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Industry 4.0 dislocations in small and medium enterprises

A supply chain management view



Edited by
David Pooe

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Published by AOSIS Books, an imprint of AOSIS.

AOSIS Publishing
15 Oxford Street, Durbanville, 7550, Cape Town, South Africa
Postnet Suite 110, Private Bag X19, Durbanville, 7551, Cape Town, South Africa
Tel: +27 21 975 2602
Website: https://www.aosis.co.za

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Cover image: This cover design was created by Leon Bellingan with the use of photographs by Unsplash (Red, blue and yellow intermodal containers photo – Free Background Image on Unsplash) and Pexels (Diverse Team Collaborating on Construction Plans · Free Stock Photo, A Two Engineer Talking Together · Free Stock Photo).

Submitted: 15 April 2025
Accepted: 13 March 2026
Published: 29 July 2026

Impression: 1

ISBN: 978-1-997449-46-1 (paperback)
ISBN: 978-1-997449-47-8 (casebound)
ISBN: 978-1-997449-48-5 (epub)
ISBN: 978-1-997449-51-5 (XML)
ISBN: 978-1-997449-50-8 (HTML)
ISBN: 978-1-997449-49-2 (pdf)

DOI: https://doi.org/10.4102/aosis.2026.BK572
How to cite this work: Pooe, D (ed.) 2026, *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town.

Printed and bound in South Africa.

Listed in OAPEN (http://www.oapen.org), DOAB (http://www.doabooks.org/) and indexed by Google Scholar.
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The publisher (AOSIS) endorses the South African 'National Scholarly Book Publishers Forum Best Practice for Peer-Review of Scholarly Books'. The book proposal form was evaluated by our Social Sciences, Humanities, Education and Business Management editorial board. The manuscript underwent an iThenticate similarity evaluation to compare the level of originality with other published works and confirmed originality and appropriate acknowledgements to other published works. The manuscript was subjected to a rigorous two-step single-blind peer review assessment before publication by two technical expert reviewers in the field, who did not include the volume editor and were independent of the volume editor, with the identities of the reviewers not revealed to the authors. The reviewers were independent of the publisher, volume editor and authors. The publisher shared feedback on the similarity reports and the reviewers' assessments with the manuscript's volume editor and authors to improve the manuscript. Where the reviewers recommended revisions and improvements, the volume editor and authors responded adequately to such recommendations. The reviewers commented positively on the scholarly merits of the manuscript and recommended that the book be published.

Research justification

Small and medium enterprises (SMEs) are widely acknowledged for their contribution to economic growth and development and continue to draw sustained interest from policymakers and academics. Despite their importance, SMEs remain vulnerable to major shocks and rapid technological change, particularly the advancements associated with Industry 4.0 (also referred to as the Fourth Industrial Revolution). Many SMEs lack the financial and technical capacity to assess, adopt and integrate these emerging technologies effectively.

This book addresses these challenges by demonstrating how SMEs can leverage supply chains as a strategic source of resilience, competitive advantage and technological adaptation. It argues that embedding SMEs within the supply chains in which they operate is essential for navigating the complex technology landscape of Industry 4.0. Instead of viewing themselves as passive observers of technological disruption, SMEs should recognise their potential to become active participants – and even leaders – in increasingly digital supply chain ecosystems.

The book consists of 10 chapters of original scholarly work, covering themes such as intelligent manufacturing (IM), blockchain technology (BCT), augmented and virtual reality, digital supply chain transformation and SME resilience. It is one of the few works that integrates the often-siloed discussions of Industry 4.0, supply chain dynamics and SME development.

Given its theoretical depth, methodological rigour (including systematic literature reviews, bibliometric analyses and case studies) and contribution to emerging debates, the book is targeted specifically at scholars and experts in SMEs, supply chain management and Industry 4.0 in South Africa and other emerging economies. It aims to stimulate further academic inquiry, support curriculum development and promote conceptual and empirical advancements in this growing field of research, particularly in an emerging economy like South Africa.

A systematic literature review, a bibliometric analysis and case studies were used as the methodology for the book's chapters. No part of the work was plagiarised or published elsewhere. In cases where chapters are based on a Doctor of Philosophy (PhD) study, the editors and authors confirm that they have been revised by more than 50% as per the minimum requirements of the Department of Higher Education and Training's *Research Outputs Policy of 2015* and that the relevant acknowledgement has been provided. All chapters were submitted to iThenticate, a plagiarism-detection software platform and, where applicable, authors adapted text and inserted acknowledgements for texts that demonstrated high similarity.

However, no plagiarism was detected in the literature reviews, research methods, findings and scientific contributions, and all chapters are free of plagiarism.

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List of abbreviations and acronyms

3D	three-dimensional
1IR	First Industrial Revolution
2IR	Second Industrial Revolution
3IR	Third Industrial Revolution
4IR	Fourth Industrial Revolution
AC	absorptive capacity
ADC	adaptive capacity
ADM	adaptive decision-making
AI	artificial intelligence
AIDS	acquired immunodeficiency syndrome
AM	additive manufacturing
AR	augmented reality
BCT	blockchain technology
BSC	balanced scorecard
CAD	computer-aided design
COVID-19	coronavirus disease 2019
CPS	cyber-physical systems
CSIR	Council for Scientific and Industrial Research
CSCO	chief supply chain officer
DCT	dynamic capabilities theory
DOI	diffusion of innovation
DSC	digital supply chain
DSCS	digital supply chain strategy
DSP	digital signal processing
ERP	enterprise resource planning
FDI	foreign direct investment
GDP	gross domestic product
HIV	human immunodeficiency virus
ICT	information and communication technology

ICTs	information and communication technologies
IM	intelligent manufacturing
IMS	intelligent manufacturing system
IoT	Internet of Things
IS	information systems
IT	information technology
KM	knowledge management
MERS-CoV	Middle East respiratory syndrome coronavirus
ML	machine learning
OECD	Organisation for Economic Co-operation and Development
PhD	Doctor of Philosophy
P2P	peer–to–peer
PO	purchase order
PPC	production planning and control
PPP	public–private partnership
R&D	research & development
RBV	resource-based view
RFID	radio frequency identification
RFP	Request for Proposal
RFQ	Request for Quotation
RFx	Request for 'X'
RPA	robotics process automation
SAIPA	South African Institute of Professional Accountants
SARS-CoV	severe acute respiratory syndrome coronavirus
SCM	supply chain management
SCR	supply chain resilience
SCV	supply chain visibility
SEFA	Small Enterprises Finance Agency
SMEs	small and medium enterprises
SMME	small, micro and medium enterprises
TAM	technology adoption model
TMS	transport management system
TPB	theory of planned behaviour
TRA	theory of reasoned action
UJ	University of Johannesburg
UK	United Kingdom
UNISDR	United Nations International Strategy for Disaster Reduction
UTAUT	unified theory of acceptance and use of technology

VCT	value chain transformation
VR	virtual reality
VRIN	valuable, rare, inimitable and non-substitutable
VUCA	volatility, uncertainty, complexity and ambiguity
WMS	warehouse management system

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Preface

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This book offers an in-depth examination of the intersection between Industry 4.0, also known as the Fourth Industrial Revolution (4IR), and supply chains, guiding small and medium enterprises (SMEs) on how to leverage or navigate any consequent dislocations.

The first chapter provides the reader with an introduction, context, historical development and characterisation of the 4IR. Chapter 2 provides a perspective on the notion and practice of supply chain management, illustrating how SMEs fit into the various elements of supply chains. Chapter 3 explores various technology adoption models, provides an overview of the digital supply chain strategy (DSCS) and examines its rationale and the barriers and enablers thereof. Chapter 4 discusses the concept of intelligent manufacturing (IM) and argues how SMEs can leverage the transition from traditional to intelligent manufacturing. Chapter 5 discusses how SMEs can embrace the use of blockchain technologies (BCT) in supply chains in a rapidly transforming, highly diversified and complex business environment. Chapter 6 focuses on the effective implementation of the DSCS and addresses key challenges that may arise during the process, outlining how to address them. Chapter 7 discusses ways to leverage Industry 4.0 in developing entrepreneurship and resilient supply chain ecosystems technology. Chapter 8 explains the need for SMEs to possess dynamic capabilities that enable them to respond flexibly and adapt to these changes. Chapter 9 provides an overview of augmented and virtual realities, examining their potential in business, current fields of application, adoption by SMEs and the critical success factors for their use. Finally, Chapter 10 explains that, in the context of the current Industry 4.0 reality, SMEs can develop the ability to be resilient and create a competitive advantage, thereby improving their performance.

How to cite: Pooe, D 2026, 'Preface', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, p. xxvii. https://doi.org/10.4102/aosis.2026.BK572.00

Chapter 1

The Fourth Industrial Revolution in context

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Introduction

Building upon previous industrial revolutions, Chapter 1 explores the emergence of the Fourth Industrial Revolution (4IR), also known as Industry 4.0, by outlining the trajectory from previous revolutions to the present digital age, setting the stage for understanding its significance. In addition, it examines the transformative technologies driving Industry 4.0, artificial intelligence (AI), Internet of Things (IoT), blockchain and robotics and discusses their potential to reshape industries and economies globally. The characterisation of Industry 4.0 and the emerging and current discourse on Industry 4.0 are also at the centre of this chapter. It seeks to provide a comprehensive overview of Industry 4.0, including its characteristics, benefits and implications for society and small and medium enterprises (SMEs). Through a multidisciplinary approach, this chapter aims to illuminate the opportunities and challenges of Industry 4.0, offering insights to inform strategic decision-making and foster innovation across large

How to cite: Pooe, D 2026, 'The Fourth Industrial Revolution in context', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 1–34. https://doi.org/10.4102/aosis.2026.BK572.01

corporations and SMEs. Ultimately, this chapter serves as a foundational resource for policymakers, educators, business leaders and entrepreneurs seeking to navigate the complexities of Industry 4.0 and harness its transformative potential for sustainable development and prosperity.

Background to Industrial Revolution

Historians believe the Industrial Revolution in the United Kingdom (UK) began in the mid–18th century. Most of the social activity at this time took place in small and medium-sized communities throughout the British Isles and the majority of Europe. Rarely did people leave their home village. The emergence of the First Industrial Revolution (1IR) marked a shift from small, cottage-based businesses, where most products were handmade, to factory-based mass production powered by steam and electricity. Many of the technological advancements that contributed to the 1IR were developed in the UK, where it all began around 1760 (Haradhan 2019). The Industrial Revolution represented a dramatic and long-lasting change in the UK's landscape and infrastructure during the 18th and 19th centuries, with textiles dominating during the early phases of industrialisation. The use of modern production methods in the textile industry marked a key turning point in history, affecting every aspect of daily life in one way or another.

The world continues to experience significant economic and business environmental transformations with new paradigms, deeply informed by digital technologies taking centre stage. The ongoing global changes and the exponential growth of technological intensity have blurred the line between the natural and virtual worlds, inspiring industries and governments to embrace the 4IR, also known as Industry 4.0. The fall of the millennium has seen increased exploitation of automation technology in organisational processes, affecting how firms conduct business. Large and small corporations have continued to explore how the technological revolution can influence their short-term performance and long-term sustainability. Digital transformation disrupts the ecosystem, leading to changes in interactions with customers, employees and other stakeholders (Fernández-Portillo et al. 2024). As novel technologies continue to invade business processes, innovative products, service offerings and positive impacts have emerged. Several machines, systems and sensors across the globe are connected, communicate and share information, presenting a new paradigm for business, social and other processes.

In South Africa, SMEs are central to the country's economic growth, employment creation and innovation and have remained vulnerable and prone to failure during this transformation. They face numerous challenges, including limited human resources and capital, which restrict their capacity to respond to market and environmental changes. Against the backdrop of this

technological transformation, information and communication technologies (ICTs) are necessary for stronger customer–supplier relationships, improved collaboration and increased productivity and efficiency. However, empirical evidence also shows that SMEs may not survive without appropriate technology adoption at the operational level (Endrődi-Kovács, Pérez Garrido & Sebrek 2024; Khanzode et al. 2024). In addition, limited experience, exposure and knowledge, along with absolute uncertainty about the use of technology, have been concerns for SMEs. Therefore, SMEs need to understand the significance and implications of the current and future revolutions to enhance their survival chances. The adoption and use of these emerging 4IR technologies have significant potential to contribute to sustainable supply chain success among SMEs in South Africa and other developing economies.

Understanding industrial revolutions

According to Ladenburg (2007), the word 'revolution' conveys a drastic change and is usually used in connection with political events, although it has also been used to describe economic upheaval. While no single event or precedent marks the beginning of a revolution, it changes the face of social and economic configurations worldwide and destabilises existing chains of command.

Definition of Industrial Revolution

The Industrial Revolution is one of the most celebrated achievements in human history, representing a decisive break in the history of technology and the economy. For instance, the popular inventions of the steam engine, coke smelting and others, which propelled the West into the mass prosperity of the 21st century, were significant industrial breakthroughs. Although there is no widely accepted definition of 'Industrial Revolution', some definitions have been commonly used. Despite the assertions of confusion surrounding the term, Liao et al. (2018) define the 1IR as the time during the 18th and 19th centuries when work began to be done more by machines in factories than by hand at home. Therefore, this definition makes it clear that machines have coexisted with human beings over time. Hoppit (1987) defines the Industrial Revolution as a significant discontinuity: the transition from one kind of society and economy to another, primarily from agricultural to industrial primacy. Vries (2008) states that the Industrial Revolution, as a generic term, refers to the emergence of modern economic growth during the transition from a pre-industrial to an industrial society. Agarwal and Agarwal (2017) define the Industrial Revolution as a structural shift in which a large proportion of the population transitioned from the agricultural to the manufacturing and mining sectors, leading to growth in the manufacturing sector and ultimately increasing national income.

This revolution is associated with the transition from a pre-industrial to an industrial society, characterised by persistent modern economic growth and substantial growth in real gross domestic product (GDP) per capita. Therefore, the Industrial Revolution represents a radical shift from a society in which most people lived on farms to one in which most people resided in towns and cities. The authors further noted that the Industrial Revolution brought advantages such as electricity, water, improved transportation, increased earnings and higher living standards. The overall consistency across the various definitions of the Industrial Revolution is the recognition of a shift towards modernisation, improved living standards, industrialisation, innovation and stronger economies.

Origins of Industrial Revolution

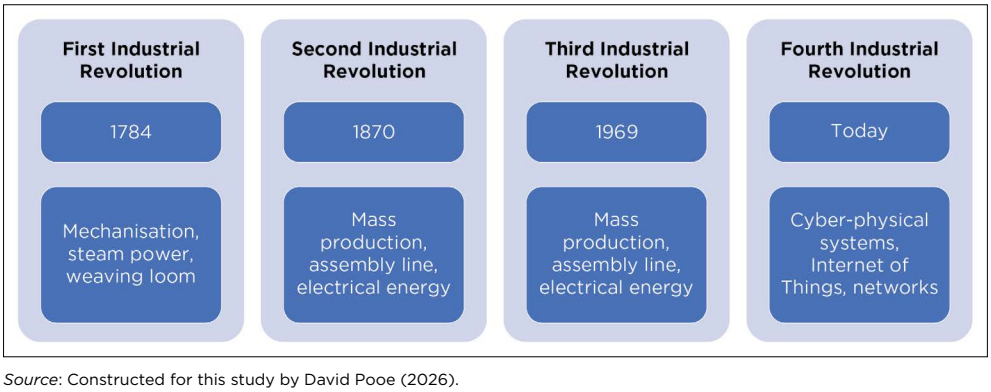
During the late 18th century, the Industrial Revolution began in the UK, bringing about civilisation, efficiency, improved economies and numerous other progressive developments that have enhanced the lives of countries and their people (Keshmiry & Hassani 2025). The surge in efficiency advancement was a singular and unique break in world economic history, marking the onset of a significant divergence between the successful Western countries and the rest of the world. These developments included the establishment of factory textile production, the shift to coke and coal in the iron industry and the refinement of the steam engine. These developments led to economic growth in the European continent. The Industrial Revolution brought modernisation to British society, as innovations helped grow the UK's economy, particularly its international economy, which was facilitated by economic developments that enabled the UK to achieve unique and highly remunerative opportunities (De Jong 2003). During the 1IR, the UK was the technological leader, which enabled the country to supply highly skilled personnel, including mechanically adept craftsmen. The workers could adapt, implement, improve and adjust to new technologies, providing micro-inventions necessary to make macro-inventions highly productive and remunerative. In addition, the UK's technological advantage facilitated a significant portion of the country's apprenticeship system, which was a dominant form of skill development at the time. The United Kingdom's Industrial Revolution was genuinely global and versatile, as it stimulated labour productivity in the agricultural sector in other countries, confirming the UK as among the first countries to experience the Industrial Revolution (Crafts & Harley 2002).

The advent of the Industrial Revolution brought about a progressive, developmental nature to civilisation and substantial development in countries that experienced it much earlier. Countries that did not industrialise earlier are still generally lagging behind in terms of the Human Development Index and the overall well-being of their citizens (United Nations Industrial Development Organisation [UNIDO] 2025). Consequently, industrialisation resulted in a marked reduction in hard labour and an improvement in the quality of life for many citizens. According to Viera (2017), since around 1815, the UK built a system of apprenticeship that was superior the likes of which had not been seen anywhere outside Europe. The system propelled the design and manufacture of machinery as many workers developed apprenticeship skills, resulting in relatively higher wages and economic growth for the UK.

Journey towards Fourth Industrial Revolution

The historical patterns of the Industrial Revolution began with the 1IR, which involved harnessing water and steam power to develop more systematic and efficient manufacturing forms. Typical descriptions mention the application of steam engines to mining and the role of steam power in enabling massive increases in manufacturing scale. Figure 1.1 illustrates the evolution of industrial development from the first to the fourth revolution since 1780 to date.

As seen in Figure 1.1, there has been a developmental trajectory from the 1IR to the 4IR, with each subsequent revolution building on the innovations of the preceding one. For example, steam power enhanced efficiency in the manufacturing sector: steel was used to build railway lines and ships were built from wood, enabling much-improved transportation of goods between countries. On the other hand, the innovations of the Third Industrial



Source: Constructed for this study by David Pooe (2026).

FIGURE 1.1: Evolution of industry from the First Industrial Revolution to the Fourth Industrial Revolution.

Revolution (3IR) have advanced significantly since the advent of Industry 4.0, which involves transferring autonomy and decision-making to cyber-physical systems (CPS) and machines, leveraging information systems (IS). There is an explicit complementary nature throughout all the revolutions, with one either building on or improving the other.

First Industrial Revolution

The First Industrial Revolution occurred from the late 18th to the early 19th centuries. It was characterised by rapid growth in the manufacturing industry, driven by the development of factories and the use of steam power. Ultimately, this development shifted the focus from agriculture to manufacturing and mining, affecting a significant portion of the population. The revolution introduced several progressive economic and technological developments in textiles, steam power and ironmaking. For instance, although people were already using wool for weaving and spinning at home, the 1IR introduced mechanised cotton-spinning techniques that drew energy from water and steam. The mechanisation increased workers' output and revolutionised the textile industry, making countries like Britain net exporters of cotton (Acemoglu & Johnson 2024). Significant technological changes also occurred in the metal extraction industry, and coal replaced firewood and other biofuels. In addition, the use of coal enhanced efficiency in the mining industry, as it required less labour for a given amount of heat than chopping wood did.

One of the most significant inventions of this era was the advancement in steam engine technology that increased their speed. Simultaneously, other technological innovations included the production of chemicals for glass, soap and bleach, as well as gas lighting and paper machines. Gas lighting enabled extended business hours, resulting in improved profits and greater convenience for consumers. The provision of streetlights enabled safe nightlife to flourish in towns, cities and households (Agarwal & Agarwal 2017). The steam engine pulled the world together and gave birth to modern transport infrastructure without denigrating road-building efforts. For example, the invention of the maritime steam engine in the 19th century drew the world to Africa. The economic growth of this era led to the emergence of a new class, known as the 'middle class'. This group did not emerge from a historically rich background, but was composed of bankers, teachers, doctors, lawyers, shopkeepers and merchants. This group could now afford to purchase fine clothing, houses, furniture and much more. However, although there were progressive developments in the UK during the 1IR, such as the introduction of the steam engine, which affected essential areas such as coal mining, railroads and powering new textile factories, these developments contributed insignificantly to productivity advances.

Second Industrial Revolution

The Second Industrial Revolution (2IR) occurred between 1870 and 1914, immediately after the 1IR. More advanced technologies and factories enabled farmers and manufacturers to produce more goods and products. It built upon the successes of the 1IR and introduced a much broader range of innovations. According to Mohajan (2020), the 2IR witnessed the emergence of new electricity-based manufacturing technologies, triggering further transformations and the launch of a 'new economy'. The Second Industrial Revolution brought about mass advancement in agriculture, manufacturing and transportation, including an abundant labour supply, strong government policies, new sources of power and an overall improved standard of living. The Second Industrial Revolution period was characterised by significant developments in steel, chemicals and electricity, with steel becoming widely used in construction, railway tracks and ships. Steel was also considerably more durable, stronger and, as such, enabled the rail network to expand. Electrification was also a fundamental invention during the 2IR. Electric lights in factories improved working conditions, reducing hazards such as fire, heat and pollution associated with gas. This invention revolutionised the world forever (Haradhan 2019).

Other technological developments of the 2IR were experienced in the petroleum, maritime, rubber, automotive, telecommunications and fertiliser industries. Consequently, the first seafaring iron steamboat was invented, which enabled faster transportation (Agarwal & Agarwal 2017). The other most crucial invention in telecommunications was the telephone, which enabled people to feel more connected than ever before and to exchange business ideas at speed (Zhang 2026). This revolution transformed the more advanced technological systems, such as electricity, from an exception to a commonplace, enabling them to be enjoyed by a larger population. The Second Industrial Revolution brought electricity from steam turbines, the replacement of wood with steel in the maritime industry and a more substantial science feed.

Third Industrial Revolution

During the Third Industrial Revolution, manufacturing became digital. There was convergence in many remarkable technologies, including intelligent software, novel materials, more dexterous robots, three-dimensional (3D) printing and various web-based services. Renewable energy was found everywhere, not only in certain places, and promoted the concept of a decentralised society, where citizens produce goods, services and energy by themselves, utilising digital production technologies and distributing renewable energy resources. The discovery of the transistor catalysed the

3IR, ushering in the electronic age that brought computers and the Internet (Kazanskiy, Khonina & Butt 2024). Gregáňová and Papcunová (2022) state that the Internet has become an integral part of modern people in the information society and an important tool for communication. Penprase (2018) states that one of the most considerable ripples of the 3IR was the move towards online education, which culminated in 'massive open online courses' (or MOOCs, as they are popularly known). The Third Industrial Revolution made education much more accessible. Information became more readily available and at low cost, shifting the focus to dynamism in educational pedagogies and collaboration among diverse teams in a project-based, peer-learning environment.

The Third Industrial Revolution inventions include the internet, 3D printing and renewable energy. The advancement of 3D modelling software has allowed designers to conceive, modify and improve designs quickly, from small, everyday products to more complex components that can now be manufactured. This helped release creative potential towards new forms embedded in everyday objects (Mateti et al. 2023). Intelligent technologies are now being used to reconfigure the world's power grid so that people can produce renewable energy and share it peer–to–peer (P2P), creating a new decentralised form of energy use. Modernisation was evident in the 3IR and in the innovations of the 1IR and 2IR. Digital innovations made collaborations between design and production much more manageable, overcoming limitations of distance and logistics.

