-1.168	.246
	Artificial Intelligence	.035	.089	.064	.392	.696
	Blockchain	.045	.067	.105	.674	.042
	Machine Learning	.430	.156	.690	2.749	.007
	Dynamic Pricing	.482	.126	.790	3.816	.000

a. Dependent Variable: Supply Chain Risk Mitigation

The regression coefficient indicated that only three predictor variables were statistically significant in reducing supply chain risks across the pharmaceutical sector in Zimbabwe. This is evidenced by the p-values of 0.001 for dynamic pricing, 0.004 for machine learning systems, and 0.012 for blockchain technology, all of which are less than the required threshold of 0.05. The beta values suggested that dynamic pricing is the most decisive influence on mitigating supply chain risks, given a beta value of β = 0790. This is followed by leveraging machine learning systems (β = 0.690) and blockchain technology (β = 0.105). The use of artificial intelligence systems was found to have a positive but statistically insignificant contribution to reducing supply chain risks in the pharmaceutical sector, with a β coefficient of 0.064.

Research findings and discussions

This section discusses research results in comparison to existing literature, pairs of similarities and points of difference between what was established in this research and what has been empirically proven in previous studies. This is instrumental in determining key proposals that can be taken to improve the quality of digitalisation of the pharmaceutical supply chain and mitigate future supply chain risks.

Artificial intelligence and supply chain risk mitigation

Regression results indicate that leveraging artificial intelligence systems has an insignificant effect on lowering supply chain risks in the pharmaceutical sector in Zimbabwe, as evidenced by a p-value of 0.696, which is greater than the critical value of 0.05. These statistical outcomes suggest that the application of artificial intelligence systems within the pharmaceutical supply chain is relatively limited. This contributes to its ability to lower supply chain risks to negligible.

Current research results distinguish themselves from existing literature, which has proven that incorporating artificial intelligence systems across supply chains has helped improve operational efficiency and minimise disruptions. Research outcomes from the works of Centobelli *et al* (2021) confirmed that artificial intelligence systems leveraging artificial intelligence systems and big data analytics were instrumental in building relationships across supply chain partners. Given the above outcomes, this research rejects $\mathbf{H_1}$. It reiterates that, even if artificial intelligence systems have a positive impact, the effect is statistically insignificant in reducing supply chain risks in the pharmaceutical sector in Zimbabwe.

Blockchain technology and supply chain risk mitigation

Research results have confirmed that leveraging blockchain technology is associated with a significant reduction in supply chain risks, given a significant value of 0.042. These statistics confirm the essence of supply chain transparency through the sharing of information across the pharmaceutical supply chain by upstream and downstream participants, leveraging blockchain technology.

Current research results corroborate existing literature from research by Gordon and Catalini (2018), where it was reiterated that blockchain technology is essential in real-time monitoring of supply chain activities, enhancing the accessibility and safety of data across supply chains. Leveraging blockchain technology is key in promoting transparency across pharmaceutical supply chains. Given the above outcomes, this study accepts $\mathbf{H_2}$ and states that leveraging blockchain technology has a positive impact on reducing the supply chain risks in the pharmaceutical sector in Zimbabwe.

Machine learning systems and supply chain risk

Regression results have shown that leveraging machine learning technologies is associated with the pharmaceutical supply chain's ability to reduce risks, with a significance value of 0.004. This illustrates the growing use of automated decision-making processes in the pharmaceutical supply chain. Current research findings support insights from the works of Mandania and Oliveira (2023) where it was highlighted that using machine learning techniques has been instrumental in promoting automated dynamic pricing and supply chain resilience in the UK, related sentiments were expressed by Karttunen *et al.* (2023) In a study in Finland, it was confirmed that using machine learning systems in digitalising the supply chain was associated with significant cost savings.

It appears that the application of machine learning is ubiquitously applicable in both developing and developed economic contexts if it is correctly implemented within organisations. This is evidenced by the similarities in the benefits associated with implementing machine learning systems in the supply chain. Given the above outcomes, this study accepts **H_3**. It asserts that machine learning-based decision-making has a positive impact on reducing the prevalence of supply chain risks in the pharmaceutical sector in Zimbabwe.

Automated dynamic pricing and supply chain risk

The study has established that leveraging automated dynamic pricing is linked to the ability of the pharmaceutical sector in Zimbabwe. This is evidenced by a significance value of 0.000, implying that dynamic pricing has the most potent effect on reducing supply chain risks associated with price variations in an economy characterised by price distortions and a hyperinflationary environment. These research results corroborate similar findings established from research by Kool *et al.* (2022).