Fourth Industrial Revolution

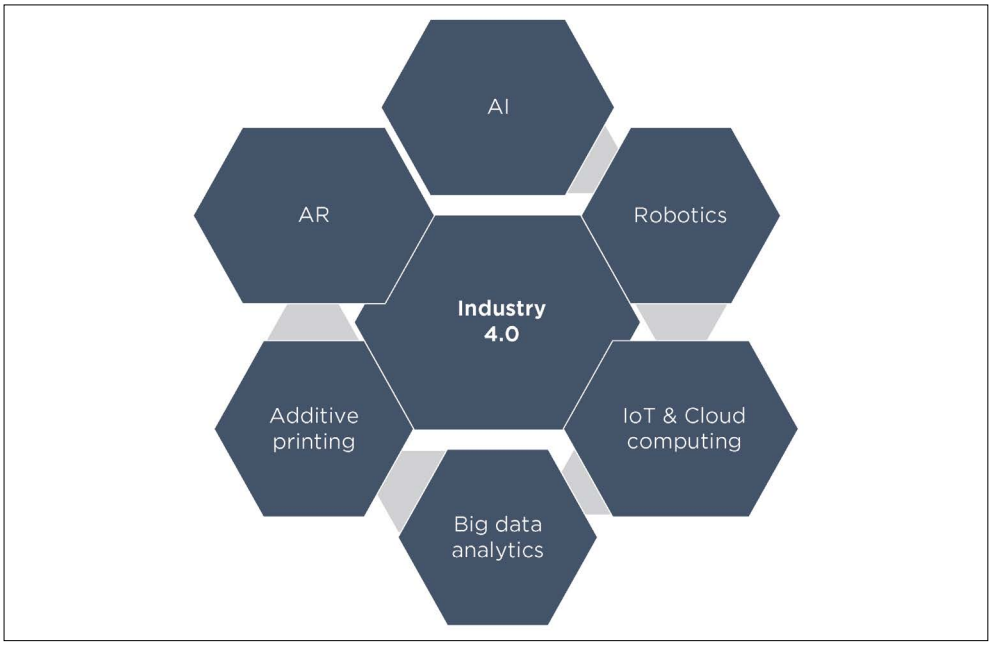
The Fourth Industrial Revolution encompasses a range of novel technological innovations that are blurring the lines between the physical, digital and biological worlds, simultaneously disrupting all social and economic disciplines. The phrase 'Industrie 4.0', translated to Industry 4.0 or simply 4IR, was coined in 2011 as part of a German government initiative to advance the digitalisation of manufacturing. The term was first introduced during the Hannover Messe in 2011 and was officially declared a German strategic initiative in 2013 to transform the manufacturing industry (Pfeiffer 2017). Since then, it has gained momentum, and the world has witnessed advancements in disruptive technologies, including CPS, the IoT, cloud computing and big data. The interactions among these intelligent ICT systems, the digitalisation of services and the ability to handle big data have emerged as the principal technical drivers of Industry 4.0. It thus appears to be a promising technological revolution that can aid in achieving production efficiency, accuracy and precision (Klingenberg, Borges & Antunes 2021).

The underlying philosophies of Industry 4.0 are summarised as the connection of machines, business processes and systems and human

beings, creating intelligent value chain networks that operate autonomously. As a result, it can drastically improve production across industries through novel modes of production, ensuring a sustainable future. Evidently, the advent of Industry 4.0 has led to industrial, operational and value chain optimisation as interaction costs and information asymmetry continue to fall. It is also essential to understand how developments in 4IR have affected society and its potential to widen inequality once machines replace human beings in the workplace, as some argue. One should also consider factors that mitigate cybersecurity risks and the vulnerability and exposure of data in public spaces, particularly in terms of personal data protection against hacking. The advent of the 4IR has introduced new business models, caused disruptions in sectors and reshaped the socioeconomic sectors. These factors collectively demonstrate the profound changes occurring across all industries. Schwab (2016) supports the point by stating that 4IR is unfolding at an exponential rate, not only changing the 'what and how' of doing things but also who we are, as we experience the transformation of the entire system across and within countries, companies, industries and society. It is the pace of change and the exponential rate of 4IR that cause anxiety across industries.

Characterisation of Industry 4.0

The Fourth Industrial Revolution or Industry 4.0 has emerged as the current movement in automation and data exchange in production technology, reshaping manufacturing processes. Industry 4.0 is a revolutionary wave that extends advanced digital technologies to a broader context, including CPS (connections between the real and virtual worlds), the IoT and cloud computing (Qin 2026). The wave has led to increased electronic device usage, reduced production costs and a shift from the real world to the digital world. Although the previous three industrial revolutions have seen significant productivity improvements, they have had little effect at the shop-floor level. Industry 4.0 is more advanced than the past three revolutions and drives productivity much more effectively by connecting the business's support functions, such as engineering. According to Schwab (2015), we stand on the brink of a technological revolution that will alter how we live, work and relate to one another. This is due to the scale, scope and complexity of the 4IR. It is expected that the transformation brought about by the 4IR will be unlike anything humankind has seen before. Schwab (2015) further notes the improved connectivity between systems enabled by mobile devices, which provide extraordinary processing power and storage capabilities, as well as unlimited access to knowledge. Figure 1.2 is a diagrammatic representation of some of the Industry 4.0 technologies discussed in this book.



Source: Constructed for this study by David Pooe (2026).
Key: AI, artificial intelligence; IoT, Internet of Things; AR, augmented reality.

FIGURE 1.2: Industry 4.0's industrial technologies.

Industry 4.0 presents an undeniable opportunity to increase productivity significantly by scaling up the adoption of merging disruptive technologies. The remarkable speed and progressive developments associated with the 4IR are causing anxiety and excitement across industries. It appears to be set to revolutionise the way we live, work and relate to one another (Mayer 2025). Some immediately noticeable benefits include the speed and efficiency with which goods and services are produced and customised. In summarising all revolutions, the 1IR provided water and steam to mechanise production, the 2IR used electric energy to create mass production and the 3IR used electronics and information technology to automate production. The Fourth Industrial Revolution builds on the 3IR, characterised by exponential expansion that merges technologies, blurring the lines between the physical, digital and biological spheres, completely uprooting industries worldwide (Fawna 2023).

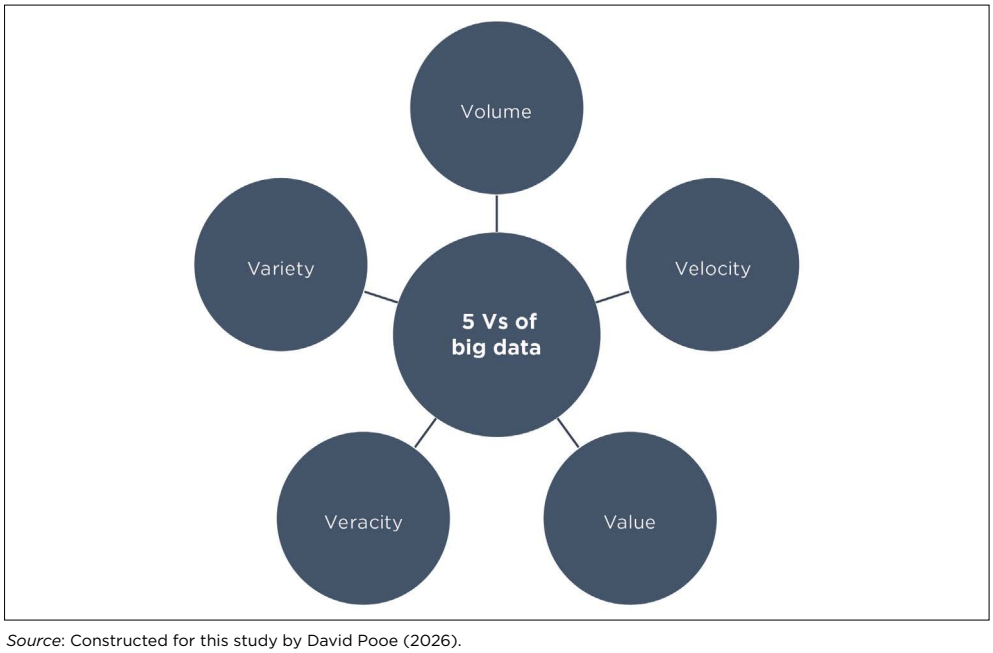
These technologies are transforming production processes and business models across industries, creating a new industrial landscape dominated primarily by information, networks and connectivity. This represents a new industrial maturity stage for product firms, enabled by the industrial IoT, in which products and processes are interconnected and integrated to deliver

greater value to customers and improve the company's internal operations. Therefore, it is evident that 4IR facilitates process connectivity in the development of goods and services, with an enhanced focus on customer value. As depicted in Figure 1.2, Industry 4.0 is characterised by the convergence of technologies such as robotics, AI, virtual reality (VR), the IoT, 3D printing and blockchain, as discussed in the sections that follow.

Big data analytics

Big data analytics refers to the process of manipulating data to reveal patterns, trends and correlations that support data-driven decision-making (Cao 2025). Big data analytics procedures are predominantly based on statistical analysis methods, such as clustering and regression, designed to make large volumes of data more usable for decision-making. The five primary and fundamental qualities of big data, also known as the 5Vs, are velocity, volume, value, variety and veracity, as shown in Figure 1.3.

Understanding the 5Vs enables data scientists to derive greater value from their data and helps the organisations they work for to become more customer-centric. Individuals, businesses and machines now produce massive volumes of data. Examples include social media, cloud applications and data from machine sensors. Businesses can gain insights from the vast amounts of data available today thanks to big data analytics.



Source: Constructed for this study by David Pooe (2026).
FIGURE 1.3: The 5Vs of big data.

Companies can use their data to identify opportunities for optimisation and improvement. Across all corporate sectors, improving efficiency results in more efficient operations, increased profits and satisfied customers.

Artificial intelligence

Artificial intelligence is defined as 'the ability of machines to perform tasks that typically require human intelligence' (Schoser 2023, p. 424). Thus, AI is commonly referred to as a field of science that describes machines' capacity to perform human-like functions such as reasoning, learning, assessing and observing. It is also argued that AI is an area of computer science that emphasises the creation of intelligent machines that work and react like humans, such as speech recognition, virtual assistance, search engine results (e.g. ChatGPT), learning, planning and problem-solving (Ghareeb, Almansooori & Ismail 2021; Reyna 2023). In recent years, AI technologies have been extensively applied in health care, advertising, aviation and image recognition, with real-world examples ranging from autonomous cars and chatbots to medical diagnosis.

Artificial intelligence technologies power self-driving car systems, enabling these cars to make real-time judgements based on information gathered from their sensors. For instance, a self-driving vehicle will utilise AI to decide the best course of action, such as slowing down or stopping, when it detects a pedestrian crossing the road. It is impossible to understate the role that AI plays in companies such as Uber, Airbnb and Etsy. The Airbnb site automatically activates its 'Smart Pricing' function when you create a listing. At this point, AI enters the picture, enabling Airbnb to automatically adjust pricing for millions of units based on variables such as demand, seasonality and local events. There are, however, limitations to AI applications, at the forefront of which is a general lack of common sense and the inability to make judgements beyond its acquired knowledge. Another limitation is that AI lacks emotional intelligence and, as such, is unable to deal with basic human emotions such as anger, pain and anxiety (Agrawal 2025).

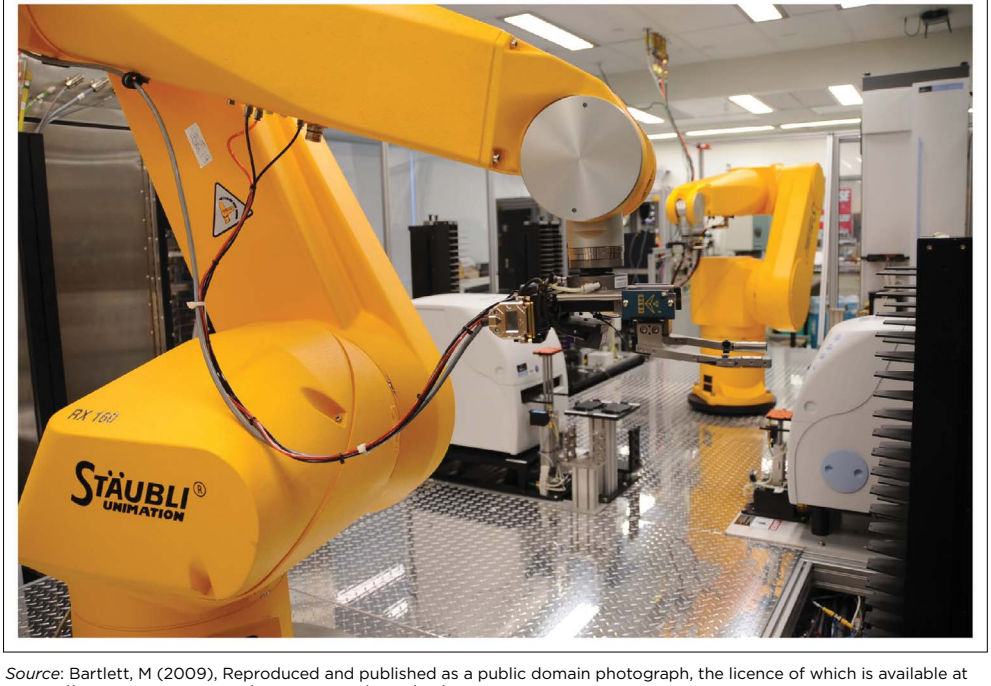
Robotics

Robotics is a field of engineering and technology focused on the design, construction and operation of robots. Robots are programmed machines capable of carrying out complex series of actions with little to no human input (Robocraze 2024). Robots are enabled to be autonomous through the rapid development of machine, sensor, actuator, digital electronics and microprocessor technologies. A robot is an electrochemical device with multiple degrees of freedom that can accomplish various tasks (Chang 2020). The concept of robotics is discussed in detail in Chapter 4. These are some types of robots and their uses.

Industrial robots

One of the most popular variations of robots is the industrial robot, which is typically a jointed structure used to perform industry-related tasks autonomously. Industrial robots are helpful because they are fast, powerful, dexterous and sensitive in manipulating diverse products (Javaid et al. 2021). The distinctive areas in which SMEs can employ industrial robots include, but are not limited to, welding, painting, assembly, packaging and labelling, palletising, product inspection and testing. For instance, industrial robotic technology can be applied in picking and placing goods from conveyor lines with high endurance, speed and precision. Figure 1.4 shows a typical industrial robot used in manufacturing.

Industrial robots can also load packaged items onto pallets with precision, saving manufacturers time, money and other resources. Another area where industrial robots have been observed to excel, particularly among SMEs, is spray painting. These robots are generally lightweight, thin and versatile, making them well-suited to the volatile, hazardous nature of solvent-based paints and coatings. It has been observed that a robot's painting is even, uniform, of high quality and precise, as the machine can access difficult-to-reach places. Because robots possess a level of flexibility that humans find difficult to achieve and operate at a high repetition rate without fatigue, this results in increased productivity.



Source: Bartlett, M (2009), Reproduced and published as a public domain photograph, the licence of which is available at <https://creativecommons.org/publicdomain/mark/1.0/deed.en>.

FIGURE 1.4: Industrial robots.

Medical robots for surgery

Over the past three decades, the use of medical robots has increased for performing various medical procedures. By definition, medical robots are robotic machines used in the field of health sciences to perform procedures and activities that medical practitioners and personnel would ordinarily perform (Silvera-Tawil 2024). Among these robots, there are medical devices that typically perform major tasks such as surgery, diagnosis and drug delivery, assistive robotics, including wearables, robots that mimic the human body in the form of artificial organs and body-part simulators. There is evidence that, in the future, the number of health tasks robots can perform will increase dramatically. Medical robots enable fast and precise operations with fewer mistakes. They can make small incisions and perform major operations with minimal damage to the patient. This results in a shorter recovery period and the use of more hygienic, safer equipment. At both large and small scales, medical robots have demonstrated their ability to reduce the prevalence of human error and the potential for mechanical failure (Cruz, Oliveira & Correia 2024). As such, these are evidently useful for small firms operating in the medical field.

Robotic aircraft and boats

There has also been an increase in the development and use of autonomous robotic aircraft and boats, which operate independently to perform military, civilian and rescue missions (Wang, Hagemann & Gonzalez-Garcia 2026). In the aviation industry, there has been a remarkable integration of robotic aircraft, promising improved cost, time and access efficiency. Advances in aircraft automation have enabled increased convenience in the carriage of goods, the opening up of new routes and improved delivery speeds. Autonomous boats, which are capable of accurately mapping and controlling human transportation, have also been developed. These self-driving robot boats are already being used to transport small items, and modifications are underway to accommodate human passengers (AIJRF 2022). Powered by robust algorithms, these autonomously navigated boats can deliver consignments, collecting data along the way and returning to their location with very low error margins. Robotics has emerged as an interdisciplinary component of the broader 4IR context, poised to expand as the list of activities that require autonomous or semi-autonomous execution continues to grow. Several cutting-edge robots are emerging at an unprecedented rate, fuelling the potential for a ‘robotic revolution’. It has been observed that SMEs can benefit from robotic technology, as it eliminates labour-intensive activities that often lead to physical strain or injury among employees, thereby increasing productivity and profitability (Arosystems 2024). However, robots cannot reach the

same level as humans because they are programmed to perform specific functions based on factors determined entirely by humans. For example, they cannot change plans as humans do or plan for new things unless they are programmed to do so.

Internet of Things and cloud computing

The Internet of Things is defined as the connection, communication and remote management of multiple networked, automated devices via the internet. Other scholars have referred to IoT as the point where there is a relatively high connection of 'things or objects', creating a worldwide network of objects uniquely linked on standard communication protocols and enabling the gadgets to send and receive data. Internet of Things is thus a scenario in which network connectivity and computing capabilities extend to objects, sensors and everyday items not typically considered computers, allowing them to generate, exchange and consume data with minimal human intervention. All of these definitions share a common characteristic: an object's ability to communicate. This capability delivers the power of IoT through data. Through arrays of sensors, each IoT device is projected to generate data that can be used to increase human collective knowledge and intelligence (Kayyali 2022).

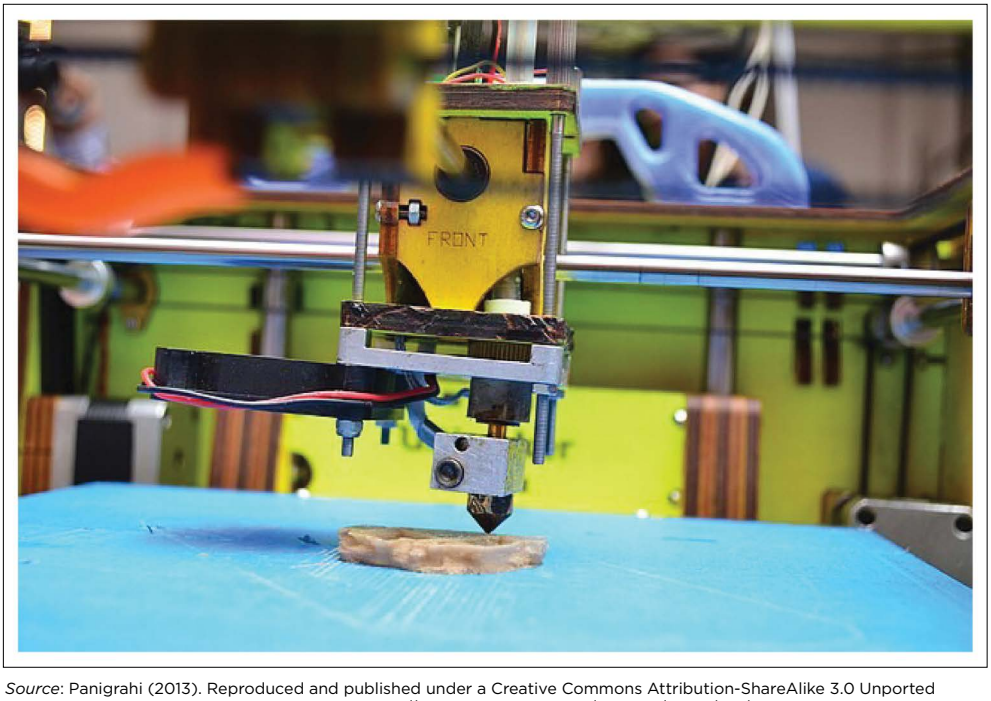
Cloud computing, on the other hand, refers to the delivery of computing services over the internet ('the cloud'), encompassing servers, storage, databases, networking, software, analytics and intelligence to facilitate faster innovation, more adaptable resource utilisation and cost savings (IBM 2026). Since SMEs operate in an era of ubiquitous computing technologies, they need to intensify their investments in these emerging technologies. Accessible data, automated syncing, ease of remote work and simple backups are a few advantages of cloud computing for small enterprises. The advantages of cloud computing for SMEs also include unmatched cybersecurity, enhanced flexibility and scalability, ongoing software updates, increased employee productivity and improved teamwork. Both IoT and cloud computing allow for real-time connectivity and integration of production and consumption processes. The Internet of Things enables access to cloud data and allows for the monitoring and control of the physical world from a distance, enabling many physical objects to act in unison through ambient intelligence (Sonthalia & Puneet 2025).

Additive printing

Additive printing, commonly known as additive manufacturing (AM) or 3D printing, is a computer-aided design (CAD) process in which 3D objects are fabricated by adding material layer by layer (Behera 2023), as illustrated

in Figure 1.5. Another definition is provided by Ponis et al. (2021), who state that additive printing, also known as 3D printing, is considered a disruptive technology for producing components with typologically optimised complex geometries and functionalities that are not achievable through traditional methods. Advances in AM have unlocked a broader range of production applications, unveiling new opportunities to produce high-precision products. Additive manufacturing emerged from developments across various technology sectors, including improvements in computing power and reductions in mass storage costs, which enabled the processing of large amounts of data typical of modern 3D CAD models within reasonable time frames (Ben Said et al. 2025).

Three-dimensional computer graphics use a 3D representation of geometric data stored in a computer to perform calculations and render images. Computer graphics is, therefore, the creation and manipulation of graphic images by means of a computer. These have proven valuable even for SMEs in South Africa, enabling firms to reduce lead time, outsourcing costs and manufacturing costs. Firms across various industries, including aviation, automotive, consumer goods and medical, have begun using 3D printing to enhance efficiency, streamline supply chains and improve productivity and market share. Chapter 4 discusses AM at great length.



Source: Panigrahi (2013). Reproduced and published under a Creative Commons Attribution-ShareAlike 3.0 Unported License, the licence of which is available at <https://creativecommons.org/licenses/by-sa/3.0/deed.en>.

FIGURE 1.5: Additive printing.

Emerging and current discourse on Industry 4.0

Industry 4.0 has garnered significant attention and interest across various industries, governments and societies. This is because the advanced technologies of the 4IR can deliver significant improvements across every aspect of human life, surpassing those of the three earlier revolutions. For example, many people in the world now use social media platforms to connect, communicate and innovate. In addition, 4IR has brought about radical changes in process automation, particularly in the manufacturing industry, thereby improving productivity. These developments present consumers with an opportunity to influence the production of goods and services they consume, enabling greater flexibility and speed. It is, however, imperative to adopt a structured, systematic 4IR implementation strategy that enables institutions to take an integrated approach as they continue to experiment and respond to the opportunities presented by 4IR characteristics. Several researchers have provided insights that advocate in favour of or against 4IR, and these discourses have emerged, as outlined in Table 1.1.

Technological discourse

According to Lee et al. (2018), the world is currently facing a period in which several technological disruptions, such as the integration of technology and AI, will generate entirely new production processes in manufacturing and services with lower resource intensity. On the other hand, digitalisation will permeate all sectors, generating new services and fostering closer customer interaction. However, technological unemployment remains a pressing problem that will exacerbate inequalities and widen the gap between labour and capital returns.

TABLE 1.1: Emerging and current discourse on Industry 4.0.

Discourse	Research
Technological discourse	Agbehadji, Awuzie and Ngowi (2021), Benassi et al. (2022), Nyagadza et al. (2022), Shi, Li and Fu (2020), Shumba and Saruchera (2023), Uleanya (2023)
Impact of innovation	Chen (2017), Dosso, Nwankwo and Travaly (2021), Kruger and Steyn (2020), Mhlanga, Ndhlovu and Hofisi (2021)
Policy discourse	Fataar (2020), Maponya and Naidoo (2023), Ostrowick (2021)
Data security	Chen and Zhao (2012), Ienca and Vayena (2020), Kaufman (2009), Shen et al. (2019)
Institutional readiness	Al-Ghnimi, Al-Maskari and Al-Riyami (2022), Dosso, Nwankwo and Travaly (2021), Ocholla and Ocholla (2020), Olaitan, Issah and Wayi (2021)

Source: Compiled for this study by David Pooe (2026).