These results support the benefits of automated dynamic pricing, as established in the works of Tuncay (2024) where it was highlighted that dynamic pricing is associated with improved customer relationship building and improved competitive advantage. It was highlighted that pricing adjustments during depression minimised warehouse costs and lowered the risk of obsolescence. Given the above outcomes, this study accepts **H_4** and states that automated dynamic pricing has a positive impact on reducing supply chain risks in the pharmaceutical sector in Zimbabwe.

Chapter summary

The chapter articulated the research results using descriptive and advanced statistical analysis. The results were collected from various participants in the pharmaceutical sector in Zimbabwe. The descriptive outcomes highlight a moderate to significant relevance of digitalising the pharmaceutical sector in Zimbabwe. These research results were confirmed by regression statistics, which specified that apart from artificial intelligence systems, the other three variables had a statistically significant effect on reducing data collection risks in the pharmaceutical sector in Zimbabwe. The upcoming chapter outlines the extent to which the study achieved its objective and proposes possible areas for future research arising from the study.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter specifies the extent to which the study resolved the objectives as stated in Chapter 1 and aligns with the methodology and results. The research was premised on digitalising the pharmaceutical sector in Zimbabwe's supply chain to mitigate risks. The primary objectives were to assess the impact of artificial intelligence systems, machine learning systems, blockchain technology, and dynamic pricing on the ability to mitigate supply chain risks. It begins by summarising the entire research, specifying the conclusions and recommendations, and proposing an area of future research that can be explored based on the outcomes of this research.

5.2 Summary of findings

The research revealed moderate levels of digitalisation in the pharmaceutical sector of Zimbabwe's supply chain. The study applied the diffusion of innovations and the UTAUT theory to frame the theoretical focus on the intensity of technology infusion in organisations. The research methodology was based on a quantitative approach, culminating in a survey method for data collection through a closed-ended and standardised questionnaire distributed to supply chain partners in the pharmaceutical sector in Zimbabwe. Research results suggested that emphasis was being placed on legacy systems in reducing supply chain risks in the pharmaceutical sector in Zimbabwe. Resultantly, the pharmaceutical sector in Zimbabwe is failing to deal with the threats to supply chain sustainability posed by the proliferation of contraband and counterfeit drugs that are disrupting the sustainability of the local pharmaceutical supply chain. The weak integration of artificial intelligence systems in the pharmaceutical sector in Zimbabwe reduces its conceptual appeal towards limiting supply chain risks in the sector. Otherwise, leveraging machine learning systems, blockchain technology, and automated dynamic pricing has been associated with a reduction in the supply chain risks

Conclusions

There is a limited application of digitalisation in the pharmaceutical supply chain, which is giving preference to legacy systems that have limited predictive power to help reduce disruptions affecting the sustainability of the supply chain.

Artificial intelligence and supply chain risk mitigation

Artificial intelligence systems have a negligible impact on the pharmaceutical sector in Zimbabwe's ability to mitigate supply chain risks. Although a 1 per cent increase in artificial intelligence system applications in the pharmaceutical sector in Zimbabwe is associated with a 0.035 percentage change in the pharmaceutical sector's ability to reduce supply chain risk, this effect was found to be statistically insignificant. To that extent, the application of artificial intelligence systems is limited across the pharmaceutical supply chain. This might demonstrate the scant application of big data analytics upon which artificial intelligence systems are built, so limitations in the use of artificial intelligence limit the predictive power of identifying supply chain disruptions within the sector and affect the agility of the pharmaceutical supply chain to detect, react and reconfigure its operations appropriately in line with the dictates of the operating environment.

Blockchain technology and supply chain risk mitigation

Regression statistics highlight that leveraging blockchain technology is the third most influential factor in enabling the pharmaceutical sector to reduce supply chain disruptions. The predictive value of blockchain technology is such that a 1 percentage point change in utilising blockchain technologies is associated with a 0.045 percentage point improvement in the pharmaceutical sector's ability to reduce supply chain variations. Leverage in blockchain technology has been associated with efforts to promote transparency of information sharing amongst participants in the pharmaceutical sector supply chain. This is of paramount importance, given the disruptions to the former pharmaceutical supply chains related to the infusion of counterfeit drugs, which pose a threat to public health.