Impact of innovation

There is a likelihood of higher income levels as entrepreneurs continue to implement novel ideas (Kritikos 2024). There is also a general likelihood of improved quality of life worldwide as income levels continue to rise. The technological innovations accompanying Industry 4.0 are causing a supply-side shift that is likely to spearhead industrial efficiency and productivity, resulting in lower transport and communication costs and ultimately, in more effective logistical processes and supply chains (Koskin & Van Nguyen 2026). As trade prices continue to decline, opportunities for greater innovation emerge, particularly among SMEs whose financial positions are typically constrained. Alongside this innovation, new markets are likely to emerge, driving economic growth and development.

Policy discourse

Policymakers should embrace emerging 4IR technologies and take advantage of the current technological wave to facilitate progress towards compliance in areas such as low-carbon and climate-resilient developments (Alexander 2021). Policymakers have the crucial task of deciding on the validity and sustainability of current policies, given the room to improve future prospects by leveraging more efficient technologies. The World Economic Forum identified other emerging policies, such as the 4IR Earth Initiative, recent G20 policy briefs and statements and other public–private partnerships (PPPs) that recognise and aim to address the challenges of this transition (World Economic Forum 2026). Harnessing the 4IR developments will require transforming the enabling environment through governance frameworks and policy protocols, investment and financing models, prevailing incentives for technology development and the nature of societal engagement. All of these will require proactive collaboration between policymakers, scientists, civil society, technology champions and investors.

Data security

There is a need to address potential concerns about data security and privacy, as well as the extent to which data can be anonymised. Therefore, companies supplying 4IR technologies have a duty to assure consumers about the safety and security features of their products. One of the most significant individual challenges posed by new information technologies is privacy. While it is instinctively understood that the tracking and sharing of information about our private lives are a part of the latest connectivity, the issue of loss of control over personal data will only intensify in the years to come.

Institutional readiness

Industry 4.0 fosters open connectivity, driving innovation, advancing technology and reshaping market dynamics, allowing information technology to permeate all sectors, primary, secondary and tertiary, and creating a fertile ground for dynamic interactions between technology, markets and society. These evolving combinations are constantly redefining the way industries operate and interact. The authors emphasise the urgent need for an institutional framework that can effectively accommodate the vast scope and swift pace of these changes. Without adaptive and forward-thinking institutional responses, societies risk being unprepared for the transformative effects of Industry 4.0. Establishing such a system is not only essential for managing disruption but also for harnessing the full potential of technological progress to foster inclusive and sustainable growth.

Benefits of Industry 4.0

Industry 4.0 presents the entire supply chain with opportunities to innovate and, simultaneously, this enhances industrial capability for innovation-driven, sustainable manufacturing. This represents a case in the supply chain where:

> [*T*]he right products, in the right quality and quantity, are delivered to the right place, for the right customers, at the right time at the right cost, while minding the environment. (Rushton, Croucher & Baker 2022, p. 34)

The growth in Industry 4.0 adoption creates a platform for firms to design novel solutions for future-oriented manufacturing, procurement and logistics management. To leverage the benefits of the Industry 4.0 paradigm fully, firms must integrate it into their corporate strategy while focusing specifically on the unique needs of the firm in this context (De Oliveira, Gonçalves & Laurindo 2022). In addition, given that future technological directions and possibilities remain vague and uncertain, firms need to formulate appropriate technology strategies that support interaction with emerging technological developments in Industry 4.0. Some evolutionary developments in 4IR which are likely to benefit SMEs include these factors.

Barrier reduction

The impact of 4IR technologies is also growingly evident among SMEs. For instance, in West Africa and Kenya, blockchain has enabled the efficient verification of property records and transactions and increased credit availability across several formerly unorganised economic sectors. Blockchains are immutable, which lowers the cost of risk and fraud. In Africa, there are also numerous opportunities to create jobs. These methods can be

transformative, given that informal businesses account for 55% of GDP in sub-Saharan Africa, with significant variations across countries. Their effects may snowball: financial inclusion increases because it leads to higher capital accumulation, investment and employment opportunities. Employees in Africa are already becoming better prepared to take advantage of the 4IR's opportunities; for instance, the World Economic Forum Report (2017) predicted that the proportion of workers with at least a secondary education is expected to rise from 36% in 2010 to 52% in 2030. Researchers also predicted that 4IR would most likely reduce the barriers between large and emerging corporations, owing to technologies such as 3D printing, which allow entrepreneurs to prototype and bring their products to reality without traditional constraints. This democratisation of technology enables SMEs to compete with larger counterparts by leveraging advanced manufacturing capabilities without substantial capital investment.

Complex problem-solving

Complex problem-solving entails making decisions based on observations and inquiries, monitoring potential future changes that could affect the viability of a solution, and understanding the effects of a proposed solution on both the affected parties and the environment. Workers must improve their proficiency in these 'soft' skills owing to the influx of new products, technologies and work methods. There is nothing soft about them; in fact, rather like concrete, they form the unshakeable base of client, workplace and business success. Although AI systems that can solve complex problems rationally could threaten many types of employment, they also offer new avenues for economic growth. While self-driving cars may gradually reduce the need for taxi and Uber drivers, the impact of autonomous trucks on the shipping industry could be far more significant, potentially leading to a substantial decrease in employment opportunities for truck drivers (World Economic Forum 2021). Schwab (2015) posits that the cognitive abilities that underpin today's educational institutions will remain crucial as technology increasingly replaces knowledge-based jobs; however, behavioural and non-cognitive skills required for teamwork, innovation and problem-solving will also become increasingly important.

New growth opportunities

The convergence of technologies that dissolve the boundaries between the physical, digital and biological realms goes beyond merely combining complementary tools; it actively creates new markets and unlocks fresh growth opportunities for all stakeholders involved in innovation. This transformative fusion draws on incremental advancements across multiple disciplines, integrating them to produce entirely new products and solutions

that would not be possible in a single field alone. As a result, it not only enhances existing capabilities but also fosters the emergence of disruptive innovations that redefine industries. The Fourth Industrial Revolution technologies provide the tools that cities need to undergo a technological revolution, as well as the data needed to monitor and manage entire cities. Many of these methods were employed during the coronavirus disease 2019 (COVID-19) pandemic to prevent the virus from spreading to bigger or unaffected areas. The widespread adoption of digital technologies holds immense potential to empower marginalised populations by providing greater access to knowledge, employment and essential services, ultimately improving their quality of life. Emerging technologies enhance the ability to collect and analyse data, enabling more targeted and effective strategies for poverty alleviation. A clear example of this is the transformative effect of mobile-based financial services, such as M-PESA, which have already demonstrated their ability to improve the lives of underserved communities. These tools are especially impactful for women, who are key drivers of sustainable poverty eradication. By offering secure platforms for saving money, these services help households to build assets, increase their financial resilience and break the cycle of poverty.

Enhanced future

Industry 4.0 is fundamentally altering global labour and production systems, necessitating that job seekers acquire the competencies required to respond swiftly to the demands of African businesses and automation more generally. Increased human productivity is one of the key benefits of Industry 4.0. With the help of technology such as AI and automation, which are enhancing our professional lives, we are now more capable than ever of making wise decisions quickly. Robots will improve human life in the future: they will cook food, play music, record our shows, drive cars and much more. Therefore, robots have the potential to enhance the quality of life significantly across various settings, including at home, in the workplace and in public spaces, by automating routine tasks and increasing efficiency. At the same time, the development and deployment of customised robots are anticipated to generate new employment opportunities, elevate the quality of existing jobs and reduce the burden of repetitive or hazardous work. This shift allows individuals to dedicate more time and energy to creative, meaningful and personally fulfilling activities, ultimately contributing to greater job satisfaction and overall well-being.

Interconnectivity

The Internet of Things enables the interconnectivity of physical devices, providing advanced connectivity for devices, systems and services that

extend beyond machine-to-machine communications to encompass various protocols, domains and applications. Klingenberg, Borges and Antunes (2022) argue that while the technologies associated with Industry 4.0 tend to evolve gradually rather than cause abrupt disruptions, it is their integration and the environments in which they emerge that hold the potential for profound societal and economic transformation. It is this cumulative and contextual impact that ultimately defines the revolutionary nature of Industry 4.0, marking a fundamental shift in how we live, work and interact with one another. The Industry 4.0 characteristics introduce a new communication channel for continuous information exchange, customer-oriented adaptation of products and services and increased value for both organisations and customers. These developments yield significant gains across various industries. This is, therefore, an apparent revolution and not an evolution, as others have argued, that changes human lives beyond imagination. There seem to be benefits in embracing the technological innovations enabled by 4IR. However, industries and governments alike must embrace these changes responsibly by developing policies that govern how innovation should be managed to avoid harming people and to operate within highly ethical business practices. It is also imperative to manage the effects of these changes on people and workers. There are significant threats and disadvantages, such as job losses from automation, misuse of personal information owing to easy access, and increased fraudulent activity from system hacking and cyber fraud. Therefore, a collaborative effort is necessary among executives and institutions to share ideas, including policy positions.

Klaus Schwab, founder and executive chairman of the World Economic Forum, author of *The Fourth Industrial Revolution*, said: 'The changes are so profound that, from the perspective of human history, there has never been a time of greater promise or potential peril' (Schwab 2016, p. 1).

Industry 4.0 and society

The history of previous industrial revolutions demonstrates that while technological innovation has brought widespread progress, it has also led to significant adverse side effects. For instance, the introduction of steam engines, steel production and railroads was accompanied by hazardous factory conditions, the exploitation of child labour, increased water and air pollution, and the spread of disease in rapidly growing urban areas (Vargas 2026). Similarly, Industry 4.0 is expected to bring both transformative benefits and societal challenges. The emergence of Industry 4.0 technologies will not only reshape how people live but will also influence humanity's perception of itself and its role in the world.

As technologies, such as expanded internet access, mobile devices and advanced communication tools, continue to evolve, civil society

organisations are gaining access to powerful resources that can support their missions. These tools enhance their ability to deliver services, monitor and evaluate programmes and communicate effectively with stakeholders. Furthermore, Industry 4.0 is reshaping business models, challenging companies to rethink how they meet customer expectations in terms of product and service quality, collaborative innovation and organisational restructuring to deliver value. As a result, job roles and required skill sets are evolving across various sectors, and routine-based tasks are becoming obsolete. Meanwhile, employees are increasingly expected to engage in oversight activities that demonstrate innovative thinking and critical problem-solving skills. The challenges and the nature of the response required for Industry 4.0 are reinforced by various researchers, as outlined in the sections that follow.

Inequality

Industry 4.0 is likely to yield greater inequality as new technologies continue to disrupt the labour market. In addition, the automation of jobs is expected to displace workers as machines take over, unintentionally exacerbating the gap between returns on capital and returns to labour. It is also envisaged that talent, more than capital, will represent the critical factor of production in the future, in that people with ideas, not workers or investors, will be the scarcest resource. Consequently, the quest for talent will most likely lead to an increasingly segregated job market. According to Bhandari and Vikhe (2025), the power of technology is increasing rapidly and facilitating extraordinary levels of innovation. This innovation enhances connectivity between people and things, but it does not necessarily pave the way for a more open, diverse and inclusive global society. Lessons from previous revolutions showed that technology and its wealth generation could serve only the interests of small, powerful groups, leaving the rest behind. The most significant impact of Industry 4.0, whether positive or negative, will be felt by human beings and society, potentially increasing inequality. It is anticipated that countries with a low skills base and inadequate information technology infrastructure will be hit the hardest. The development of new skills will require practical experience and an internship before a potential worker can be confirmed as competent.

Cybersecurity risks

Cybersecurity and system hacking are among the challenges companies face in the 4IR. There is a heightened sense of awareness regarding the extensive connection of human beings to various devices, which calls for greater cybersecurity awareness and the assessment of risks to mitigate any threats and to provide sufficient insurance coverage for these assets. New threats

against national infrastructure and digital crime are prompting researchers to consider new methods for handling cyber incidents. Governments and the commercial sector must utilise these new, internet- and web-enabled technological architectures and be prepared to combat emerging threats.

On the other hand, Industry 4.0 has significant implications for how organisations conduct business, as its core is the advent of CPS that blend hardware, software and people to complete work. Adding AI and machine learning (ML) to the mix transforms how factories are run, how services are delivered and how people contribute to the economy. The cybersecurity risks also require smart technologies and vigilance to protect institutional and personal data, ultimately reducing the potential for fraudulent activity. Institutions of higher learning face immense pressure to provide 4IR-relevant teaching and learning, as well as to conduct research and develop innovative ideas that will inform future curricula. This calls for a profound mind shift among academics, including enhanced collaboration within and between faculties.

Education

Industry 4.0 dissolves the physical, digital and biological boundaries, fundamentally transforming how universities deliver education. This shift necessitates re-evaluating traditional teaching methods and adopting new or alternative curricula that are aligned with emerging technological landscapes. Given the inevitable and rapid pace of change driven by Industry 4.0, higher education institutions must act urgently. To prepare students for the demands of the future workforce, substantial revisions to science and technology programmes are essential. These updates should equip learners with the skills and knowledge necessary in rapidly evolving fields such as genomics, data science, AI, robotics and nanotechnology. As a result, universities must not only update but must also integrate these disciplines into their core educational offerings. Moreover, it is essential to rethink the structure of traditional sciences, biology, chemistry and physics and to incorporate interdisciplinary approaches that reflect the interconnected nature of Industry 4.0 technologies. Placing greater emphasis on computer science, coding and digital literacy will be vital in fostering a new generation of graduates who are not only scientifically grounded but are also technologically fluent. In doing so, universities can ensure that they cultivate adaptable, innovative thinkers equipped to thrive in an increasingly complex and digitised world.

Law and ethics

Finally, AI, automation, robotics and electronic engineering bring new ethical considerations to the forefront. For example, in genetic engineering,

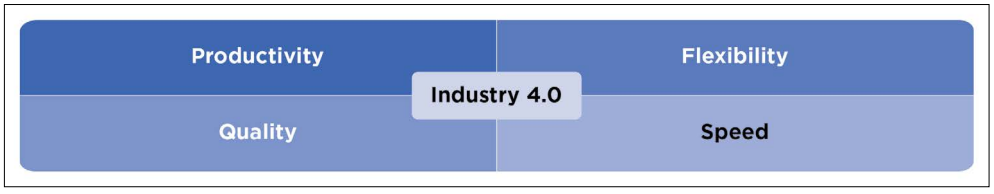
many debates have arisen over tools and research technologies. The conflicting views on the matter are that, while preventing genetic engineering is desirable, it lacks guidelines, regulations or ethical boundaries to prevent the over-manipulation of genetics for desirable traits. The long-term effects of Industry 4.0 depend primarily on societal reactions, public policies, legal frameworks and the homogeneous dissemination of information. Heterogeneity among nations that adopted 4.0 and within companies with different levels of digitalised infrastructure could result in niches of inequality and non-sustainability patterns. Therefore, it remains imperative to understand the implications of Industry 4.0 in society, as both organisations and governments have a responsibility to protect citizens. This is achieved by introducing legal frameworks that regulate how human-impacting innovations and research are controlled, without stifling progress or societal participation in this significant development. There is also an opportunity for businesses to diversify and be creative as several alternatives and cheaper services emerge. It is essential to understand that customer focus and responsiveness are crucial, and that any form of complacency will result in closure or liquidation. Regulating the conduct of researchers and innovators is also vital. This should be achieved by developing compelling pieces of legislation that can withstand court challenges and are easy to implement. It is also essential to establish policies that protect individual data and ensure privacy and safety.

Industry 4.0 and small and medium enterprises

As discussed to this point, Industry 4.0 represents a significant shift towards digitalisation and connectivity in manufacturing processes. Hence, this shift presents both opportunities and challenges for SMEs. Industry 4.0 has fundamentally transformed business operations, compelling leaders to adopt more innovative and unconventional approaches. It has redefined competition by reshaping markets and introducing entirely new business models. It has impacted manufacturing and service industries alike. For instance, companies such as Netflix have disrupted the traditional television industry by offering on-demand streaming services that cater to modern consumer preferences. Similarly, ride-hailing platforms such as Uber have challenged the conventional taxi industry by providing more flexible, efficient and user-friendly transportation solutions.

In the accommodation sector, Airbnb has revolutionised travel by offering alternative lodging options that are often more affordable and personalised than traditional hotels. These examples highlight how digital platforms and technologies have enabled businesses to deliver services that are similar or even superior in more efficient, accessible and convenient ways. Industry 4.0 does not only encourage innovation but also

demands that businesses remain agile and responsive to rapidly evolving consumer expectations and technological advancements. Further business impact is realised in the production of goods and services. The digitisation of products, big data and cloud computing makes it easier to understand and meet customer needs more accurately. Figure 1.6 presents some of the outcomes of adopting Industry 4.0.



Source: Compiled for this study by David Pooe (2026).
FIGURE 1.6: Industry 4.0 outcomes.

Productivity

Productivity refers to the 'amount of value created for each hour that is worked in a society' (McKinsey Global Institute 2025). From an economic point of view, productivity is the rate and the efficiency with which inputs such as labour and capital are converted into required outputs. Higher productivity is expected from automating processes that streamline production and shorten timelines. By identifying and monitoring key productivity indicators, businesses can manage and enhance the efficiency of their workforce better. In this regard, McKinsey Global Institute (2025) argue that for organisations to enhance their productivity, they will need to adopt the technology rapidly and redeploy workers' time efficiently to other activities. This includes the SMEs. The transformative potential of Industry 4.0 lies in its ability to merge advancements across physical, digital and biological domains. This integration paves the way for extensive automation and autonomous decision-making across various sectors, including manufacturing. As a result, we are moving towards highly adaptive, self-regulating production environments, where factories operate with minimal human intervention and can produce personalised or fully automated products rapidly at scale. Industry 4.0 could make products and services more easily accessible and transmissible for businesses, consumers and stakeholders throughout the value chain.

Flexibility

Over the past decade, manufacturers have focused on automating their factories to increase efficiency and reduce costs. While this has led to higher production rates and greater output, it has also increased

operational inflexibility. Industry 4.0 is now bridging the gap between technology and risk management, enabling manufacturers to add flexibility to their traditional low-cost production models. This flexibility stems from the use of advanced machines and robots that can perform multiple production tasks simultaneously, thereby accommodating a diverse range of products. Small and medium enterprises are known to have the inherent advantage of greater flexibility compared to their larger counterparts. This flexibility is crucial for adapting to rapid changes in market demands, customer requirements and supply chain uncertainties. Technology also allows customers to specify their preferences for product features, delivery times and methods with greater ease, driving a shift towards more personalised production. With the help of 4IR, manufacturers can adapt to these changing demands by creating customised products and adopting more sustainable, responsible manufacturing practices, meeting both consumer expectations and environmental goals.

Quality

The advancement of enabling technologies, such as AI and 3D printing, has paved the way for a wide array of new applications. These technologies create a feedback loop that leads to continuous improvements in core technologies, a hallmark of general-purpose innovations. Given its extensive impact across various industries, it is no surprise that Industry 4.0 has sparked significant discussions in both business and political spheres about its economic implications, particularly regarding product quality. This technological trend holds the potential to revolutionise production processes, research and development activities, business models and the organisational structures of companies in diverse industries. The integration of advanced machines and robots capable of executing multiple production tasks simultaneously enables manufacturers to remain flexible, producing a variety of products efficiently. As a result, 4IR enables manufacturers to meet evolving demands by offering customised products while also embracing more sustainable, responsible production practices that align with both consumer expectations and environmental sustainability goals. The quality of products is enhanced through sensors and wearables that can monitor production in real-time and act on errors as they occur. The Fourth Industrial Revolution is about designing innovative products through hyper-connected CPS in environments where humans and machines cooperate to achieve goals and use big data to generate value.

Speed

Finally, speed is enhanced as companies adopt simulation and modelling techniques that shorten the product development cycle. Industry 4.0

brings individualised production, horizontal integration in collaborative networks and digital integration of supply chains, as well as changes in inter-institutional relations, work organisation and ultimately, in society. Today, business transformation is advancing well as organisations scale innovation through expanded digitalised reach, intelligence, disruptive service development, rapidly evolving customer expectations, transparency and trust. In this changing environment, enterprises are embarking on a race to lead in their digital innovation capabilities, competing and ultimately dominating in the rapidly digitising global economy.

Industry 4.0 and beyond

The pace of change brought about by 4IR necessitates a re-evaluation of corporate structures and workplace business practices, particularly at a leadership level. The core of 4IR is the ultimate reduction in human capital, and leaders are struggling with how this changes business dynamics, strategies and roles. Therefore, the paramount importance of the right technology strategy during this time cannot be overemphasised. If manufacturing SMEs are to prosper in the future and to compete successfully, both nationally and internationally, there is a strong suggestion that they should adopt Industry 4.0. The advent of 4IR demands exceptional governance practices supported by transformational leadership excellence and systemic programme management knowledge. In addition, effective and efficient cross-functional and inter-organisational management of projects and programmes in virtual networks of partners emerged as a critical enabling competency for institutions operating in the 4IR economy. These developments present challenges for organisational design, development and governance and emphasise the need for strategic transformation and change management of 4IR institutions. According to Suryadi et al. (2024), transformational leadership is necessary to shift away from the old motivations of bureaucratic powers towards inspiring people to believe in a new vision of economic and social progress, and to balance the attention between actions that promote progress and the motivation of virtual team members. The Fourth Industrial Revolution requires leaders to understand its complexities and acknowledge the need to train, support and inspire employees to develop themselves and their skills adequately (Mayer 2024). The authors argue that new skills need to be attracted, that employees in institutions should be reskilled, and that new job titles should be considered.

Global and regional readiness for Industry 4.0

The journey towards Industry 4.0 is neither uniform nor linear. Rather, it unfolds as a complex narrative shaped by global disparities, regional

strengths and the unique vulnerabilities of SMEs. At the global level, readiness assessments reveal a sobering reality. Most nations remain in the early stages of digital transformation. The Global Readiness Assessment Model for Industry 4.0 (GRAMI4.0) indicates that 75% of countries score below 0.5 on a scale, where 1.0 represents full preparedness, underscoring a widespread lack of readiness for the 4IR (Alamsjah & Yunus 2022). This global picture is mirrored at the firm level, where maturity models consistently show that manufacturing industries – even in advanced economies – are clustered at initial stages of adoption (Alamsjah & Yunus 2022).

Regionally, readiness is deeply influenced by industrial heritage, institutional support and socio-technical conditions. In Northern Italy, for example, SMEs embedded in 'Made in Italy' sectors exhibit adoption patterns shaped by both industry specificity and regional innovation dynamics (Bettiol, Capestro & Di Maria 2022). In South Africa, readiness is constrained by skill gaps, with Industry 4.0 demanding competencies far beyond those required in traditional manufacturing, prompting calls for targeted human capital development (Inyang & Kanakana 2024; Takawira & Pooe 2025). Malaysia's manufacturing SMEs illustrate another dimension: While organisational capabilities and market factors drive readiness, firm size moderates the impact of institutional support, revealing structural asymmetries in how digital transformation unfolds (Wong & Kee 2022).

Emerging economies face distinct sociotechnical challenges. In Brazil, leading manufacturers grapple with skill shortages, uneven technological infrastructure and the need to balance human and machine capabilities in contexts where institutional frameworks are less robust (Marcon et al. 2025). Similarly, in Denmark's SMEs, readiness is often hindered not by insurmountable barriers but by managerial unawareness of the strategic drivers of Industry 4.0 – suggesting that perception and vision are as critical as resources (Ghannouchi 2023).

Global frameworks such as the Smart Industry Readiness Index offer structured pathways, assessing readiness across process, technology and organisational dimensions (Adel, Alani & Jan 2024). Yet, these tools reveal that while exposure to Industry 4.0 concepts may be high, detailed understanding and role clarity remain moderate in many sectors, as seen in Malaysia's construction industry (Abdul-Samad et al. 2024). This gap between awareness and actionable capability is a recurring theme across regions.

For SMEs, the readiness narrative is particularly fraught. Systematic reviews highlight that they lag behind larger firms in leveraging disruptive technologies, often struggling with initial adoption decisions

(Ghobakhloo et al. 2022). Multi-case surveys show that while SMEs prioritise smart manufacturing, they pay less attention to digital platform business models – potentially limiting their ability to integrate into global value chains (Modrak, Soltysova & Sobotova 2024). Lean 4.0 practices, combining leadership, customer focus and advanced manufacturing technologies, emerge as critical enablers, linking operational and technological readiness to sustainable supply chain performance (Qureshi et al. 2023). In summary, global and regional readiness for Industry 4.0 is a mosaic of progress and hesitation. Advanced economies may lead in infrastructure and innovation networks, but even they face maturity gaps. Emerging economies contend with deeper structural and skill-related barriers. For SMEs everywhere, readiness is not merely a technical challenge – it is a strategic transformation that requires aligning vision, capabilities and ecosystem support. This uneven landscape sets the stage for the supply chain dislocations and competitive realignments that will define the next chapter of the 4IR.

Policy and regulatory environment

The policy and regulatory environment for Industry 4.0 is emerging as both a catalyst and a constraint in transforming SMEs and their supply chains. In many emerging economies, the role of the state is not peripheral but central – government policy, subsidies and institutional frameworks can decisively shape the trajectory of adoption. Evidence shows that targeted policy interventions, such as financial incentives and supportive regulatory frameworks, can transform organisational structures, making them more transparent, flexible and capable of integrating advanced technologies (Mohiuddin et al. 2023). This transformation is not merely administrative; it also redefines how SMEs align with digital ecosystems, enabling them to participate more effectively in global supply chains.

However, the narrative is far from uniform. In some contexts, weak governance frameworks, leadership instability and inadequate infrastructure undermine the potential of policy to drive change (Saleh & Ijab 2025). These institutional voids exacerbate existing SME vulnerabilities – financial instability, skill shortages and limited access to technology – creating a policy paradox in which the very actors meant to enable transformation may inadvertently slow it down. Internationally, policy design reflects differing socio-technical philosophies. Germany's Mittelstand 4.0 initiative, for example, demonstrates how competence centres can bridge the gap between policy intent and SME capability, offering hands-on support, knowledge transfer and networked innovation opportunities (Prodi et al. 2022). By contrast, in other regions, policy remains aspirational, with limited mechanisms for operationalising support at the firm level.

The regulatory dimension is equally complex. While Industry 4.0 technologies promise enhanced transparency, traceability and sustainability – aligning with global goals such as responsible production and ethical sourcing – these benefits are contingent on addressing regulatory gaps in data privacy, cybersecurity and interoperability standards (Alhammadi et al. 2024). Without coherent regulatory frameworks, SMEs risk exposure to compliance uncertainties that can deter investment and innovation. For SMEs, the interplay between policy and regulation is not abstract – it directly influences their capacity to adopt, adapt and scale Industry 4.0 solutions. Tailored policy frameworks that differentiate support based on digital maturity, foster collaborative innovation networks and integrate sustainability objectives into supply chain governance are emerging as best practices (Neves et al. 2025). Yet, the challenge remains to translate these principles into actionable, context-sensitive measures that account for the heterogeneity of SME sectors and regions. In this evolving landscape, the policy and regulatory environment is not a static backdrop but an active, shaping force in the Industry 4.0 narrative. For SMEs, it can mean the difference between being swept aside by the dislocations of Industry 4.0 or leveraging them as opportunities for competitive renewal.

Frameworks for small and medium enterprise adaptation to Industry 4.0

The adaptation of SMEs to Industry 4.0 is not a straightforward technological upgrade – it is a strategic transformation that requires navigating structural constraints, market pressures and evolving supply chain dynamics. Frameworks designed for this transition increasingly blend technological integration with organisational change, sustainability imperatives and resilience-building measures. One narrative thread begins with the development of digital capabilities. Studies show that SMEs must invest in foundational infrastructure, cultivate an innovation-oriented culture and adopt business models that integrate digital technologies with human-centric manufacturing processes (Kans & Campos 2024). This is not merely about acquiring technology; it is about embedding it into the value chain to catalyse competitiveness, often through accessible channels such as cloud computing, which can trigger firm-level innovation when supported by adequate investment (Qin, Xie & Jia 2024).

Another strand focuses on incremental and scenario-based transformation. Frameworks that characterise and evaluate Industry 4.0 scenarios allow SMEs to implement change progressively, aligning projects with their growing digital maturity (De Paula Ferreira et al. 2022). This incrementalism is critical for resource-constrained firms, enabling them to

avoid the pitfalls of overextension while still building towards full integration. Sustainability-oriented frameworks add a further dimension. Concepts such as Circular Supply Chain 4.0 integrate lifecycle thinking, IoT and remanufacturing into supply chain design, ensuring that digital transformation aligns with waste reduction, energy conservation and regulatory compliance (Cavalieri, Reis & Amorim 2024; Lin 2024). These approaches often employ life cycle assessment and circular economy metrics as guiding tools, making sustainability a structural component rather than an afterthought.

Resilience frameworks map Industry 4.0 technologies – AI, ML and blockchain – onto supply chain functions to enhance visibility, agility and disruption management (Sharma, Mishra & Agrawal 2025). Such mappings are particularly relevant for SMEs in volatile markets, where supply chain shocks can be existential threats. Adaptation models also address barriers unique to SMEs: limited financial resources, skill shortages, weak IT infrastructure and cultural resistance (Arroyabe et al. 2024). Methodologies such as the Technology–Organisation–Environment framework and fuzzy decision-making approaches help SMEs to prioritise investments and strategies that yield the greatest operational and market impact (Gaspar et al. 2025). In weaving these threads together, the emerging narrative is clear: SME adaptation to Industry 4.0 requires multi-layered frameworks that combine technological pathways, organisational readiness, sustainability integration and resilience planning. These frameworks are not static blueprints but rather adaptive guides, evolving alongside the SMEs they serve, and enabling them to turn the dislocations of Industry 4.0 into opportunities for competitive renewal.

Conclusion

In conclusion, 4IR is here, and the time is now to make a collaborative effort, embrace its opportunities, and take a collective approach to preparing organisations for how they will respond to their challenges and opportunities. It disrupts the business world across sectors while creating numerous opportunities for unprecedented businesses. This chapter has provided an understanding of the history of industrial revolutions and, most importantly, an awareness that they have occurred throughout the history of humanity. It has also highlighted the critical role of transformation in society, and how civilisation or modernisation has shaped the lives of many people across the globe. The general areas of interest covered in the chapter include the various definitions of the term and the origins and reflections on the three preceding revolutions.

The chapter also covered 4IR in great detail, including its characteristics, emerging and current discourse, its impact on society and, most importantly, its impact on leadership and the workplace. It is also clear that industries involved in producing goods and services, such as manufacturing SMEs, will benefit most from innovative production techniques, shorter production turnaround times, customisation of goods, and greater value added to customers. While overall frameworks describing the Industry 4.0 paradigm have been explored, the SME context remains largely unexplored. Thus, there is a need to relate Industry 4.0 to SMEs in South Africa. Entrepreneurs and small business managers will cultivate the organisational competencies that affect the adoption of Industry 4.0 technologies positively.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Author's contribution

D Pooe was responsible for the *conceptualisation*, *methodology*, *validation*, *formal analysis*, *investigation*, *resources*, *data curation*, *visualisation*, *supervision*, *project administration* and *funding acquisition*. He also *prepared the original draft of the chapter* and *conducted the review and editing*. All software-related work was completed using Microsoft Word.

Competing interests

The author declares that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the author's own and not an official position of the institution, funder or the publisher.

Chapter 2

Supply chain management and small and medium enterprises

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Introduction

In continuing with the contextual understanding of Industry 4.0, Chapter 2 focuses on supply chain management (SCM) in the small and medium enterprise (SME) context. It bridges the discussion from the broader industrial landscape to the specific challenges and opportunities faced by SMEs in managing their supply chains. This chapter explores various facets of SCM

How to cite: Pooe, D & Munyanyi, W 2026, 'Supply chain management and small and medium enterprises', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 35–59. https://doi.org/10.4102/aosis.2026.BK572.02

relevant to SMEs, including demand management, sourcing, performance monitoring and logistics, against the backdrop of Industry 4.0. In addition to these critical aspects, it also covers the specificities of procurement processes, emphasising the importance of strategic sourcing and procurement practices tailored for SMEs. Moreover, the chapter examines the role of performance monitoring in enhancing supply chain efficiency and agility, which is crucial for SMEs striving to remain competitive in dynamic market environments. Furthermore, it addresses the challenges and solutions pertaining to warehousing and inventory management, elucidating how SMEs can optimise their storage facilities and inventory control systems to streamline operations and reduce costs. This chapter explores the complexities of transport and logistics management, highlighting innovative approaches and technologies that can empower SMEs to overcome logistical hurdles and achieve greater responsiveness in their supply chains. Finally, it investigates the emerging concept of reverse SCM, shedding light on how SMEs can manage product returns, recycling and disposal processes effectively to minimise waste and maximise value recovery.

Supply chain management

With the rise in globalisation, individual firms no longer compete as independent entities with unique brand names but as integral parts of supply chain links. As such, a firm's ultimate success will depend on its managerial ability to integrate and coordinate the intricate network of business relationships among supply chain partners (Drucker 1998; Lambert & Cooper 2000).

Overview of supply chain

Over the past decade, most firms, including SMEs, have paid more attention to the effectiveness and efficiency of separate business functions such as purchasing, production, marketing, financing and logistics. However, failure to ensure connectivity among these functions has led to many organisational shortcomings in meeting strategic goals and, in most cases, to inefficiencies caused by duplication of effort and resources. To capture the synergy of inter-functional and inter-organisational integration and coordination across the supply chain and subsequently, to make better strategic decisions, many firms have begun to realise the strategic importance of planning, controlling and designing a supply chain as a whole.

Definition of supply chain

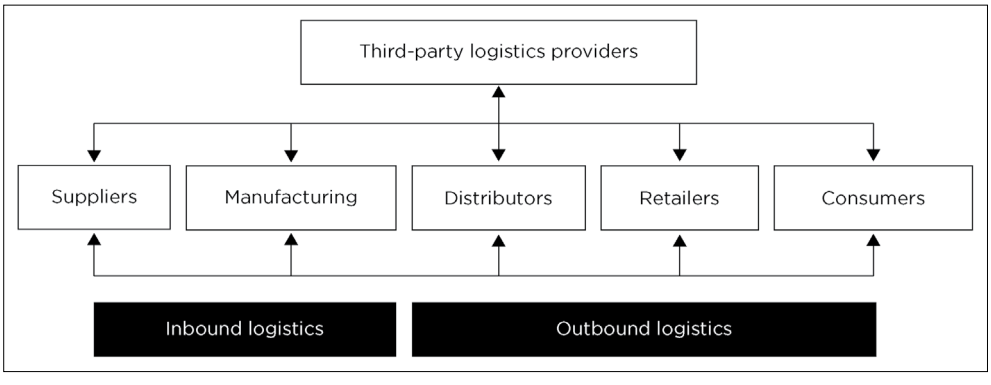
A supply chain is a collection of operations and procedures designed to enhance the movement of goods, services and associated data from

suppliers to customers or points of need. It spans various levels in the supplier network, extending to the customers and their subsequent clientele. This encompasses activities such as supply chain planning, acquisition, production, distribution, transportation and related services in an organisation and its network of collaborators (Hugos 2024; Montag 2023). It is a network of all the individuals, organisations, resources, activities and technology involved in creating and selling a product. It encompasses all the business processes, from acquiring raw materials through manufacturing to the eventual delivery to the consumer. The focus is on all the activities involved at each production stage, the information being communicated and other components that contribute to the finished product or service. According to Ishii and Ohba (2023), a supply chain consists of different entities that seek to add value to products, from raw materials to the final products, while exchanging critical information on the market and production. Supply chain management encompasses:

> [...] the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers and customers. In essence, supply chain management integrates supply and demand management within and across companies. (Mukhamedjanova 2020, p. 760)

This can be observed in South Africa, where small-scale farmers are using agricultural value chains that involve sequential linkages through which raw materials and resources are converted into marketable products. An agriculture value chain (AVC) consists of a 'set of actors and activities that bring agricultural produce from production to final consumption where at each stage, value is added to the product' (Smidt & Jokonya 2022, p. 560). Figure 2.1 is an illustration of a typical supply chain.

Although each entity is essential in a supply chain, the degree of importance varies depending on the value of the information the entity produces.



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).

FIGURE 2.1: Supply chain.

Multiple stakeholders usually manage the supply chains in a more decentralised manner. Although these stakeholders pursue distinct objectives, their behaviour and decision-making processes aim to ensure the viability of the supply chain. In a traditional manufacturing environment, managing these supply chain activities determines the efficiency of inbound material movement and outbound goods movement. This, in turn, ensures that the finished product flows downstream to the consumer in a timely manner. Small and medium enterprises can either create or join the supply chain that best suits their unique characteristics. The decision to join an existing supply chain will also depend on the specific requirements for participation.

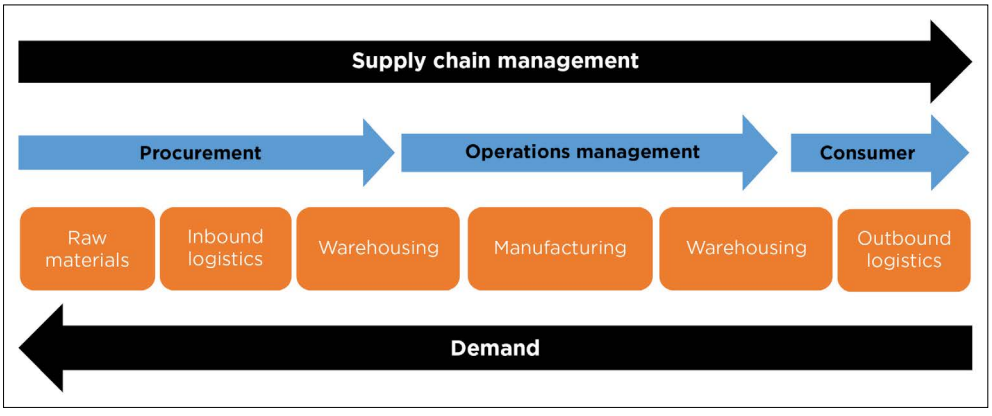
Supply chain management

In line with the aforementioned definition of supply chain, SCM involves managing the flow of goods, services and information from the initiation of a business transaction to the point where the customer is located. Supply chain actors must manage the flow of raw materials and the processes involved in transforming them into final products. This is achieved through a series of entities and activities with compatible capacity, demand and cost parameters. Effective SCM takes a broader view of the factors that influence the supply chain's performance, as this helps in understanding the strategic decisions needed to support supply chain activities. Actors streamline supply-side activities actively to maximise customer value and attain a competitive edge in the marketplace. In managing the supply chain, observable uncertainties and irregularities arise from changes in customer demand, supplies, logistics and lead times.

Uncertainties regarding customer demand are the most significant challenge affecting supply chain performance. In that context, there is a need for comprehensive demand forecasting to address the uncertainties in the supply chains.

The IBM Watson artificial intelligence (AI) system assists in cancer treatment, reducing uncertainty for the oncology departments around the world for specialists, doctors and practitioners (Ibegbulam et al. 2023). Figure 2.2 illustrates the key processes of SCM.

Effective SCM affects the organisation's financial performance positively, thereby delivering value. It also plays a direct role in ensuring customer satisfaction by delivering products and services on time and accurately. As such, an organisation's profitability is largely dependent on the management of its supply chain (Kadiane, Zhang & Shi 2023). Supply chain management goes further to encompass areas related to strategy formulation and how firms can identify the appropriate strategy to operationalise supply chain activities and the strategic functions that support the decisions made in the

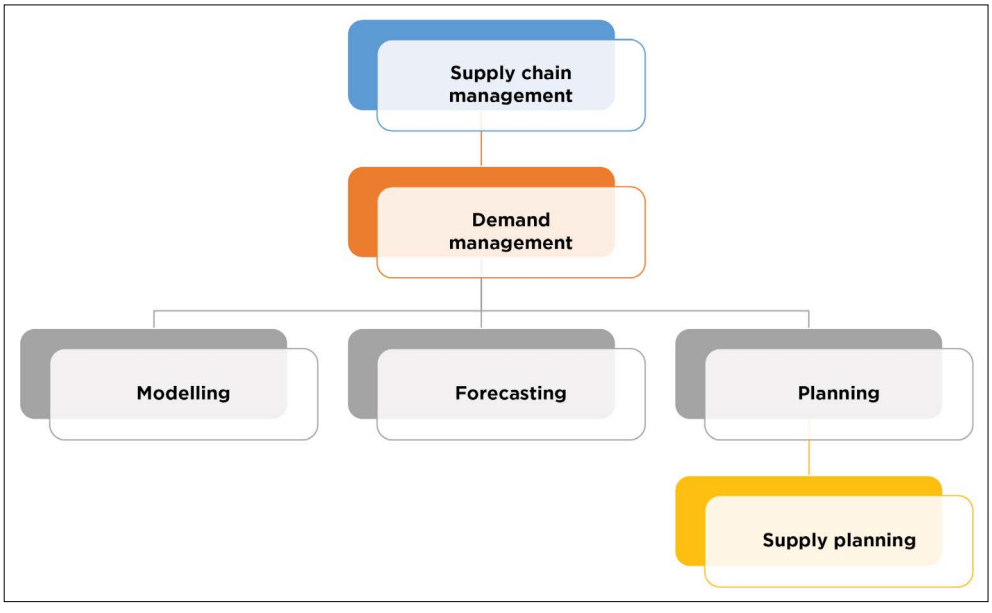


Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 2.2: Supply chain management.

supply chain. In South Africa, the SME sector has been neglected in SCM development, despite SCM being a predominant activity for SMEs. Supply chain management is central to the growth and development of SMEs because it allows them to build solid relationships with their customer, generating more revenue and attaining a competitive advantage. It has been argued widely that, as the global business environment continues to change, SME participation in major supply chains will contribute to economic growth. There are numerous elements of SCM, including demand management, sourcing and procurement, warehousing and inventory management, transport and logistics and reverse SCM. These are discussed in the sections that follow.

Demand management

Ensuring that supply chains add value remains a constant concern for managers. For example, managers are well aware that failing to meet customer needs and demands can lead not only to lost sales but also to lost customers and other prospective customers. In this case, customer demand may well exceed available inventory. On the other hand, managers also recognise that holding excessive inventory to meet customer demand every time may not be the most prudent course of action, as it can be too costly for the business. Thus, the answer lies somewhere between holding enough inventory and employing enough capacity to meet future demand. The process of seeking to achieve such a balance is called demand management. Demand management is a supply chain process that aims to match customer demand with the supply chain's capabilities (Altekar 2023). Demand management enables organisations and supply chains to forecast demand to meet customer requirements. Thus, demand management balances supply and demand. As shown in Figure 2.3, the



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 2.3: Demand management process and components.

process of demand management comprises modelling, forecasting, demand planning and supply planning.

- *Modelling*: This component requires the business's demand planning team to acquire data from other groups linked to sales and demand drivers such as innovation, social media strategy and market trends.
- *Forecasting*: Demand forecasting uses predictive analytics to forecast future demand for services or products. Demand forecasting enables reliable supply decisions by providing estimates of coming sales and revenue.
- *Demand planning*: The demand planning process forecasts product or service demand to ensure you can satisfy customers. Demand planning aims to strike a balance – sufficient inventory levels to meet orders without a surplus.
- *Supply planning*: Supply planning is the part of the demand management process handled by supply or inventory management. The goal is to identify and address the most critical problems, plan across multiple tiers of locations and simulate potential responses to optimise inventory and customer service costs. Then, a business can write and execute a plan based on the best available data, with customer needs in mind, considering all inputs (Kalla, Scavarda & Hellingrath 2024).

Similar to many business needs, the digitalisation of supply chain and demand planning is becoming increasingly prevalent. Advances in machine

learning (ML) for supply chain operations enable real-time adjustments and revisions to forecasts, optimising lean inventory levels while ensuring accurate demand fulfilment. When effectively implemented, the demand planning process can significantly enhance a supply chain's profitability (Mishu et al. 2026). Skilfully anticipating and planning demand can be a distinct source of competitive edge. In real-time forecasting, ML algorithms enable businesses to update forecasts in real time. Adaptability is crucial in dynamic markets where demand patterns can change rapidly. Lean inventory management improves efficiency as digital technologies optimise inventory levels by providing insights into demand fluctuations (Ramdass & Nair 2025). This allows organisations to maintain leaner inventories without compromising their ability to meet customer demand. Machine learning reduces the bullwhip effect by increasing precision. The bullwhip effect occurs when small changes in consumer demand amplify fluctuations upstream in the supply chain. This precision helps maintain a more stable and efficient supply chain (Moreno-Baca et al. 2025).

The successful implementation of demand planning using ML can provide a competitive advantage. Small and medium enterprises that can accurately anticipate and fulfil customer demand are better positioned in the market. In addition, digitalisation helps identify cost-saving opportunities. Machine learning enhances organisational profitability through leaner inventories, reduced carrying costs and improved efficiency across the supply chain. Accurate demand planning ensures customer satisfaction and loyalty by ensuring products are available when and where customers need them. Machine learning models also help identify potential risks by analysing historical data within the supply chain. This proactive approach allows organisations to implement risk mitigation strategies effectively. Digital platforms facilitate improved communication and collaboration among supply chain partners. Real-time data sharing ensures that all stakeholders have access to the latest information. The use of ML and data analytics enables the generation of data-driven insights and informed decision-making. Organisations can base their strategies on actionable insights derived from vast amounts of data (Amola 2025). Digital supply chain solutions, including ML applications, yield scalability. They can adapt to changing business needs, making them suitable for both SMEs and large enterprises.

Therefore, the digitalisation of supply chain and demand planning processes, particularly through the application of ML, is revolutionising how businesses operate. The ability to forecast demand in real time and optimise inventory levels contributes to efficiency, cost savings and a competitive edge in the marketplace. It is a transformative trend that aligns with the broader Industry 4.0 paradigm and the increasing use of advanced technologies in business operations.

Sourcing and procurement

Sourcing is the process of vetting, selecting and managing suppliers who can provide the inputs an organisation needs for day-to-day running. Sourcing is tasked with conducting research, developing and executing a strategy, defining quality and quantity metrics and selecting suppliers that meet these criteria. Strategic sourcing is the process of determining the spend profile and supplier base of an organisation to ensure that its procurement needs are met effectively and profitably (Cardoso & Biazzin 2020). It involves connecting data, spend analysis, market research, negotiation and contracting to achieve maximum business performance (Bag & Rahman 2024). As the name suggests, sourcing focuses on creating sources through which an organisation can obtain its supplies. Therefore, sourcing maintains the supply chain of an organisation and ensures that it always has access to the tools it needs to deliver on its objectives, as the end goal of sourcing is procurement.

Sourcing steps

The stages involved in sourcing include sending analysis, market research, Request for 'X' (RFx), negotiation, contracting, onboarding and performance monitoring.

Spend analysis

This is a crucial process that involves examining and assessing the spending patterns and procurement activities of an organisation. It provides valuable insights into where and how money is being spent, helping organisations make informed decisions to optimise costs, negotiate better contracts and enhance overall procurement efficiency. In sourcing, spend analysis plays a pivotal role in shaping procurement strategies. Spend analysis is typically applied in sourcing by gathering data from various sources, including purchase orders (POs), invoices, contracts and other financial records, and by performing data cleansing to ensure accuracy. This involves removing duplicates, correcting errors and standardising formats. Hence, spend analysis is a dynamic and powerful tool that empowers organisations to make data-driven decisions, enhance procurement efficiency and optimise costs in their sourcing activities. It forms the foundation for strategic sourcing initiatives, helping organisations achieve better value for money and improved supplier relationships.