Machine learning systems and supply chain risk mitigation

Regression statistics indicate a positive relationship between machine learning and the ability to mitigate supply chain risks. A 1% increase in investments in machine learning is associated with a 0.430% reduction in supply. These statistics indicate that both supervised and unsupervised machine learning, which leverage historical supply chain data, are instrumental in enhancing the ability of pharmaceutical sector supply chains to reduce disruptions. The efficacy of leveraging machine learning within the context of the pharmaceutical supply chain is based on participants' ability to share information, which can help enhance the system's learning capabilities to detect, sense, seize, and reconfigure supply chain activities, thereby mitigating the effects of disruptions.

Automated dynamic pricing and supply chain risk

Dynamic pricing has the most significant influence on managing supply chain disruptions in the pharmaceutical sector in Zimbabwe, which are characterised by price instability caused by a depreciating local currency and regulations governing the foreign exchange market. To that end, a 1% increase in dynamic pricing strategy is associated with a 0.482 percentage point change in the pharmaceutical supply chain's ability to reduce suffrage and disruptions caused by price distortions. Leveraging dynamic pricing reduces the bullwhip effect associated with changes in the end-user market, which can have significant impacts on the upstream participants in the pharmaceutical supply chain in Zimbabwe.

Recommendations

The following recommendations are proposed as best practices that participants along the pharmaceutical supply chain can adopt to improve their digitalisation scope and reduce disruptions in the supply chain.

Artificial intelligence systems and supply chain risk

It is essential to enhance and reevaluate pharmaceutical sector and artificial intelligence implementation policies and strategies, given the limited impact of artificial intelligence on reducing supply chain risks. Investments in artificial intelligence systems enable the pharmaceutical supply chain to effectively forecast demand and manage inventory, which are critical aspects of minimising disruptions across the pharmaceutical supply chain.

The focus of integrating artificial intelligence should also be placed on using complementary technologies, including machine learning systems, which have been found to significantly contribute to the sustainability of risk mitigation efforts within the pharmaceutical supply chain. In addition, leveraging machine learning is also associated with an enhanced predictive capacity in the pharmaceutical industry to limit disruptions. In this regard, it is also imperative for the pharmaceutical industry to leverage the Internet of Things to digitalise its operations, promoting the visibility and traceability of transactions and other activities that might potentially disrupt the sector's operations.

Blockchain technology and supply chain risk mitigation

The pharmaceutical sector needs to implement blockchain technology for tracking high-risk components that pose a threat to public health, such as counterfeit drugs. There is a need for stronger collaboration among supply chain participants to create a blockchain-based technological system that shares information and promotes transparency. This is essential in detecting the country of origin of different drugs and consolidating current efforts to mitigate the disruptions caused by these contrabands on the sustainability of the pharmaceutical supply chain. In addition, addressing the scalability challenges in the pharmaceutical supply chain is instrumental through developing a hybrid model which incorporates the use of cloud platforms and blockchain for enhanced security and operational efficiency.

Machine learning systems and supply chain risk

It is imperative to promote transparency in the decision-making of automated machine learning systems through stakeholder engagement. This process is essential in reducing potential bias that could undermine the pharmaceutical sector's ability to mitigate risks. Prioritising explainable ability in future intelligence systems helps in auditing future intelligence outputs as well as in refining the algorithms for supply chain-specific risks that require mitigation. It is also essential for the pharmaceutical sector to enter strategic partnerships with artificial intelligence vendors who specialise in supply chain analytics to help develop sector-specific systems that can predict supply chain disruptions.

Automated dynamic pricing and supply chain risk

The pharmaceutical sector can optimise the available pricing algorithms given the most substantial impact of dynamic pricing on reducing supply chain risks. Through refining these algorithms, the pharmaceutical supply chain will be in a position to balance its profitability objectives with risk minimisation through providing short-term incentives to increase demand during times of shortages. Leveraging real-time data related to inventory levels and competitive activity is also instrumental in the price adjustment process. Moreover, leveraging automated dynamic pricing based on usage rates can provide a fair assessment of the price variations that do not amount to discrimination.

Areas Of Future Research

Future research must undertake a comparative analysis of the relative influence that digitalisation is mitigating supply chain risks between developing and developed countries with the view of coming up with best practices on how various technologies can be leveraged within the context of resource competency shortcomings and expertise gaps that characterise developing countries.