Market research

This process involves gathering and analysing information on suppliers, products and market trends to identify opportunities, mitigate risks and optimise procurement strategies. Market research in sourcing and procurement plays a crucial role in helping businesses make informed decisions about purchasing goods and services. Market research in sourcing involves numerous activities, such as outlining goals, identifying key suppliers, market segmentation, trend and cost analysis, risk assessment, compliance, technology integration, supplier relationship management, responsibility, data analytics and documentation. Clearly outlining the goals of your market research: are you looking for new suppliers, assessing market trends or optimising costs?

- *Identifying key suppliers*: List potential suppliers and categorise them based on relevance to your business, evaluating their reputation, financial stability and past performance.
- *Market segmentation*: Divide the market into segments based on product types, regions or other relevant factors. The organisation needs to understand the dynamics of each segment and how they might impact its procurement strategy.
- *Trend analysis*: An organisation must remain updated on current market trends, technological advancements and changes in regulations. There is a need to understand how these trends might influence the sourcing decisions.
- *Cost analysis*: Compare prices from different suppliers, consider the total cost of ownership, including shipping, taxes and potential risks.
- *Supplier evaluation*: Develop a supplier evaluation framework based on factors such as quality, reliability and responsiveness. Conduct site visits or audits for critical suppliers.
- *Risk assessment*: Identify potential risks such as geopolitical, economic or supply chain disruptions and develop risk mitigation strategies.
- *Legal and regulatory compliance*: Ensure that suppliers comply with relevant laws and regulations, and also assess potential legal risks associated with suppliers.
- *Benchmarking*: Compare the procurement processes and costs of an organisation with industry benchmarks and identify areas for improvement.
- *Technology integration*: Explore the use of technology, such as procurement software and data analytics, to streamline processes and enhance decision-making.
- *Supplier relationship management*: Develop and maintain strong relationships with key suppliers, regularly assessing supplier performance and providing feedback.

- *Environmental and social responsibility*: Consider the environmental and social impact of the organisational procurement decisions and evaluate the sustainability practices of suppliers.
- *Data analytics*: Leverage data analytics to identify patterns, forecast demand and optimise inventory levels. In this way, an SME can use the data to negotiate better terms with suppliers.
- *Document findings*: Curate findings and insights from your research and use this documentation for future reference and strategy adjustments.

Request for 'X' process

After completing the supplier market research, the next step is to solicit RFx from suppliers. The RFx process refers to a series of steps involved in procuring goods and services through competitive bidding (Procurementtactics 2025). The 'RFx' stands for Request for 'X', where 'X' can represent various types of documents such as Request for Proposal (RFP), Request for Quotation (RFQ) or Request for Information. Each type serves a specific purpose in the sourcing process. This step assists in supplier identification and negotiating strategy. It is essential for effective communication of the organisation's explicit requirements, as well as the ultimate goals and performance objectives, so that suppliers have a comprehensive understanding of what the organisation demands. This is crucial to facilitate the submission of an adequate proposal and the development of strategies aligned with the objectives of your business. The given data will provide valuable information, such as price structure, delivery and warranty conditions, product or service specifications, and so on. After compiling the provided data, you may now establish criteria for selecting suppliers based on what you can source. The Request for 'X' process is therefore designed to ensure a fair and transparent procurement process, allowing organisations to select the most suitable suppliers based on their capabilities and the specific needs of the project or requirement.

Negotiation

This is a critical aspect of the sourcing process, in which both buyers and suppliers come together to reach an agreement on terms, conditions and pricing. Successful negotiations can lead to mutually beneficial relationships, cost savings and improved terms for both parties. It is critical to note that sourcing negotiation requires a combination of strategic planning, effective communication and a collaborative approach to achieve outcomes that meet the needs of both the buyer and the supplier. There are several key considerations and strategies for sourcing negotiations. Firstly comes preparation, where you thoroughly understand

your own needs and constraints, research the market and competitors to gain insights into pricing and industry standards, and identify your negotiation objectives and priorities. Secondly, establish your objectives, goals and priorities for the negotiation to identify critical terms such as price, delivery schedules, quality standards and payment terms. Next is understanding the suppliers' perspective, suppliers' business model, challenges, objectives, key priorities and potential areas for flexibility. Thereafter, rapport building establishes a positive, collaborative relationship with suppliers to foster open communication and trust. This is followed by flexibility and the willingness to make trade-offs to achieve a mutually beneficial agreement. During this phase, an organisation needs to prioritise negotiation points and be prepared to compromise on less critical issues, aiming for win-win solutions in which both parties derive value from the agreement. It should avoid overly aggressive tactics that may strain the relationship in the long term.

Contracting

After negotiation, contracting entails formalising agreements between buyers and suppliers. The contract serves as a legal document outlining the terms, conditions and obligations of both parties throughout the procurement process. Effective contracting is crucial for managing risks, ensuring compliance and maintaining a successful business relationship (Prayitno & Aprili 2026). By carefully controlling the onboarding process, organisations can enhance collaboration with suppliers, ensure alignment with strategic sourcing goals, mitigate risks and strengthen the overall resilience of the supply chain (Habibi et al. 2026). Effective onboarding contributes to a more agile and responsive supply chain network. According to Zou et al. (2019), some of the key aspects of contracting in sourcing include:

- *Scope of work*: Clearly define the deliverables expected from the supplier. This includes specifications, standards and any other relevant details.
- *Terms and conditions*: Outline the terms and conditions of the agreement, covering areas such as payment terms, delivery schedules, quality standards, performance metrics, confidentiality clauses, dispute resolution, compliance, governance, warranties and guarantees.
- *Risk management*: Identify and allocate risks between the parties, the best alternative to a negotiated agreement, provisions for mitigating and managing risks.
- *Documentation and record keeping*: Maintain accurate and comprehensive records of all contract-related communications, changes and transactions.

Onboarding

This refers to the process of integrating new suppliers into the sourcing and procurement functions of an organisation. Onboarding, as the name suggests, involves activities and procedures that familiarise suppliers with the organisation's policies, procedures, expectations and systems. The goal is to establish a smooth and effective working relationship that aligns with the sourcing strategies and objectives of an entity. Akinleye and Adeyoyin (2021) state that onboarding in sourcing includes, but is not limited to, these aspects:

- *Technology integration*: Incorporate the suppliers into relevant technology platforms, such as enterprise resource planning (ERP) systems or SCM tools. This ensures that the supplier can effectively exchange data and information with your organisation.
- *Quality standards and specifications*: Clearly communicate the organisation's quality standards and specifications for goods or services, and clarify any specific requirements or expectations related to product and/or service quality.
- *Performance expectations*: This involves defining key performance indicators, expectations for supplier performance and establishing a clear framework for ongoing performance measurement and evaluation.
- *Communication channels*: Outline communication channels and points of contact within the organisation, establishing regular communication schedules to discuss ongoing projects, address concerns and foster collaboration.
- *Collaborative planning*: Collaborate with the suppliers on joint planning initiatives, such as demand forecasting and inventory management, together with discussing ways to optimise the supply chain for mutual benefit.

Onboarding suppliers is crucial in SCM, particularly for SMEs seeking to establish robust and reliable supplier networks (De Goeij et al. 2021). This entails more than just initiating contractual agreements; it involves establishing mutual understanding, communication channels and shared goals. Effective onboarding ensures that suppliers comprehend the expectations, quality standards and operational requirements of an SME. It involves providing comprehensive training on processes, systems and compliance protocols to ensure smooth integration into the supply chain ecosystem. Furthermore, fostering strong relationships during the onboarding phase can lay the foundation for long-term partnerships built on trust, transparency and collaboration, ultimately contributing to the resilience and competitiveness of the SME's supply chain.

Performance monitoring

This is a critical aspect of SCM that helps organisations ensure their sourcing strategies are effective, suppliers are meeting expectations and the overall procurement process contributes to organisational goals. It allows organisations to assess the quality of products or services provided by suppliers. Performance monitoring is critical for maintaining high standards and meeting customer expectations (Petropoulos et al. 2026). When carried out at regular intervals, it ensures that suppliers adhere to contractual agreements, regulatory requirements and ethical standards. It also helps identify and mitigate risks associated with non-compliance or other issues that may impact the supply chain. Performance monitoring helps track sourcing-related costs. By analysing financial metrics, organisations can identify cost-saving opportunities, assess the impact of sourcing decisions on the bottom line and optimise spending (Khojasteh, Mousavi Jahan Abadi & Ng 2026). This way, performance monitoring contributes to better visibility into the supply chain, allows organisations to track key supply chain metrics, such as lead times, inventory levels and order fulfilment, and provides insights into overall supply chain resilience. Monitoring performance can also be viewed as a component of a continuous improvement culture, where organisations can identify areas for improvement, enhance efficiency, streamline processes and optimise their sourcing strategies over time. Hence, performance data provides valuable insights for decision-making (Farag 2026; Hunjet 2021). Whether evaluating the performance of current suppliers, selecting new suppliers or optimising sourcing strategies, having accurate, up-to-date information is essential. Performance data provides valuable insights for informed decision-making.

Procurement

On the other hand, procurement is a critical component of SCM that involves acquiring goods, services or information from external sources to meet the needs of an organisation (Altekar 2023). It plays a pivotal role in ensuring that the supply chain operates smoothly and efficiently. Procurement is the process of acquiring goods, services or works from external sources, typically suppliers or vendors, to meet an organisation's needs (Acheampong et al. 2026). It involves various steps, including identifying needs, selecting suppliers, negotiating, purchasing, receiving and inspecting, and paying. The goal of procurement is to obtain the necessary resources in a cost-effective and efficient manner. It plays a critical role in an organisation's success, affecting cost control, quality and overall operations. Various procurement methods, strategies and technologies are used to optimise this process.

Importance of procurement for small and medium enterprises

Procurement is highly important for SMEs for several reasons, including cost control. Effective procurement allows SMEs to negotiate better prices with suppliers, helping to control costs and improve profitability. It also enables SMEs to source high-quality goods and services, ensuring that their products meet the desired standards and customer expectations. Efficient procurement practices can give SMEs a competitive edge by providing access to high-quality inputs at lower costs, enabling them to offer lower prices and superior products or services. Procurement strategies can help SMEs to diversify their supplier base, reducing dependency on a single source and mitigating supply chain risks. By collaborating with suppliers, SMEs can access new technologies and innovations, fostering growth and product development. Building strong relationships with suppliers can lead to better terms, extended credit and a more responsive supply chain, which is vital for SMEs. Many customers and investors now value sustainable practices, and procurement can help SMEs to source environmentally friendly and ethical products and services that align with these values. In a nutshell, procurement is a critical function for SMEs, as it helps them to manage costs, maintain product quality, stay competitive, manage risks and support sustainable and ethical practices. It plays a significant role in the overall success and growth of SMEs.

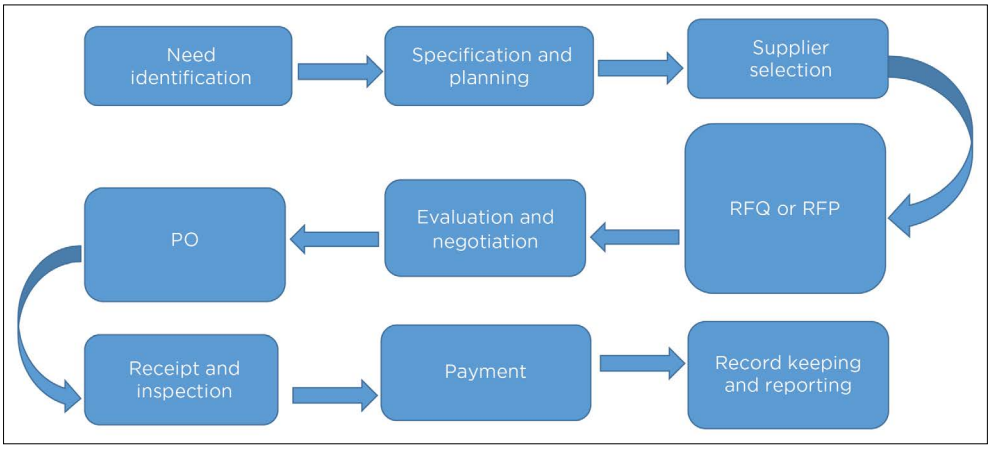
Procurement process

The procurement process includes preparing and processing a demand, as well as receiving and approving payment. Comprehensively, this can involve purchase planning, standards, specifications determination, supplier research, selection, financing, price negotiation and inventory control (Farrington & Lysons 2020; Parisi & Donyavi 2026). The procurement process is shown in Figure 2.4.

The procurement process is a series of steps that an organisation follows to acquire goods, services or works from external sources (typically suppliers or vendors). It ensures that the organisation obtains the necessary resources efficiently and effectively. The next sections explain the procurement cycle in greater detail.

Need identification

The cycle begins with identifying the need of an organisation for a particular product, service or work. Various departments within the organisation can initiate this. For example, the information technology (IT) department may



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
Key: RFP, Request for Proposal; RFQ, Request for Quotation; PO, purchase order.

FIGURE 2.4: Procurement process.

identify the need for new software to improve efficiency, or the operations team may recognise the need for additional machinery to meet increased production demands. Accurately identifying the need is crucial, as it forms the foundation for the entire procurement process and influences subsequent steps such as specification development, supplier selection and contract negotiation. Properly understanding the requirements ensures that the organisation procures the right goods or services to fulfil its objectives effectively and efficiently.

Specification and planning

Once the need is identified, detailed specifications are developed. This includes defining the quantity, quality, features and any other specific requirements necessary to fulfil the identified need effectively. For instance, if the organisation requires new office furniture, the specifications might outline preferred materials, dimensions, ergonomic features and any special considerations. Concurrently, procurement planning is crucial, including determining the available procurement budget, selecting appropriate procurement methods (such as competitive bidding or direct negotiation) and establishing a timeline for the acquisition process. Effective planning ensures that the procurement process aligns with organisational goals, maximises resource utilisation and minimises risks associated with delays or budget overruns.

Supplier selection

The organisation selects potential suppliers or vendors who can meet the requirements identified during the specification and planning phase. This

can involve creating a list of approved suppliers based on past performance, reputation or industry certifications. Alternatively, organisations may conduct a comprehensive supplier evaluation process to assess factors such as capability, reliability, financial stability and adherence to ethical standards. Supplier selection is critical as it affects the quality, cost and timely delivery of goods or services procured directly. By engaging reputable, competent suppliers, organisations can mitigate risks and ensure successful outcomes for their procurement initiatives.

□ Request for Quotation or Request for Proposal

After selecting potential suppliers, the organisation initiates the procurement process by sending out RFQs or RFPs. These documents outline the organisation's requirements and solicit bids, proposals or quotes from the suppliers. Requests for Quotation are typically utilised for straightforward purchases where specifications are well defined, and the primary consideration is price. On the other hand, RFPs are used for more complex projects or services that may require detailed proposals addressing aspects such as technical solutions, timelines and pricing structures. By utilising the appropriate solicitation method, organisations can communicate their needs effectively and evaluate supplier responses to make informed procurement decisions.

□ Evaluation and negotiation

Upon receiving bids or proposals from suppliers in response to the RFQs or RFPs, the organisation initiates the evaluation process. The received bids are assessed meticulously based on predetermined criteria, including price competitiveness, quality standards, delivery timelines and the supplier's reputation. This evaluation phase enables the organisation to compare offerings objectively and to select the most suitable supplier for the procurement. Subsequently, negotiations may ensue with the chosen supplier(s) to refine terms, pricing structures and contractual agreements. The negotiation process aims to achieve a mutually beneficial arrangement that meets the needs of both the organisation and the supplier, fostering a collaborative and sustainable business relationship. Effective negotiation skills and a thorough understanding of procurement requirements are pivotal to reaching agreements that optimise value and mitigate risks for all parties involved.

□ Purchase order

Upon finalising negotiations and reaching an agreement with the selected supplier, the next step in the procurement cycle is to issue a PO. This formal

document serves as a legally binding contract between the organisation and the supplier, outlining the specific terms and conditions of the purchase. The purchase order includes essential details such as the agreed-upon price, quantity, delivery schedule, payment terms, shipping instructions and any other relevant terms agreed upon during the negotiation process. By issuing a PO, the organisation provides clarity and certainty to both parties regarding their respective obligations, facilitating smooth transaction processing and ensuring compliance with procurement policies and regulations. In addition, the PO serves as a critical audit record and helps to track the status of the procurement process from order placement to fulfilment.

□ Receipt and inspection

Upon the delivery of goods or completion of services, the organisation proceeds with the crucial step of receipt and inspection. This involves physically receiving the items or verifying the completion of services to ensure they align with the specifications outlined in the PO. Through meticulous inspection, the organisation evaluates various aspects, including quality, quantity, functionality and compliance with agreed-upon standards. Any discrepancies or defects identified during the inspection are documented and addressed in accordance with established protocols and procedures. By conducting thorough inspections, the organisation safeguards against receiving substandard or defective goods, mitigating risks associated with potential rework, delays or additional costs. Furthermore, this stage reinforces accountability and transparency in the procurement process, fostering trust and confidence between the organisation and its suppliers.

□ Payment

Upon verification of the received goods or completion of services through the receipt and inspection process, the organisation proceeds with payment to the supplier. Payment is processed in accordance with the agreed terms outlined in the PO or contract. These terms may encompass various payment arrangements, including immediate payment upon receipt, instalment payments based on project milestones or deferred payments with specified credit terms. The organisation ensures adherence to financial protocols and procedures during the payment process, which may involve reconciling invoices, verifying compliance with contractual obligations and obtaining necessary approvals for disbursements. Timely and accurate payments do not only demonstrate the organisation's commitment to fulfilling its financial obligations but also maintain positive relationships with suppliers, fostering a conducive environment for future collaborations.

In addition, proper payment management contributes to financial transparency and accountability, aligning with regulatory requirements and internal control standards.

Record-keeping and reporting

As a critical aspect of the procurement cycle, the organisation maintains meticulous documentation and records to facilitate auditability and reporting. This involves systematically recording essential information for each stage of the procurement process, including, but not limited to, POs, supplier contracts, invoices, receipts, inspection reports and correspondence with suppliers. By maintaining comprehensive records, the organisation ensures transparency, accountability and compliance with regulatory requirements and internal policies. These records serve as a valuable resource for internal auditing, external regulatory inspections and performance evaluation. Furthermore, effective record-keeping enables the organisation to analyse historical procurement data, identify trends and make informed decisions to optimise future procurement activities. Through regular reporting mechanisms, stakeholders gain insights into procurement performance, expenditure patterns and compliance levels, facilitating strategic planning and risk management efforts.

The procurement cycle is a structured and systematic approach to acquiring resources and is essential for managing costs, ensuring quality and achieving the organisation's goals efficiently. The specific steps and processes may vary depending on the organisation and the nature of the procurement.

Warehousing and inventory management

Warehouse and inventory management are crucial components of any business that handles physical goods (Limi & Rangarajan 2025). These functions play a pivotal role in ensuring efficient operations, customer satisfaction and cost control. Warehouse and inventory management are intertwined practices, but they serve distinct purposes in the supply chain. Warehousing involves the physical storage of goods in a facility, while inventory management focuses on tracking and controlling the quantity and flow of those goods. Both functions are interconnected and essential for smooth operations.

Effective warehouse management is crucial for several reasons. First and foremost, it ensures that products are stored securely and efficiently. The layout of a warehouse, from the arrangement of goods to the management of space, affects the speed and accuracy of order fulfilment directly. Inefficient warehousing can lead to lost products, wasted space

and increased labour costs. Furthermore, warehouses serve as a buffer in the supply chain. They allow businesses to store excess inventory, which can help to mitigate supply disruptions, seasonal fluctuations or changes in customer demand. This strategic use of warehousing helps to maintain a stable and reliable supply of products, ultimately benefiting customers and the bottom line.

Inventory management, on the other hand, focuses on optimising stock levels. It ensures that a company neither overstocks nor understocks its products. Overstocking can lead to unnecessary storage costs and the risk of obsolescence, while understocking can result in lost sales and dissatisfied customers. Proper inventory management strikes a balance, enhancing profitability and customer satisfaction. To achieve effective warehouse and inventory management, businesses adhere to several key principles. These include accurate record-keeping, regular cycle counting or physical inventory, and the use of technologies such as barcoding and radio frequency identification to track and trace products. In addition, businesses often employ inventory control methods such as ABC analysis, which classifies items by value and the degree of control required.

In recent years, technology has brought about a significant transformation in warehouse and inventory management. The adoption of warehouse management systems (WMS) and inventory management software has become commonplace (Rathee & Rani 2025). Warehouse management systems optimise the placement of goods, automate order picking and enable real-time inventory tracking. Similarly, inventory management software aids in demand forecasting, calculating reorder points and facilitating supplier communication. The rise of e-commerce has also influenced warehouse and inventory management practices. The need for rapid order fulfilment and the ability to handle a vast array of products have forced businesses to re-evaluate their warehousing strategies. The concept of 'omni-channel warehousing' has emerged, in which warehouses must support multiple channels, including in-store, online and direct-to-customer sales.

Automation and robotics have revolutionised warehouse operations further. Automated guided vehicles and robots can handle material movement and picking tasks with speed and precision. These technologies reduce labour costs, increase efficiency and enhance safety in the warehouse. The integration of Internet of Things (IoT) and data analytics has provided businesses with valuable insights into their warehouse and inventory operations. Real-time data on inventory levels, movement patterns and even environmental conditions can be analysed to make informed decisions. Predictive analytics helps in demand forecasting and optimising reorder points.

Warehouse and inventory management are vital components of any business involved in the supply chain. They ensure efficient storage, control over stock levels and the ability to respond to changing customer demands. The principles of accurate record-keeping, regular counting and technology adoption play a pivotal role in these processes. The evolution of technology, from WMS to automation and data analytics, continues to reshape the landscape of warehouse and inventory management, making it more efficient and responsive to the dynamic demands of the modern marketplace.

Transport and logistics

Transportation refers to the movement of goods, while logistics encompasses the management of inbound and outbound transportation from manufacturers to end users. Logistics refers to the receipt, production and distribution of goods and materials in the quantities requested by customers to their final destination (Wang 2024; Yadav et al. 2023). It is also the strategy that determines how your company stores products in its warehouse, tracks orders and delivers products to its customers. These terms are often used interchangeably, but they represent two distinct parts of the supply chain. Transport and logistics are integral to the supply chain, involving the movement and coordination of goods and materials. The term refers to the management of the flow of goods and services from the point of origin to the point of consumption. Transport and logistics are fundamental to modern commerce, playing a crucial role in moving goods from suppliers to end consumers. Effective management and the integration of advanced technologies are essential for businesses to compete in the global marketplace while addressing environmental and sustainability concerns.

Transport and logistics play a vital role among SMEs. These businesses often face unique challenges and opportunities in managing their supply chains, and effective transport and logistics strategies are essential for their success. Small and medium enterprises typically operate with limited resources. Efficient transport and logistics help reduce operational costs, which are critical to their sustainability and profitability. Many SMEs outsource their logistics needs to third-party providers.

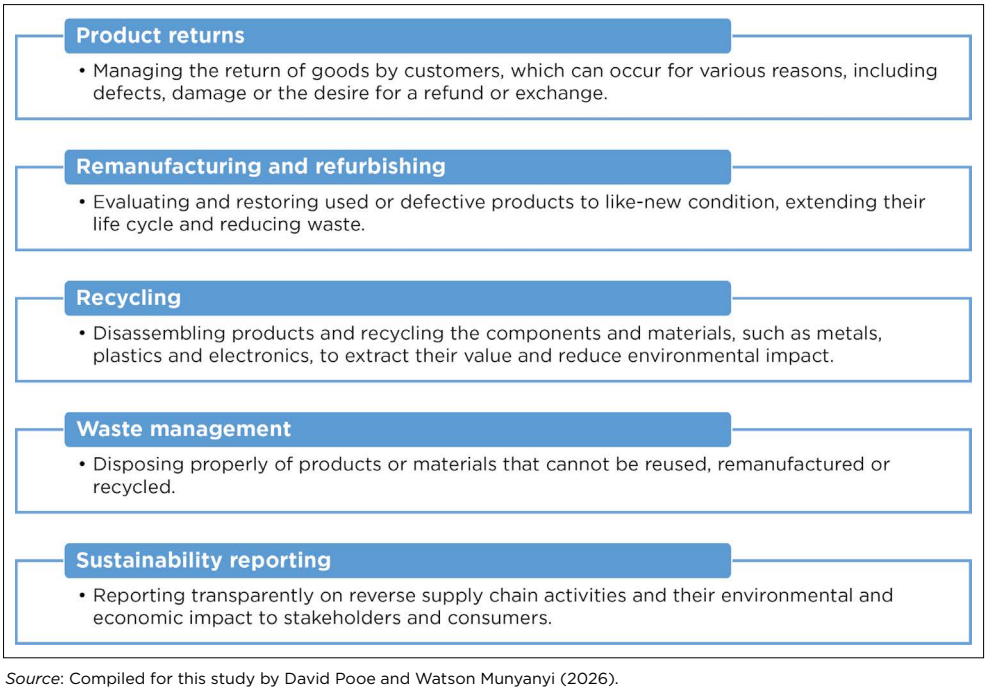
This can help them to access expertise and resources without the need for significant in-house investments. Efficient last-mile delivery is crucial for SMEs, especially e-commerce businesses. This involves delivering products to the end customer quickly and cost-effectively. Many SMEs are adopting modern technologies, such as transportation management systems and WMSs, to streamline their logistics operations. Recent global disruptions, such as the coronavirus disease 2019 (COVID-19) pandemic, have highlighted

the importance of building resilient supply chains. Small and medium enterprises are taking steps to diversify suppliers and transportation options to mitigate risks. They often need to be resourceful, adaptable and cost-effective in managing their supply chains. Leveraging technology and sustainable practices while focusing on meeting the specific needs of their markets can help SMEs to thrive in a competitive business environment.

Reverse supply chain management

In recent years, the concept of SCM has evolved to encompass the full life cycle of products, giving rise to the notion of reverse SCM. This approach focuses on the processes involved in recovering and managing products, materials and components at the end of their life cycles. Reverse SCM is a critical aspect of sustainability and responsible resource management, with the potential to minimise waste, reduce environmental effect and even create economic value from returned and discarded products. At its core, reverse SCM involves the systematic handling of products and materials that are no longer in use. This encompasses several key activities as shown in Figure 2.5.

In an era of increasing environmental concerns, it is essential to minimise waste and reduce the carbon footprint. Reverse SCM promotes responsible



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).

FIGURE 2.5: Reverse supply chain management.

disposal and recycling practices, which are critical for a sustainable future. Also, recovering and reusing materials from end-of-life products reduces the need for raw materials, conserving resources and energy. This not only has environmental benefits but can also lead to significant cost savings. Companies that manage their reverse supply chain effectively can create economic value by refurbishing and reselling products, recycling materials or repurposing components. In addition, providing trouble-free product returns and recycling options enhances customer satisfaction and builds trust, which can lead to customer loyalty and repeat business. In some industries, there are legal requirements for responsible product disposal and recycling. Non-compliance can result in fines and damage to a company's reputation.

Incorporating reverse SCM into a company's operations requires a systematic approach. This includes setting up collection points for returns, establishing refurbishing or recycling centres, and implementing rigorous quality control processes for refurbished products. Effective communication with customers about the return process and sustainable options is also crucial. Reverse SCM is a strategic imperative for businesses seeking to enhance sustainability and economic efficiency. It aligns with growing consumer demand for responsible product disposal and recycling. By optimising the management of returned and end-of-life products, companies can reduce waste, minimise their environmental impact and create value from materials that would otherwise be discarded. Ultimately, reverse SCM represents a win-win scenario for businesses, customers and the environment.

Policy, regulatory and institutional support for small and medium enterprises

Government support plays a critical role in enabling SMEs to remain competitive and responsive in an increasingly Industry 4.0–driven environment (Mohiuddin et al. 2023). Such support extends beyond financial assistance to include institutional frameworks, policies and regulations designed to create an enabling ecosystem for technological adoption. Public and private institutions – including governments, universities and industry bodies – are instrumental in shaping regulatory environments that protect domestic markets while facilitating innovation and digital transformation among SMEs. The importance of institutional intervention was particularly evident during the COVID-19 pandemic, when global supply chain disruptions exposed the vulnerabilities of SMEs in both production and service delivery. In response, governments implemented foreign direct investment (FDI)–related policy adjustments aimed at regulating cross-border investments and safeguarding local market access.

These measures had a more pronounced effect on emerging economies such as South Africa and India than on advanced economies, highlighting the role of policy in enhancing economic resilience during periods of systemic disruption.

At the global level, institutions have focused increasingly on balancing the acceleration of Industry 4.0 technologies with ethical, social and human considerations. While smart and digital supply chain technologies have improved productivity and value creation, they have also raised concerns about workforce displacement, inequality and ethical technology use. Intergovernmental frameworks, such as the Organisation for Economic Co-operation and Development (OECD) AI principles, have emerged to promote human-centred, transparent and accountable approaches to AI. These principles have informed landmark regulatory developments, including the European Union's risk-based AI governance framework, which seeks to mitigate societal risks while enabling responsible innovation.

As Industry 4.0 adoption intensifies, policy discourse has expanded to include mechanisms for mitigating its socioeconomic consequences. Initiatives such as Universal Basic Income have gained attention as potential tools for addressing technological displacement and income inequality through redistributive economic models. In parallel, concerns regarding the widening digital divide between developed and developing economies have prompted calls for inclusive digital infrastructure and coordinated global action. Advanced economies continue to outpace developing nations in AI deployment, prompting governments to integrate digital technologies into core public-sector functions while investing in innovation ecosystems.

In the South African context, policy priorities have shifted increasingly towards strengthening business resilience in response to Industry 4.0–related disruptions. The government has introduced policy frameworks aimed at promoting advanced manufacturing, digitally enabled supply chains and the ethical application of AI. These initiatives emphasise the augmentation of human decision-making, productivity enhancement and alignment with national development objectives. In addition to formal policy instruments, South African SMEs benefit from institutional support mechanisms that provide access to funding, digital infrastructure and technical expertise. Government agencies and coordinated development programmes offer incubation services, shared digital hubs, and streamlined regulatory support, enabling SMEs to overcome resource constraints and to participate more effectively in the digital economy. Collectively, these institutional interventions underscore the central role of coordinated policy and governance in supporting SME adaptation to Industry 4.0 and ensuring inclusive and resilient economic transformation.

Conclusion

In conclusion, Chapter 2 has provided a comprehensive overview of SCM and its significance for SMEs. Beginning with an introduction to SCM, the chapter delved into various aspects, including demand management, sourcing and procurement, performance monitoring, procurement strategies, warehousing and inventory management, transport and logistics, and reverse SCM. Through this exploration, readers have gained insights into the intricate processes involved in managing the flow of goods and services from the point of origin to consumption or disposal, with a focus on optimising efficiency, reducing costs and enhancing customer satisfaction. Moreover, the chapter underscored the critical role of SCM in driving competitiveness and sustainability for SMEs in the dynamic business landscape of today. As the journey through SCM continues, SMEs must adapt and innovate, leveraging technological advancements and strategic partnerships to navigate challenges and seize opportunities for growth and resilience. With a solid understanding of SCM principles and practices, SMEs can streamline their operations, foster collaboration across supply chain partners and ultimately, achieve long-term success in the global marketplace.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and W Munyanyi; *methodology* (desktop-based literature review and conceptual synthesis), D Pooe and W Munyanyi; *validation*, D Pooe and W Munyanyi; *investigation* (systematic review and interpretation of secondary sources), D Pooe and W Munyanyi; *resources*, D Pooe; *writing* – original draft preparation, D Pooe; *writing* – review and editing, W Munyanyi and D Pooe; *visualisation*, W Munyanyi; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 3

Small and medium enterprises and digital supply chains

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Introduction

The strides that small and medium enterprises (SMEs) are taking in adopting Industry 4.0 technologies have increased significantly, and these new technologies are beginning to transform and exert a profound influence across all industries and organisations. In particular, supply chains are affected significantly by these changes and their associated effects. Effective supply chain management (SCM) lies at the heart of business

How to cite: Munongo, S & Pooe, D 2026, 'Small and medium enterprises and digital supply chains', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 61–85. https://doi.org/10.4102/aosis.2026.BK572.03

operations, particularly for SMEs. The previous chapter focused on the intricacies of SCM, exploring its components and the unique challenges and opportunities it presents for SMEs. As digital technologies revolutionise industries, SMEs must adapt their supply chain strategies to remain competitive. Digital technologies, including big data analytics utilising machine learning (ML), the Internet of Things (IoT), artificial intelligence (AI) and blockchain, have emerged as essential tools for fostering agile, adaptable and resilient SCM. Smaller manufacturers are taking the initiative to digitise their supply chains for greater productivity, resilience and sustainability.

Effective SCM lies at the heart of business operations, particularly for SMEs. This chapter is centred on unpacking how digital technologies help organisations to enhance data security, strengthen connectivity with supply chain partners, improve traceability and optimise supply and demand management capabilities. It examines various models and strategies for adopting digital supply chain (DSC) practices, elucidating the advantages, barriers and enablers of digitalisation for SMEs. The chapter also examines various technology adoption models, provides an overview of the digital supply chain strategy (DSCS) and examines its rationale as well as the barriers and enablers. Thereafter, it looks at the DSC decision-making process and its development among SMEs. Finally, the chapter covers the development of SME DSCSs and risk management.

Business context

The business context of an organisation is a dynamic environment. Presently, disruptions driven by increased tariffs, trade conflicts and a global pandemic have thrust supply chains into the spotlight of business discussions (Saini et al. 2022). The rise of digitalisation has accelerated changes, demanding quick decision-making across entire supply chains (Yu, Wu & Tan 2025). To stay competitive, organisations must implement efficient processes to minimise delays and avoid losses in materials, energy, finances and information. The rapid pace at which managers must adapt to constantly evolving market conditions can be overwhelming. Moreover, as the world becomes more digital, consumers are expecting faster service, greater convenience and higher accuracy. Technology has enabled many businesses to meet these expectations, with the growth of the DSC playing a key role in boosting manufacturers' efficiency, improving visibility and reducing costs for all stakeholders and increasing customer satisfaction, among other factors (Liu & Chi 2024). However, many SMEs must stay abreast of rapidly evolving digital trends that are reshaping traditional SCM, shortening response times and raising customer expectations.

The pace of change can be daunting, particularly for those who are not accustomed to the digital landscape. However, SMEs must invest swiftly in DSCs for their continuity.

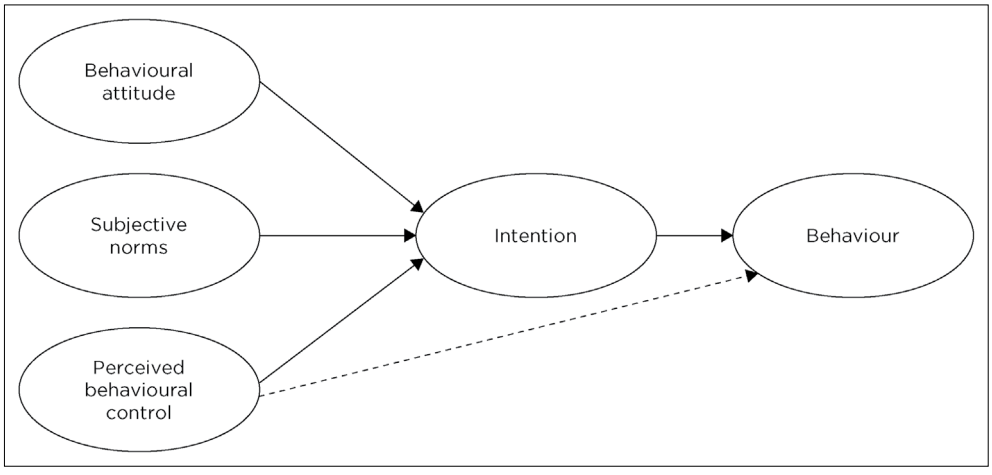
Technology adoption models

Technology adoption is defined as the decision to acquire and utilise an innovation (Queiroz et al. 2025). Many models have been proposed over time to explain how and why individuals make their decisions regarding technology adoption. Five technology adoption models applicable to SMEs in the context of Industry 4.0 are discussed in this chapter: (1) the theory of reasoned action (TRA); (2) the technology acceptance model (TAM); (3) the theory of planned behaviour (TPB); (4) the diffusion of innovation (DoI) model; and (5) the unified theory of acceptance and use of technology (UTAUT).

Theory of reasoned action

The theory of reasoned action was coined by Ajzen and Fishbein (1975). Based on a social psychology framework, this model highlights attitude, subjective norms and behavioural intention as key factors influencing adoption behaviour. Ajzen and Fishbein (1975) define attitude as an individual's overall evaluation of the desirability or undesirability of a particular object or behaviour. Subjective norms refer to a person's perception of the opinions of significant others regarding a specific behaviour. Theory of reasoned action posits that both attitude and subjective norms shape behavioural intention, which, if strong enough, will lead to actual behaviour. Therefore, an individual who believes strongly that performing a certain action will lead to a positive outcome is likely to develop a positive attitude towards that behaviour. Conversely, if one believes that a particular behaviour will result in a negative outcome, they will most likely develop a negative attitude towards it. Theory of reasoned action and its respective components are depicted in Figure 3.1.

While seemingly simple, the TRA has been regarded widely as a solid foundation for subsequent theories of technology adoption and, therefore, applicable to explaining SME owners' and/or managers' adoption of Industry 4.0 technologies. However, the TRA has some limitations. It disregards an individual's capacity to control their own behaviour. Furthermore, the TRA does not incorporate extensively other important variable constructs which facilitate technology adoption. The framework overlooks influential dynamics such as the adopter's age, gender, perceived risks, relative advantages, costs and location, among others (Munongo 2019).

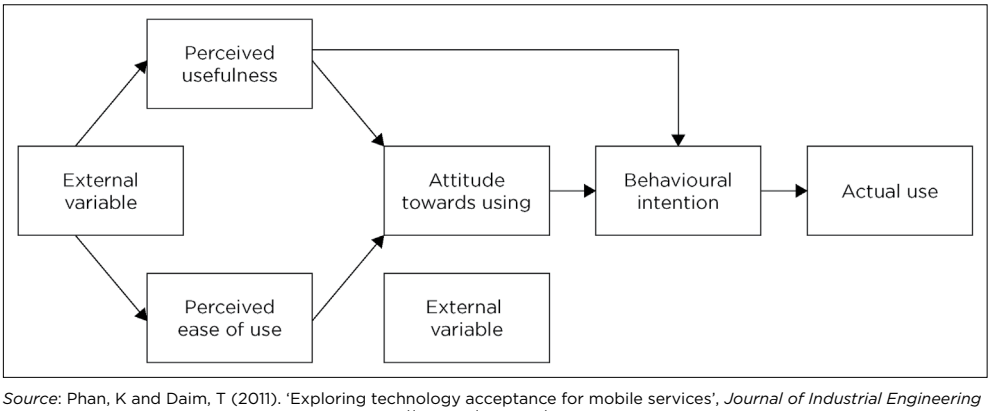


Source: Funke (2017) 'How much knowledge is necessary for action?' in P Meusburger, B Werlen & L Suarsana (eds.), *Knowledge and action*. *Knowledge and Space*, vol. 9. Springer, Cham. https://doi.org/10.1007/978-3-319-44588-5_6. Creative Commons Attribution 4.0 International (CC BY 4.0).

FIGURE 3.1: Theory of reasoned action.

Technology acceptance model

The technology acceptance model, introduced by Davis (1989), was developed to explain the adoption of technological innovations in the information systems (IS) domain. It is an extension of the TRA, emphasising the causal link between two key components – perceived ease of use and perceived usefulness – and their influence on attitude, behavioural intention and actual technology usage, as depicted in Figure 3.2.



Source: Phan, K and Daim, T (2011). 'Exploring technology acceptance for mobile services', *Journal of Industrial Engineering and Management*, vol. 4, no. 2, pp. 339–360. https://doi.org/10.3926/jiem.2011.v4n2. Creative Commons Attribution 4.0 International (CC BY 4.0).

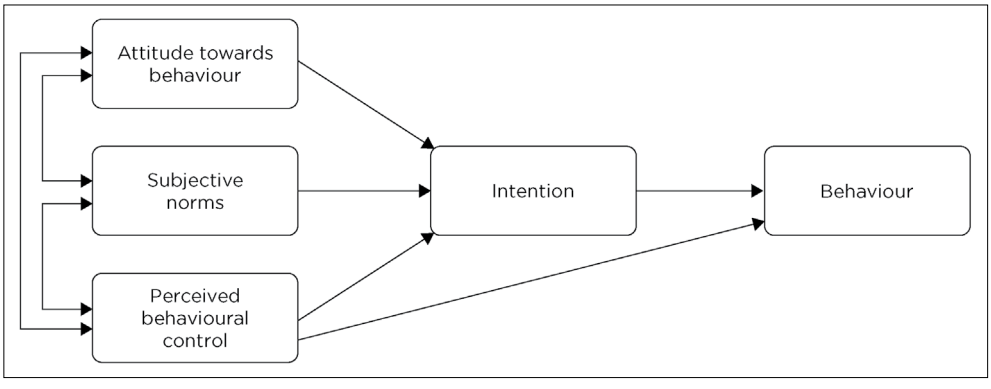
FIGURE 3.2: Technology acceptance model.

Technology acceptance model views perceived usefulness as the extent to which individuals feel that using a specific system or technology will improve their performance in tasks. Equally, perceived ease of use refers to how much an individual believes that utilising a particular system demands minimal physical and mental effort. The theory suggests that the adoption of technology depends on a user's intention to behave in a certain way, which, in turn, is influenced by the attitude towards use. Attitude is influenced by perceived usefulness and perceived ease of use. Interestingly, perceived usefulness is influenced by perceived ease of use. The underlying notion of the TAM is that the simpler a technological system is, the more likely it is to be seen as advantageous by the user and, ultimately, adopted. Although the TAM was originally introduced to identify the factors influencing computer acceptance, it has empirically become a foundational theory in technology adoption research across diverse fields.

Theory of planned behaviour

Ajzen introduced the TPB in 1991 as a modification of the TRA, addressing the limitation of predicting behaviour solely under volitional control as presented in Figure 3.3.

The theory characterises perceived behavioural control as an individual's assessment of how easy or difficult it is to perform a particular behaviour. This assessment reflects the person's understanding of the necessary skills, resources and opportunities required to engage in that behaviour (Munongo 2019). According to the TPB, perceived behavioural control, subjective norms and attitudes shape behavioural intentions collectively, subsequently affecting adoption. Moreover,



Source: Ajzen, I (1991). 'The theory of planned behaviour', *Organisational Behaviour and Human Decision Processes,* vol. 50, no. 2, pp. 179–211. https://doi.org/10.1016/0749-5978(91)90020T. Creative Commons Attribution 4.0 International (CC BY 4.0).

FIGURE 3.3: Theory of planned behaviour.

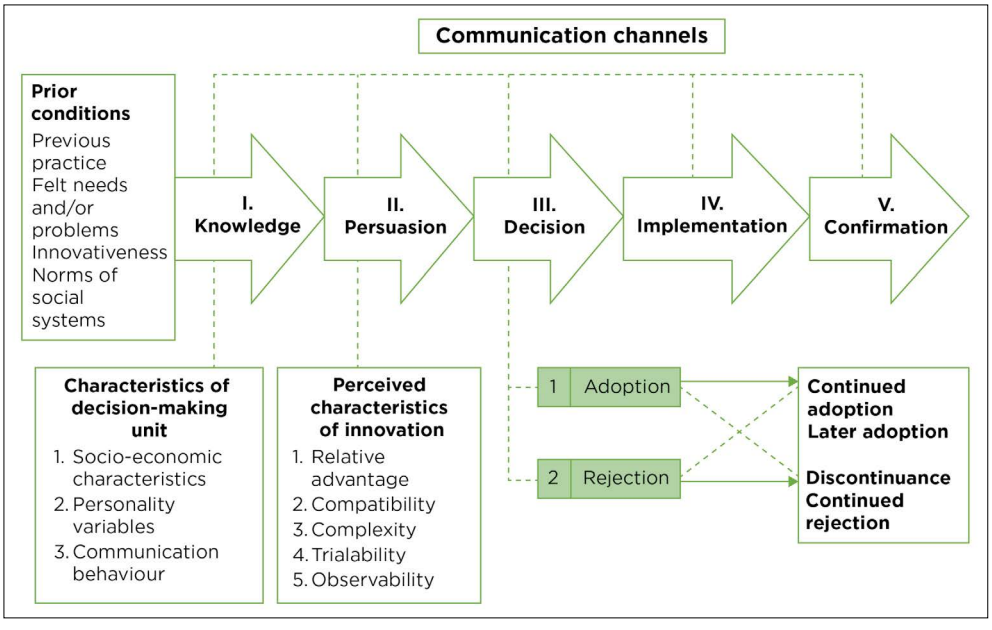
perceived behavioural control also influences adoption behaviour directly. The validity of the TPB has been confirmed extensively through empirical research on behavioural intention to adopt various digital platforms.

Diffusion of innovation theory

The diffusion of innovation theory, developed by Rogers (1995, 2004), explains how, why and at what pace new ideas and technologies infiltrate societies and cultures. It views diffusion as the process through which an innovation is shared over time through specific channels among members of a social system. According to this theory, an innovation is an idea, practice or object perceived as new by an individual or another adopting entity. Also, the communication process in diffusion involves the innovation itself, an individual with knowledge or experience of the innovation, another individual without such familiarity, and a communication channel that connects them. These channels can include mass media, which is often the most effective for raising awareness of an innovation. However, the DoI suggests that interpersonal channels can be more persuasive in encouraging individuals to adopt new innovations. In addition, the theory highlights the role of time in the innovation-decision process, as it helps to determine an individual's level of innovativeness and the relative speed at which the innovation is adopted.

The diffusion of innovation further hypothesises that the process of adopting an innovation unfolds in five phases: knowledge, persuasion, decision (adoption or rejection), implementation and confirmation. Rogers (1995, 2004) suggests that these stages are influenced by prior conditions, the characteristics of the decision-making unit and the perceived attributes of the innovation. The theory identifies five key attributes of an innovation that affect an individual's adoption decision: relative advantage, compatibility, complexity, trialability and observability.

Relative advantage refers to the extent to which an innovation is perceived as superior to the idea it replaces. Compatibility relates to how well the innovation aligns with the adopter's existing values, past experiences and needs. Complexity describes the perceived difficulty of understanding and using the innovation, which tends to hinder adoption; greater complexity reduces the likelihood of adoption. Trialability reflects how easily an innovation can be experimented with on a small scale, while observability pertains to how visible its outcomes are to others (Munongo 2019). Figure 3.4 depicts the five stages of the innovation diffusion process, showing how the prior conditions, communication channels, distinct features of the decision-making unit and perceived characteristics interact.



Source: Rogers, EM (2003). *Diffusion of innovations*, 5th edn., The Free Press, New York. Adapted by Mahat, N, Bohari, AA, Azman, MA, Khalil, Adnan, AS and Malek, MI (2022). Creative Commons Attribution 4.0 International (CC BY 4.0).