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Appendix A: Questionnaire

I kindly request your participation in the study, which is focused on **digitalisation and mitigating supply chain risks in the pharmaceutical industry in Zimbabwe.** You can select an appropriate response from the given options. You are not expected to provide any personal information, and rest assured that all responses are kept confidential and are used for the intended academic purposes.

Section A: Organisational Characteristics

1. How long have you operated as a pharmaceutical supply chain partner?

   Less than 1 year 1 to 5 years
   2 to 5 years 6 to 10 years
   11 to 15 years More than 15 years

2. What role do you play in the pharmaceutical supply chain? "

   Raw material supplier Manufacturer Wholesaler
   Retailer
   Transportation and logistics

3. How big is your organisation relating to the number of employees?

   Between 1 and 10 11 to 20
   21 to 30 31 to 40
   41 to 50 51 to 100
   More than 100

Section B: Digitalisation

Using the scale below, kindly indicate your opinions on the following statements.

1: Not at all **2:** Very slightly **3:** Slightly **4:** Moderately **5:** Significantly **6:** Very significantly **7:** Extremely

Code	**Artificial intelligence systems**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
AI1	How has your organisation adopted AI systems into its core business strategy?							
AI2	How have employees across different departments adopted AI systems in their daily workflows?							
AI3	How are customers/users adopting AI-powered products or services offered by your organisation?							

AI4	How has your organisation invested in training and development programs to support adopting AI systems?							
AI5	How has adopting AI systems led to changes in organisational structure or processes?							
AI6	How has adopting AI systems impacted the overall productivity of your organisation?							
AI7	How has adopting AI systems influenced innovation within your organisation?							
	Blockchain technology	**1**	**2**	**3**	**4**	**5**	**6**	**7**
BC1	How has your organisation adopted Blockchain technology into its core business strategy?							
BC2	How have employees across different departments adopted Blockchain technology in their daily workflows?							
BC3	How are customers/users adopting Blockchain-based products or services offered by your organisation?							
BC4	How has your organisation invested in training and development programs to support adopting Blockchain technology?							
BC5	How has adopting Blockchain technology led to changes in organisational structure or processes?							
BC6	How has adopting Blockchain technology impacted the overall efficiency of your organisation?							
BC7	How has adopting Blockchain technology influenced innovation within your organisation?							
	Machine learning technologies	**1**	**2**	**3**	**4**	**5**	**6**	**7**
ML1	How has Machine learning-based demand forecasting significantly reduced inventory shortages and surpluses?							
ML2	How has Machine learning-driven projective risk analytics has improved organisational performance?							
ML3	How has Machine learning algorithms for anomaly detection in procurement and distribution have reduced the risk of counterfeit drugs?							
ML4	How has Machine learning logistics optimisation to minimise delays across the supply chain?							
ML5	How has integrating machine learning improves the reliability and quality of pharmaceutical raw material sourcing?							
ML6	How has adopting Machine learning impacted the employee productivity?							
ML7	How has adopting Machine learning influenced innovation within your organisation?							
	Automated dynamic pricing	**1**	**2**	**3**	**4**	**5**	**6**	**7**
DP1	How has automated dynamic pricing in your organisation optimised inventory levels?							
DP2	How has real-time price adjustments improved our ability to maintain a stable supply of drugs?							

DP3	How has automated dynamic pricing enhanced revenue management?							
DP4	How has using demand-sensitive pricing reduced financial risks associated with the expired pharmaceutical products?							
DP5	How has automated dynamic pricing improved the affordability and accessibility of essential medicines?							
DP6	How has automated dynamic pricing impacted the overall efficiency of your organisation?							
DP7	How has adopting automated dynamic pricing influenced innovation within your organisation?							

Section B: Supply Chain Risk

Using the scale below, kindly indicate your opinions on the following statements.

1. Extremely low risk
2. Very low risk
3. Low risk
4. Moderate risk
5. High risk
6. Very high risk
7. Extremely high risk

	Supply chain Risk	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SCR1	What is the current level of risk associated with supplier reliability and performance?							
SCR2	What is the current level of risk associated with inventory management and stockouts?							
SCR3	What is the current level of risk associated with disruptions to transportation and logistics?							
SCR4	What is the current level of risk associated with collaboration and coordination with suppliers?							
SCR5	What is the current level of risk associated with lack of visibility and transparency in the supply chain?							
SCR6	What is the current level of risk associated with product quality and safety?							
SCR7	What is the overall level of risk to your organisation's supply chain?							

Appendix B: Turnitin Report