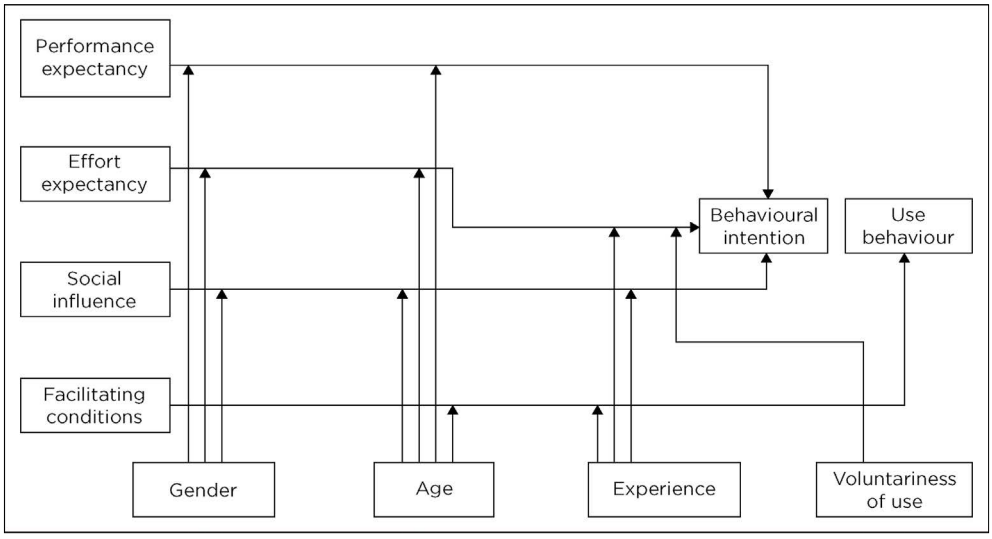
FIGURE 3.4: The innovation-decision process.

Unified theory of acceptance and use of technology

The unified theory of acceptance and use of technology, introduced by Venkatesh et al. (2003), integrates elements from several technology adoption theories, including the TRA, the TPB, the decomposed TPB, the TAM, the DOI theory, the social cognitive theory and the motivational model. The unified theory of acceptance and use of technology posits that performance expectancy, effort expectancy and social influence shape behavioural intention towards technology acceptance directly, which subsequently affects actual usage (adoption). In addition, facilitating conditions influence usage behaviour directly while age, gender, user experience and voluntariness of use serve as key moderating variables in the model.

The unified theory of acceptance and use of technology model is shown in Figure 3.5.

The model has been applied successfully across various sectors, including health care, education and consumer technology, highlighting



Source: Adapted from Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology, by Venkatesh, Thong, and Xu (2012), MIS Quarterly, 36(1), pp. 157–178.

FIGURE 3.5: Unified theory of acceptance and use of technology model.

its adaptability to different user types and technological contexts (Tamilmani et al. 2021). Momani (2020) describes the UTAUT as one of the most comprehensive models for examining technology usage behaviour, noting its simplicity owing to a limited number of constructs and moderating variables. This simplicity enhances its applicability and accessibility, particularly in studying the acceptance of new technologies or IS.

However, despite its strengths, the UTAUT also has notable limitations. For instance, Dwivedi et al. (2019) point out its reliance on moderators such as age, gender, experience and voluntariness, which may not be applicable universally across different cultural and contextual settings, potentially leading to biased outcomes. In addition, the model has been criticised for excluding certain constructs, such as individual attitudes and external factors that influence technology acceptance significantly, thereby limiting its predictive accuracy in specific scenarios (Dwivedi et al. 2019). Moreover, the original UTAUT model requires adaptations to remain relevant in rapidly evolving technological landscapes. For example, the development of UTAUT2 incorporates additional factors, such as hedonic motivation and habit, to address these gaps (Tamilmani et al. 2021).

Therefore, while UTAUT offers a strong foundation for understanding technology adoption, its limitations underscore the need for continuous refinement and contextual adjustments to enhance its relevance and applicability in diverse environments.

Digital supply chain strategy

Overview and importance

A digital supply chain strategy leverages digital technologies and tools to streamline SCM processes, improve efficiency, reduce costs and enhance the customer experience (Nasiri et al. 2020). Such a strategy is premised on web-enabled capabilities, such as ML, AI, augmented and virtual reality, predictive analytics, big data, IoT and three-dimensional (3D) printing, across every aspect of the end-to-end supply chain (Queiroz et al. 2021). Similarly, the Digital Supply Chain Institute (2017) defines a DSCS as a customer-focused platform model that gathers and optimises the use of real-time data from diverse sources, facilitating demand stimulation, matching, sensing and management to enhance performance and reduce risk. We can also view a DSCS as an intentional set of intelligent, value-driven network methodologies that leverage new technologies and data analytics to create value and revenue for the organisation through digital planning, supply, manufacturing and logistics. On the other hand, Ivanov and Dolgui (2021) describe the DSCS as a set of interconnected processes that utilise advanced technologies and provide deeper insights into the roles of each stakeholder. This approach empowers participants to make well-informed decisions about material sourcing, product demand and all associated relationships.

The digital supply chain strategy, therefore, entails the complete integration of traditional SCM technologies, including demand planning, asset management, warehouse management, transportation and logistics management, procurement and order fulfilment. However, Jenkins (2022) highlights that digitising a supply chain effectively also requires extracting data from these processes and equipping the necessary tools to generate that data. This equipment integration is achieved through sensors and monitors, collectively referred to as IoT. This technology is commonly used to oversee manufacturing or logistics operations. By utilising gateways, the data can be shared with various stakeholders throughout the supply chain. This is then aggregated and analysed by these stakeholders to determine the reliability of product availability. For example, digital technology could allow a small to medium-sized clothing retailer not only to track the number of shirts in specific colours, styles and sizes in a warehouse, but also to know how many are currently being manufactured and their position in the production queue (Jenkins 2022).

While many conventional supply chains rely on a combination of paper-based and IT-enabled processes, a genuine DSC surpasses this hybrid approach by leveraging full connectivity, system integration and the data-generating capabilities of ‘smart’ components. While both digital and

traditional supply chains encompass functions such as product design, sourcing raw materials and components, forecasting demand, planning product launches, managing supply, choosing sales channels, providing support and giving customers visibility into their orders, Ivanov and Dolgui (2021) note several variations between the two operating models. Firstly, where traditional supply chains focus on planning and reacting, DSCs emphasise predicting and prescribing actions. Secondly, traditional supply chains are mainly static, relying on rules based on historical transaction data, despite lag times. In contrast, fully DSCs operate in real time, are dynamic and can adapt to changing conditions (Kaushik & Jain 2021). Thirdly, Jenkins (2022) highlights that traditional supply chains are linear, whereas DSCs operate as networks with multiple interconnected nodes. Fourthly, traditional supply chains typically rely on isolated systems, while DSCs integrate data from both IT and operational technology systems. Instead of optimising individual nodes, shipments or orders, DSCs focus on balancing profit and service levels.

Fifthly, in traditional supply chains, identifying potential problems and predicting their effects often requires extensive effort. Companies usually conduct regular resilience assessments of their most critical suppliers based on stock-keeping units and manually outline steps to maintain production if any links fail. In contrast, DSCs leverage shared quality and control data from suppliers, allowing companies to anticipate issues and respond proactively without extensive preplanning. Ultimately, in traditional supply chains, humans make decisions based on machine inputs, while in DSCs, machines drive decisions with human oversight. The flow of products in traditional systems tends to be linear, with each step reliant on the previous one. Although straightforward in concept, this approach depends on each process step performing as expected. Delays or failures by a subassembly provider or shipper may go unnoticed for days or weeks, often leading to missed deadlines and dissatisfied customers (Jenkins 2022).

A digital supply chain strategy leverages technological advances to provide greatly enhanced visibility into supply chain operations. The increased near-real-time insight into supplier performance and customer needs allows supply chain managers to cultivate more intricate relationships with multiple suppliers, thereby protecting themselves against various disruptions. Digital supply chains prioritise customer focus and strive to fulfil the three key pillars of excellence in demand fulfilment: speed, personalisation and choice. The practical implications of this approach vary depending on the organisation's specific goals. However, ultimately, the DSC combines internal systems and data with both structured and unstructured external information. It enables two-way communication with suppliers and provides complete supply chain visibility (SCV) for all stakeholders. New technologies gather, monitor and analyse data to offer real-time predictions and actionable recommendations.

Advantages of a digital supply chain strategy

A digital supply chain strategy offers numerous benefits, including increased visibility and connectivity, supply chain sustainability, real-time tracking, better customer experiences, and greater flexibility and agility. In fact, Jenkins (2020) establishes that, through a DSC, an organisation can yield thrice the return on innovation, a 20% reduction in its time-to-market turnaround, a 30–50% increase in demand forecasting accuracy, an 8% increase in customer satisfaction and a 20–50% reduction in product scrap and rework costs.

The concept of total SCV is not new. However, in the context of a DSC, SME visibility translates to connectedness. Consider this: with how many of your supply chain partners are you digitally connected? How many do you collaborate with at a strategic planning level? This connectedness extends beyond material suppliers. Think more broadly: are you connected to your logistics providers to navigate disruptions and ensure timely deliveries? What about your assets, such as plant machinery? Are you leveraging IoT technology to connect with manufacturers that can monitor asset health in real time, predict failures and take proactive measures to prevent them? This level of connectedness is essential to achieve true SCV.

Sustainability should be considered from both environmental and business perspectives. In the face of significant climate change, environmental issues are crucial. However, many SMEs prioritise growth over sustainable business growth. Growth and sustainability are linked closely; SMEs that use fewer resources and minimise waste operate more efficiently, ultimately saving money. In addition, a DSCS can foster new business models that accelerate growth while reducing the carbon footprint. For instance, if an SME adopts direct-to-consumer models, it can lower transportation costs significantly by shipping products directly to customers instead of routing them through distribution points (Cornelius 2023). Today, companies can establish e-commerce platforms and ship directly to their clients. Moreover, SMEs can leverage 3D printing or additive manufacturing for cost-effective, customised production, enabling them to be closer to their end customers. Predictive maintenance can also extend the lifespan of assets, while IoT and ML can enhance energy efficiency for large capital equipment deployments. It is essential to highlight that a DSC must be flexible to enable SMEs to implement and support such innovations.

Turbid (2018) explains that the primary objective of the DSCS of an SME is to enhance efficiency, eliminate waste and increase profitability. By adopting such a strategy, a business can allocate resources, assets, personnel and inventory effectively to where they are most needed at any

given moment. This proactive approach helps to mitigate transportation and manufacturing risks, particularly in unpredictable operating environments, thereby reducing costs. A fully implemented DSCS offers significant benefits, including savings in resources, time, money and a smaller environmental footprint. Moreover, it enables real-time tracking for improved operational visibility.

A fully implemented DSC leverages Industry 4.0 technologies to eliminate paper usage, manual data entry and the need for information requests, such as phone calls. Instead, SMEs have seamless access to the necessary data in real time. The deployment of IoT sensors and tracking devices, for instance, enables real-time monitoring of product movements across all stages of manufacturing, transportation and logistics in the supply chain (Daniel 2017).

Digitising the supply chain strategy enables a fully demand-driven approach. Bigliardi et al. (2022) argue that SMEs can leverage real-time sales and demand data to refine their strategies, focus on high-selling products, and cut costs by minimising or eliminating the production of low-demand items. In addition, Industry 4.0 technologies such as AI offer significant automation benefits. Algorithms can optimise inefficiencies and make decisions based on real-time data without requiring manual intervention. This degree of automation is essential for giving SMEs a competitive edge in a business landscape that demands agility.

Adoption of a DSCS also leads to improved customer experiences. Issues faced by customers when receiving a product or service after payment can ruin an otherwise positive experience. Also, if the supply chain strategy of an SME lacks the agility to respond to new trends with new products, customers will look elsewhere (Chan et al. 2019). Hence, it is the innovative supply chain business models which customers crave. This might involve using an application to deliver your services more efficiently, implementing a subscription programme to reduce substantial capital expenditures, or adopting a service model in which customers pay for usage without owning the equipment, all within agreed-upon terms and conditions.

Types of digital supply chain strategies

There are several types of DSCS available to SMEs, which are discussed in the next sections.

Automation strategy

This strategy involves the use of robotic process automation (RPA), ML, blockchain and AI to streamline and automate repetitive tasks in the supply

chain, such as data entry, inventory management and order processing. These Industry 4.0 technologies have the potential to optimise supply chain operations, enhance efficiency and lower costs (Bejlegaard, Sarivan & Waehrens 2021; Hofmann et al. 2019). Artificial intelligence, for instance, can be leveraged to analyse vast volumes of data, identify patterns and anomalies and deliver critical predictive insights, enabling SMEs to enhance their supply chain operations.

Visibility strategy

Real-time data analytics and tracking systems are used to gain visibility into supply chain processes, identify bottlenecks and optimise operations (Roy, Gilbert & Lai 2019). For example, cloud-based solutions provide SMEs with real-time insights into their supply chain operations, empowering them to make well-informed decisions and adapt swiftly to changes in demand. The Internet of Things technologies allow enterprises to gather and analyse data from connected devices, enabling real-time monitoring of inventory levels, equipment performance and delivery status (Sunmola & Apeji 2024). On the other hand, blockchain technology (BCT) provides a secure, transparent way for SMEs to track goods throughout the supply chain, enabling real-time tracing of product origins and ensuring authenticity.

Collaboration strategy

The collaboration strategy aims to streamline processes and enhance efficiency in the SME ecosystem. By leveraging cloud-based platforms and collaboration tools, SMEs can facilitate seamless communication and foster stronger relationships with suppliers, partners and customers (Zaridis, Vlachos & Bourlakis 2021). This approach fosters a more connected and agile business environment, enabling SMEs to adapt quickly to market changes and seize growth opportunities. In addition, modern collaboration technologies promote transparency and accountability, thereby enhancing trust and alignment among all stakeholders.

Predictive analytics strategy

The predictive analytics strategy leverages big data and advanced diagnostic tools to offer SMEs invaluable insights into their operations (Nzeako et al. 2024). These tools can forecast demand for products or services by analysing historical data, helping SMEs to optimise inventory levels and production schedules. Moreover, predictive analytics can anticipate potential supply chain disruptions, enabling proactive measures

to mitigate risks. Through stress testing and scenario simulation, SMEs can model various scenarios and assess their potential effect on business operations. This proactive approach enables SMEs to make well-informed decisions and respond swiftly to evolving market conditions (Adewusi et al. 2024). By leveraging predictive analytics, SMEs can stay ahead of the curve, identify opportunities for growth and maximise operational efficiency.

Optimisation strategy

The strategy employs Industry 4.0 technologies, including 3D printing, blockchain and IoT, to optimise production, reduce waste and increase efficiency across the supply chain.

Customer-centric strategy

The customer-centric strategy strongly emphasises leveraging Industry 4.0 technologies to enhance the overall customer experience. By embracing advancements such as AI, SMEs can deliver personalised recommendations tailored to individual customer preferences (Kang et al. 2024; Lacroix 2021). These AI-driven recommendations enhance customer satisfaction and foster loyalty and repeat business. Real-time updates are crucial in keeping customers informed throughout their interactions with SMEs. Whether it is tracking order statuses or receiving notifications about service appointments, real-time updates enhance a seamless, transparent customer experience. In addition, faster delivery times facilitated by Industry 4.0 technologies contribute to heightened customer satisfaction and loyalty (Agarwal 2024). Moreover, integrating Industry 4.0 technologies enables SMEs to gain valuable insights into customer behaviour and preferences. This data-driven approach allows SMEs to anticipate customer needs and tailor offerings accordingly, further strengthening customer relationships (Martinelli & Tunisini 2019). Ultimately, by prioritising the use of Industry 4.0 technologies, SMEs can position themselves as leaders in providing exceptional customer experiences in today's competitive landscape.

Sustainability strategy

The sustainability strategy aims to integrate digital tools and technologies to monitor and mitigate environmental impact across SME operations. By leveraging these tools, SMEs can track and analyse various aspects of their operations, including carbon emissions, waste generation and water usage (Nayal et al. 2022; Pyun & Rha 2021). Through real-time monitoring

and data analysis, SMEs gain insights into their environmental footprint, enabling them to identify areas for improvement and to implement targeted interventions. Furthermore, digital technologies facilitate the adoption of sustainable practices throughout the supply chain. By collaborating with suppliers and partners, SMEs can trace and optimise resource use, promote eco-friendly production methods and reduce waste. This collaborative approach fosters a culture of sustainability across the entire value chain, driving collective efforts towards environmental conservation (Stroumpoulis & Kopanaki 2022). Moreover, implementing digital solutions enables SMEs to enhance resource efficiency and operational resilience. By optimising energy consumption, minimising waste and reducing water usage, SMEs can lower operating costs while reducing their environmental impact. This dual benefit contributes to long-term sustainability and enhances SMEs' financial viability in an increasingly resource-constrained world (Akbari & Hopkins 2022; Jena & Singhal 2023). Ultimately, by embracing digital tools and technologies as part of their sustainability strategy, SMEs can demonstrate their commitment to environmental stewardship while positioning themselves for long-term success in a rapidly evolving marketplace.

Digital twin technology

Digital twin technology allows SMEs to develop virtual representations of their physical assets or systems. These digital twins are potent tools for simulating and optimising supply chain operations. By using digital twins, businesses can test various scenarios and utilise data-driven insights to improve efficiency and effectiveness across their supply chains (Lu, Liu & Min 2021; Marino, Pariso & Picariello 2024). Integrating digital twin technology into supply chain strategies enables SMEs to improve performance, increase agility and ultimately, achieve a competitive advantage in the market. Digital twin technology is revolutionising the way SMEs approach SCM. Small and medium enterprises can gain valuable insights into their operations by developing virtual models of physical assets or systems. These digital twins enable businesses to simulate scenarios, identify potential bottlenecks and optimise processes without disrupting real-world operations. In addition, digital twins facilitate predictive maintenance, allowing SMEs to anticipate equipment failures and minimise downtime (DeMarchi et al. 2024; Yasin et al. 2021). Overall, leveraging digital twin technology empowers SMEs to make more informed decisions, enhance supply chain resilience and maintain a competitive edge in the fast-changing business environment of today.

Barriers to digital supply chain strategy adoption

There are several barriers and enablers that can affect the adoption of DSCSs.

Resistance to change

One of the biggest barriers to adopting DSCSs is resistance to change from employees and stakeholders who may be comfortable with existing systems and processes. Some stakeholders may be resistant to change, making it difficult to implement new digital technologies and processes.

Lack of resources

Owing to their size, many SMEs suffer from resource constraints. However, implementing DSCSs can require significant resources, including financial and human capital. The cost of implementing new technologies and upgrading existing infrastructure, for instance, can be a significant barrier to adoption. In addition, a lack of skilled, knowledgeable employees and experts with the technical expertise to implement and maintain DSCSs can be a significant barrier.

Data quality and availability

Digital supply chain strategies rely heavily on data, which must always be accurate. Poor data quality or limited access to data can hinder their adoption. Data quality and availability are critical components of successful DSCSs. Accurate and reliable data are essential for informing decision-making processes and optimising operations. Poor data quality, such as outdated or incomplete information, can lead to inefficiencies and errors in SCM. Similarly, limited access to data can impede the effectiveness of DSCSs, preventing businesses from leveraging insights to drive improvements. Therefore, ensuring high-quality data and maximising data availability are paramount for SMEs looking to implement and benefit from DSC initiatives.

Cybersecurity concerns

Digital technologies can increase the risk of cyberattacks, compromising the security of supply chain operations. Data concerns can inhibit the adoption of SME DSCSs, as enterprises need to ensure that data are accurate, protected and accessible.

Integration challenges

Integrating SME digital technologies with existing systems and processes can be complex and time-consuming. Legacy systems can be difficult to integrate with new technologies and processes, creating challenges for SMEs looking to adopt DSCSs.

Enablers of digital supply chain strategy adoption

The factors facilitating the adoption of a DSCS include:

Agility and flexible business model

An agile and flexible business model can empower SMEs to respond swiftly to shifts in the market, changes in customer demand and unexpected supply chain disruptions. By embracing flexibility, SMEs can adjust their operations, processes and strategies in real time, ensuring resilience and adaptability in dynamic business environments.

Collaboration and partnerships

Collaborating with partners, suppliers, peers, technology providers and other stakeholders is essential for SMEs aiming to adopt DSCSs. Through collaboration, SMEs can identify common challenges, share knowledge and resources and leverage collective expertise to drive innovation and efficiency across the supply chain ecosystem.

Data management capabilities

Effective data management capabilities are fundamental for the successful implementation of DSCSs. These capabilities ensure the quality and availability of data, enabling SMEs to harness insights for real-time monitoring, analysis and decision-making. Robust data management practices lay the foundation for a data-driven approach to supply chain optimisation.

Digital infrastructure investment

Adequate funding and investment in new technologies and infrastructure are imperative for SMEs seeking to adopt a DSCS. Investing in a robust digital infrastructure comprising hardware and software systems enables SMEs to implement and support DSCSs effectively, fostering innovation and competitiveness in the marketplace.

Capacity development

Providing employees with the necessary training and development opportunities is crucial for building the skills and knowledge required to adopt and utilise DSCSs effectively. Capacity development initiatives empower SMEs to leverage technology, optimise processes and drive continuous improvement throughout the supply chain.

Leadership commitment

Strong leadership commitment is crucial for advancing the adoption of DSCSs in SMEs. Leadership support helps to overcome resistance to change, fosters a culture of innovation and provides the necessary resources and direction for successful implementation. With committed leadership at the helm, SMEs can navigate challenges and seize opportunities in their journey towards DSC excellence.

Digital supply chain strategy decision-making for small and medium enterprises

The decision-making process in SCM is intricate and engages several individuals across various teams. For any organisation, an efficient decision-making process is the strongest safeguard against uncertainty. Many organisations rely on their SCM experts to develop and execute effective decision-making strategies (Haslam College of Business 2023). A supply chain manager must make tough decisions, often under time pressure, using real-time data. Strong problem-solving skills are essential for addressing issues in the supply chain. A minor manufacturing issue can escalate into a significant problem if your organisation lacks effective decision-making processes (Soni et al. 2022). Effective decision-making in SCM is essential not only because of challenges in manufacturing and logistics, but also because of other complexities. The Haslam College of Business (2023) explains that shifts in consumer demand and perception can rapidly affect organisational operations, immediately and frequently.

Rational decision-making model

To make effective decisions in digital SCM, SMEs typically follow a series of steps outlined by the Haslam College of Business (2023). These steps include:

1. Identifying the problem or opportunity
2. Exploring possible solutions
3. Conducting a gap analysis

4. Collecting data and evaluating alternative solutions
5. Choosing the best possible solutions
6. Selecting the most appropriate solution for the situation
7. Implementing the chosen solution.

☐ Identifying problems in supply chain

A small and medium enterprise must identify or anticipate challenges before they arise and be proactive in addressing them to prevent disruption to the supply chain. While it is impossible to forestall every issue, an enterprise should be able to recognise problems as they occur and quickly develop and execute solutions.

☐ Exploring possible solutions

Several digital solutions can be explored, including cloud-based platforms, IoT for real-time tracking, AI for demand forecasting and blockchain for enhancing transparency and security.

☐ Gap analysis to develop and communicate solutions

In this step, through a supply chain leader or strategist, an SME will investigate the areas of the DSCS that need attention. This process involves developing solutions for existing challenges and effectively communicating operational changes to all stakeholders. It may also involve informing and educating all team members about the process adjustments. Furthermore, this may include collaborating with external suppliers in manufacturing, transportation or warehousing.

Furthermore, as supply chains are dynamic, so should an SME's leadership and decision-making process be. Instead of waiting for a challenging situation to arise within its DSCS, its management must monitor trends in SCM to stay up-to-date with current best practices. A proactive SME can quickly identify and leverage opportunities to improve its DSCS, whereas a reactive one cannot. Accordingly, the proactiveness of an SME is highly dependent on its ability to leverage real-time data and Industry 4.0 technology to analyse problems and opportunities.

☐ Collecting data you need to make well-informed decisions

Data collection is an essential component of effective long-term decision-making in DSCSs. A small and medium enterprise should establish structures that continuously gather and analyse data on the performance of different components within the supply chain. Precise, real-time data is essential for

effective problem-solving and optimal allocation of team resources. When the DSCS decision-making process is based on reliable, recent data, an SME is better able to make informed choices. Therefore, the Haslam College of Business (2023) highlights that an SME must keep up with the latest software innovations that enhance data collection and ensure the smooth operation of its supply chain strategy.

☐ Analysing probable solutions

Disruption is an inevitable part of life. For an SME's DSC decision-making, the best practice is to build uncertainty and contingencies over the possible choices. This means that an SME factors in a certain margin to account for the unexpected. Accordingly, each decision should include a backup plan to address situations that may arise and make the original plan ineffective.

☐ Choosing best possible solution

This step involves using the DSCS team and other relevant external stakeholders' input to select the ideal solution from a pool of possibilities, given the risk-return trade-off. All stakeholders at every point of a supply chain are vital resources, assisting the SME in problem-solving, transforming the best ideas into actionable plans, and ensuring that all team members are synchronised with operational changes. The solution choice should also incorporate legal and regulatory considerations. The small and medium enterprise's DSCS decision-making is influenced by various external aspects which are often beyond its control. Therefore, it is crucial to remain aware of both potential and actual changes to the legal and regulatory framework governing the operations of each supply chain. The digital supply chain strategy decision-making must consider both actual and potential legal and regulatory developments, so the rest of the organisation can adjust accordingly.

☐ Implementing your decision

Finally, the selected course of action is put in place, with regular performance reviews and necessary adjustments made accordingly.

■ Digital supply chain strategy development

Strategy development involves exploring and recognising strategic alternatives, choosing the most viable ones, and determining resource allocation to meet the organisational objectives (Ben-Abdallah, Shamout & Alshurideh 2022; Mishra & Mohanty 2022). The implementation of a DSCS

is crucial in today's dynamic and rapidly globalising business environment. The digital economy is driving a transformative shift in business models and DSCSs globally, blurring the lines between industries. Regardless of the niche, modern customers now demand swift delivery of products and services tailored to their specific needs (Brenner 2018; Casciani, Chkanikova & Pal 2022).

To this end, Bejlegaard, Sarivan and Waehrens (2021) submit that effective DSCSs enable organisations to differentiate themselves in a competitive market. By adopting these strategies, companies can enhance speed, precision, flexibility and attention to detail. As supply networks grow increasingly complex, dynamic and dispersed, SCM has evolved from being merely a business competency to an area in urgent need of transformation. Organisations must adopt more sustainable and efficient approaches to managing their supply and demand networks. Therefore, strategy development is the process of creating a plan that enables a company to achieve sustainable growth, outlining specific data and objectives that detail how your team intends to reach each goal (Broman & Robèrt 2017). The company's vision and mission are integrated into the SCM strategy to align all team members towards achieving common goals.

Situational analysis

Creating an SCM strategy enhances efficiency, increases revenue and profits, reduces costs, develops new product and service opportunities, and allows organisations to remain longer in their markets. A situational analysis involves various methods to examine the internal and external factors of a business. It leverages market research to assess potential growth, identify target customers, analyse competitors and evaluate the overall state of the business (Clarke, Washburn & Friese 2022). Situational analysis establishes a foundation for understanding the environment in which a plan is implemented. It serves as a shared reference point for the planning process and helps prioritise actions effectively (Straková et al. 2018). A SWOT analysis can be conducted by management, supply chain teams and key employees to provide a comprehensive overview of the strengths, weaknesses, opportunities and threats of a company in its environment. This tool is valuable for identifying strengths and weaknesses in the supply chain, as well as the opportunities and threats it presents (Shinde et al. 2023; Sobb, Turnbull & Moustafa 2020). Once these opportunities and threats are identified, actionable plans such as internal reorganisations or investments can be developed to capitalise on opportunities and mitigate threats.

Strategy formulation

Strategy formulation is a comprehensive concept encompassing a variety of evidence-based interventions, including goal setting, meeting basic psychological needs, fostering effective communication and implementing transformational and complex leadership (Adham & Sukkar 2024; Schuller 2020). It involves leveraging available knowledge to outline the intended direction of a business and the actionable steps needed to achieve its goals. This process is essential for resource allocation, setting priorities, aligning the organisation and validating business objectives. Mintzberg (2017) highlights that the strategy formulation process entails selecting the most suitable course of action to achieve organisational goals and objectives while fulfilling the SCM vision. The optimal action is determined by evaluating organisational goals, strengths, potential, limitations and external opportunities.

Strategy implementation

Strategy implementation involves converting the selected strategy into organisational actions to attain planned goals and objectives (Tawse & Tabesh 2021). Strategy implementation can also be viewed as how an organisation should develop, utilise and integrate its organisational structure, control systems and culture to execute strategies that lead to competitive advantage and better performance. The supply chain structure allocates particular value-developing tasks and roles to the employees and states how these tasks and roles can be correlated to maximise efficiency, quality and customer satisfaction – the pillars of competitive advantage. However, organisational structure alone is not enough to motivate employees. A strong organisational control system is also crucial for equipping managers with tools to provide motivational incentives to employees and to collect feedback on both individual performance and overall organisational results.

Strategy monitoring and evaluation

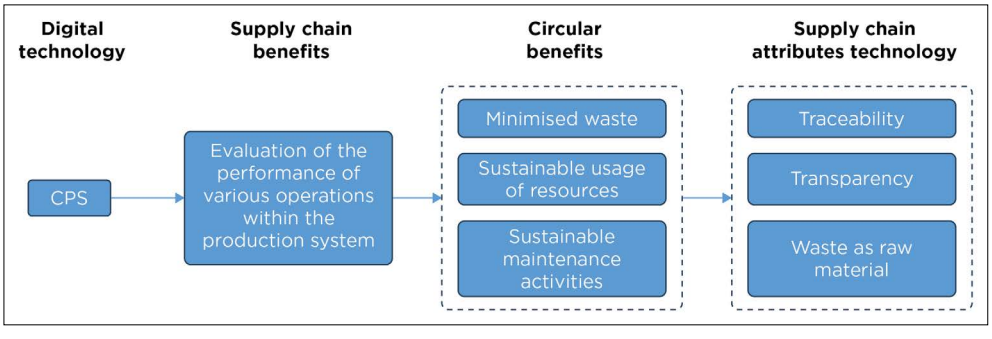
Strategy monitoring and evaluation are equally important as strategy formulation, as they assess the efficiency and effectiveness of overall plans in achieving intended outcomes (Grant 2024). Strategy monitoring involves analysing a strategy to determine how effectively it has been implemented and executed. As an internal analysis tool, it should be incorporated into a broader strategic assessment of the organisation to guide decision-making about the strategy. On the other hand, strategy evaluation is the ongoing assessment of the quality of a logistics function or service output to monitor progress towards achieving predefined objectives and goals. This process helps identify and address potential shortcomings.

Green digital supply chains and circularity

There is a growing realisation that a growing number of industries globally are contributing to environmental degradation, primarily through emissions, increased waste volumes, noise pollution and resource consumption. Consequently, the pressure on businesses to reduce their environmental footprint is mounting. The current linear production and consumption models are widely seen as largely responsible for this environmental footprint. Thus, in an attempt to become more sustainable and eco-friendlier, many businesses are transitioning their operations from linear to circular models, thereby joining circular economies (Liu, Zhang & Wu 2023). The transition to circular models has led businesses to embrace circular activities, which caused them to transform their supply chains into circular supply chains (Genovese et al. 2017; Tanveer et al. 2023). Transforming an enterprise infrastructure towards circular supply chains would require the adoption of a 3R framework of reduce, reuse and recycle. Hence, the process of product design, development, customisation and distribution is an essential step towards circular supply chains.

The Industry 4.0 technologies, including the IoT, cyber-physical systems (CPS), cloud manufacturing and big data analytics, can be leveraged to facilitate the circular flow of materials and to establish circular supply chain infrastructure. As discussed earlier, through its sensors and monitors, the IoT technology provides real-time information sharing for supply chain partners and is commonly used to oversee manufacturing or logistics operations. The result will be improved resource and operational efficiency, increased collaboration and innovation across the supply chain and improved warehouse and logistics management practices that are vital for circular supply chains (Tanveer et al. 2023). Figure 3.6 illustrates the circular benefits and the supply chain attributes.

Businesses use different metrics to assess various aspects of energy consumption, carbon emissions and carbon footprint. These metrics help



Source: Tanveer et al. (2023). Creative Commons Attribution 4.0 International (CC BY 4.0).
Key: CPS, cyber-physical system.

FIGURE 3.6: Circular benefits and the supply chain attributes.

businesses adopt greener technologies, ultimately contributing to both environmental and economic benefits. The metrics include sector-specific tools and life-cycle assessment, a comprehensive method that assesses environmental impacts across all stages of a product's life cycle.

The integration of Industry 4.0 technologies, such as AI, ML and blockchain, is pivotal for enhancing carbon tracking, waste reduction, ESG performance and circular economy practices. These technologies provide the tools needed for accurate data collection, real-time monitoring and informed decision-making, driving sustainable development and operational efficiency across various sectors (Soni et al. 2024). To analyse the carbon footprint of businesses, various metrics are employed to capture the diverse aspects of energy consumption and carbon emissions. For example, BCT can enhance transparency and accuracy and improve the reliability of data for decision-making in carbon tracking and ESG reporting. Machine learning and big data technologies have the potential to analyse complex datasets and enhance predictive capabilities, enabling decision-making for sustainable practices.

Small and medium enterprises are increasingly integrating green DSCs and circular economy practices to enhance sustainability and competitiveness. Recent studies have demonstrated a positive relationship between the adoption of BCT and green SCM. The studies have also shown enhanced transparency, reduced transaction costs and improved trust (Khan et al. 2025). The integration of digital technologies with green supply chain practices enhances circularity and sustainability significantly. By adopting advanced digital tools and fostering green infrastructure, businesses can modify their supply chains from linear to circular, promoting long-term environmental and economic benefits. However, overcoming technological, financial and cultural barriers remains crucial for achieving these goals.

Conclusion

In summary, adopting DSCSs is not just advantageous, but it is imperative for SMEs aiming to thrive in the digital era. Despite potential barriers such as limited resources or resistance to change, SMEs can navigate these challenges by harnessing enablers such as agile business models, collaboration, robust data management capabilities, investment in digital infrastructure, capacity development and leadership commitment. By leveraging these enablers, SMEs can achieve greater efficiency, flexibility and innovation in their supply chain operations. Adopting digital transformation is not merely about maintaining relevance; it entails positioning oneself for sustained success in a rapidly evolving marketplace where digital integration is increasingly becoming the norm. By adopting

DSCSs strategically, SMEs can future-proof their businesses and position themselves as leaders in their respective industries.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and S Munongo; *methodology* (*desktop-based literature review and conceptual synthesis)*, D Pooe and S Munongo; *validation*, D Pooe and S Munongo; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and S Munongo; *resources*, D Pooe; *writing – original draft preparation*, D Pooe; *writing – review and editing*, S Munongo and D Pooe; *visualisation*, S Munongo; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 4

Intelligent manufacturing in Industry 4.0

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Introduction

In South Africa, manufacturing has become the basis for national economic growth, and manufacturing small and medium enterprises (SMEs) are playing a significant role in this regard while at the same time influencing people's livelihoods. Currently, manufacturing as we know it is undergoing a significant transformation amid new production technologies and innovation. Emerging technologies have transformed manufacturing

How to cite: Munyanyi, W & Pooe, D 2026, 'Intelligent manufacturing in Industry 4.0', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 87–108. https://doi.org/10.4102/aosis.2026.BK572.04

practices, strategies, frameworks and even the operations of both large and small businesses significantly, with the world undergoing significant transformation, such as declining profitability, increasing customer expectations, shorter product life cycles and the fast pace of technological advancements. Traditionally, manufacturing firms have focused on enhancing sustainable production through linear supply chains and vertically integrated systems, but the success of implementing such networks has been limited. This chapter explores the transition from traditional manufacturing to intelligent manufacturing (IM) within the Industry 4.0 framework, focusing on the prospects and challenges faced by SMEs.

Manufacturing small and medium enterprises in South African context

In South Africa, manufacturing SMEs have played a pivotal role in enhancing employment and contributing to the gross domestic product (GDP) (Enaifoghe & Ramsuraj 2023). In this context, manufacturing SMEs are organisations with fewer than 250 employees and an annual turnover of less than ZAR14m. However, over the years, the South African government has expressed significant concern about the lack of sustainable growth in the manufacturing SME sector. Survival among these organisations has remained significantly low, with a rate of almost 20% over the long term (Botha et al. 2021; Maduku & Kaseeram 2021). This is despite the government's efforts to facilitate SME development in South Africa through the National Development Plan, introduced by the South African National Planning Commission. Both practitioners and scholars have highlighted that the difficulties these SMEs face in accessing external finance and the slow uptake in modern technology are chief among the factors contributing to the demise of manufacturing SMEs. The coronavirus disease 2019 (COVID-19) pandemic has exacerbated the situation of SMEs, and pressure on their operations continues to mount amid national lockdown measures and domestic and international travel restrictions. All these have caused revenues to shrink precipitously, and a sizeable number of SMEs have closed down. Only a few that have managed to be more dynamic and have adopted the right survival strategies have remained operational.

Despite the efforts of government and other private players to support SMEs, most fail to survive beyond five years. Small and medium enterprises face several challenges in the current macroeconomic environment in South Africa. Some of the challenges have been attributed to the social and economic inequalities created by South Africa's history. It has been argued that black small business owners in South Africa often lack access to cheaper

external finance to improve their businesses owing to poor credit histories, among other reasons. In addition, conservative cultures in lending institutions in South Africa make them resistant to lending to SMEs and startups. However, the greatest challenge facing these SMEs has been the limited adoption and use of technology in the manufacturing process, which could have enhanced their access to larger markets and enabled them to identify novel ideas for business growth. The use of technology, especially information and communication technology (ICT) in organisations, has been at the centre of modern research on SME development. The central argument has been that technology can address some of the significant challenges that SMEs face, including low sector growth.

From traditional to intelligent manufacturing

As manufacturing industries continued to achieve greater milestones through successive phases of the Industrial Revolution, existing human knowledge and skills struggled to keep pace with industrial advancements. According to Pereira, Kennedy and Potgieter (2019), traditional manufacturing systems struggled to manage process uncertainties and complexity because operators could not adapt quickly enough to technological advancements. With increasing consumer demand for high-quality products, there was a growing need to boost production and quality while reducing production costs. This focus on resource optimisation and sustainable production methods placed additional strain on manufacturers.

Background to intelligent manufacturing

Over time, traditional systems were unable to meet the growing demands effectively, as manual operators struggled to adapt to the complexities or to retain the large amounts of data required to predict production outcomes. For instance, traditional manufacturing systems required operators to set specific input parameters for machines and equipment before production began, often relying on trial-and-error or the operator's experience. Despite their experience, machine operators could not always anticipate every possible uncertainty or complexity that could arise during production. As a result, when issues occurred, the entire process had to be halted and adjusted, which was both time-consuming and costly. These delays could have been prevented if the machine could record past uncertainties and suggest appropriate input parameters accordingly. This highlighted the need to integrate advanced technology into machines to enable quick forecasting and to adopt a flexible, self-learning manufacturing approach.

Information technology played a key role in the development of intelligent manufacturing systems (IMS).

The continuous deepening of ICT applications in the manufacturing field during the Third Industrial Revolution (3IR) has led to the informatisation of manufacturing systems, resulting in digital, integrated and networked manufacturing. The dawn of the Fourth Industrial Revolution (4IR) has unveiled remarkable technological capabilities and protocols that have enabled industries to transition into more organised, efficient, sustainable and autonomous ecosystems. The result was further development from comprehensive digital, networked manufacturing to IM. Intelligent manufacturing emerges from the Industry 4.0 context, as manufacturing systems are updated to an intellectual level. The industrial revolutions that manufacturing ecosystems have experienced over the years, from Industry 1.0, 2.0 and 3.0 to the current Industry 4.0, have influenced the future of industrial production systems. Industry 4.0, regarded as the most fundamental economic and production transformation of the century, is expected to have a significant impact on manufacturing.

Intelligent manufacturing paradigms

The new paradigm ushered in by Industry 4.0 involves the advanced digitalisation of factories, the internet and future-oriented technologies that convey intelligence in devices, machines and systems (Pramanik et al. 2020). Industry 4.0 encompasses an extensive array of technologies that transform production processes, data management, consumer interactions and competitiveness. The technological advances of Industry 4.0 are believed to be contributing to superior multidimensional and end-to-end digital integration. This integration has been achieved by combining intelligent, automated devices into industrial and data environments. Mobile telecommunications is also said to have provided the prerequisite interconnectedness for business services, processes and information systems (IS), accelerating Industry 4.0. One result of this industrial transformation has been the emergence of smart manufacturing systems that are highly flexible and responsive to environmental dynamism. Highly developed automation and digitisation technologies under Industry 4.0 have the potential to make firms more agile and responsive, further improving performance and service levels.

The concept of IM evolved over time, integrating the latest technological advancements into production processes. Based on the extent of information technology used and how it is integrated with manufacturing

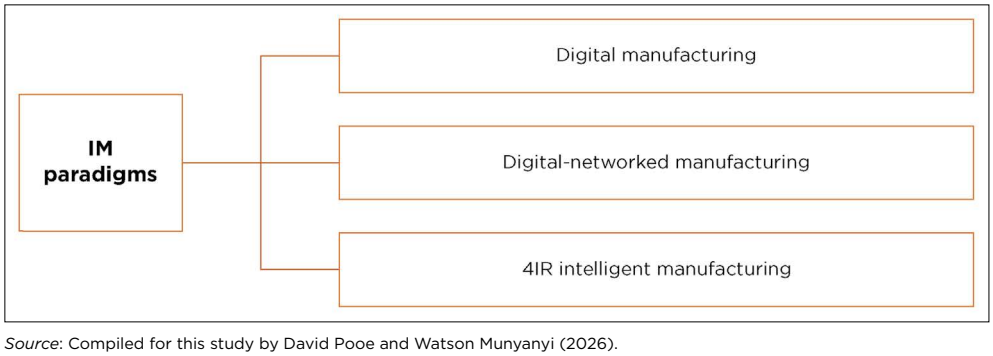
systems, IMS can be categorised into three general models or paradigms, as depicted in Figure 4.1.

Digital manufacturing

The earlier industrial revolutions are credited with initiating the first generation of IM, marked by the emergence of the digital manufacturing paradigm. This laid a crucial foundation for the development of subsequent IM paradigms. The invention of computers enabled manufacturers to produce production plans and output designs on computers rather than on paper charts and graphs. Since then, most of the manufacturing activities have gone digital. The result has been a reduction in the time needed to manufacture products customised to consumer expectations. In addition, the use of machinery to simulate product designs led to improvements in value chains, enhanced product quality and optimal resource use.

Digital-networked manufacturing

The second generation of IM integrates the internet into the computerised manufacturing system. The internet connects ideas, processes and data across various production units and allows collaborative manufacturing. The networking technology enabled companies to collaborate in research and development (R&D) and to connect with companies in the same industry (horizontal integration) and with those operating at different levels of the production process in the same industry (vertical integration). User interaction is the first step to transforming the production process into a user-centric one.



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
Key: IM, intelligent manufacturing; 4IR, Fourth Industrial Revolution.

FIGURE 4.1: Intelligent manufacturing paradigms.

Industry 4.0 enabled intelligent manufacturing

The integration of artificial intelligence (AI) with digital and networking technologies has led to strategic breakthroughs in IM. In the Industry 4.0 era, an IM now utilises service-oriented architecture via the internet to provide collaborative, customisable, flexible and reconfigurable services to end-users, thus enabling a highly integrated human-machine manufacturing system. The essence of AI in manufacturing processes can revolutionise production techniques completely and replace human intelligence. Artificial intelligence gives new-generation IM the power to engage in R&D and to formulate new processes, designs, products and business models without human intervention. Since machines are faster than humans, AI will reduce the time required for production and for innovating and ideating. Each of the models mentioned is not mutually exclusive; instead, they build upon the characteristics of the previous one.

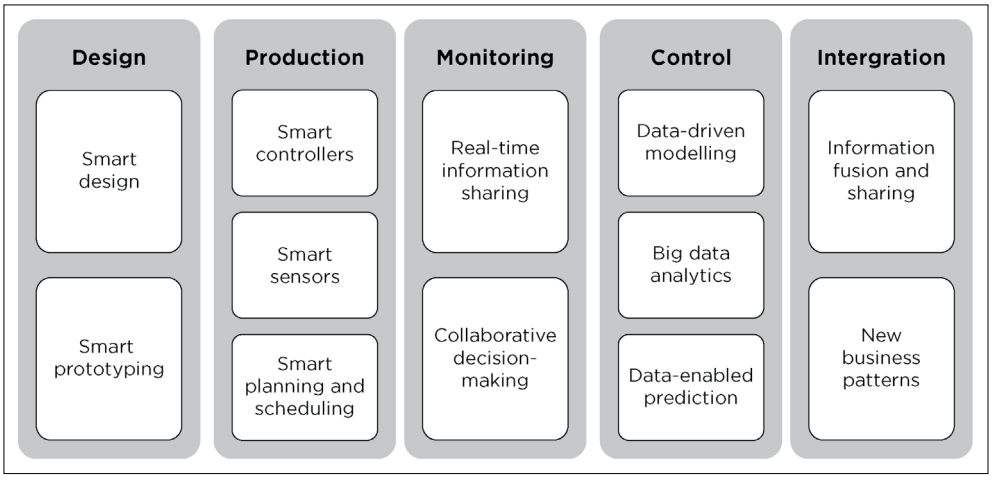
Intelligent manufacturing

Given the challenges highlighted, digital transformation is no longer a choice for SME manufacturers but an imperative for survival. Emerging from the 4IR is the phenomenon of IM. This notion is anchored in launching intelligent factories through a network linking devices that modernise production within them. In addition, mobile communication devices and other intelligent objects collaborate to enable efficient use of industrial resources and intelligent logistics. As such, firms need to understand the development and application of enabling technologies appropriate for Industry 4.0 implementation and digital transformation. Despite the general acceptance of this industrial revolution and the widely recognised benefits of Industry 4.0, there is limited literature on the enabling technologies for implementing IM practices in the context of SMEs. The schematic layout of the Industry 4.0-enabled IMS is shown in Figure 4.2.

According to Phuyal, Bista and Bista (2020), the IM connects product design, analytics, manufacturing processes, stock and supply chain systems, product customisation, real-time machining units, product delivery systems and end customers. This is done through cloud computing, which enables on-demand manufacturing, product customisation and maintains the demand-and-supply ecosystem more efficiently.

Defining intelligent manufacturing

Intelligent manufacturing, also known as smart manufacturing, is a broad manufacturing concept that optimises production through the use of advanced information and manufacturing technologies. As Industry 4.0 gains momentum and recognition, there is an increase in the adoption of



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 4.2: Schematic layout of an intelligent manufacturing system.

smart systems such as autonomous sensing, intelligent interconnection, learning analysis and decision-making in the manufacturing sphere. This has led to the emergence and growth of what is now known as IM. For instance, the growth of AI has led to the development of an intelligent scheduling system that allows manufacturers to schedule tasks using AI techniques and to share them with many users via an internet-enabled platform. Scholars and practitioners have accepted that IM is a new manufacturing model that integrates intelligent science and technology to upgrade, design, produce and manage the entire product life cycle. This is achieved through smart sensors, adaptive decision-making models, advanced materials, intelligent devices and data analytics to enhance production efficiency and product quality. The dynamics regarding the IM concept are anticipated to be of significant help to manufacturing SMEs, especially given the volatility of the business environment. This is primarily because IM will allow SMEs to detect and respond proactively and timeously to changes in the business environment, thereby improving the quality and overall output of firm performance.

Mechanics of intelligent manufacturing

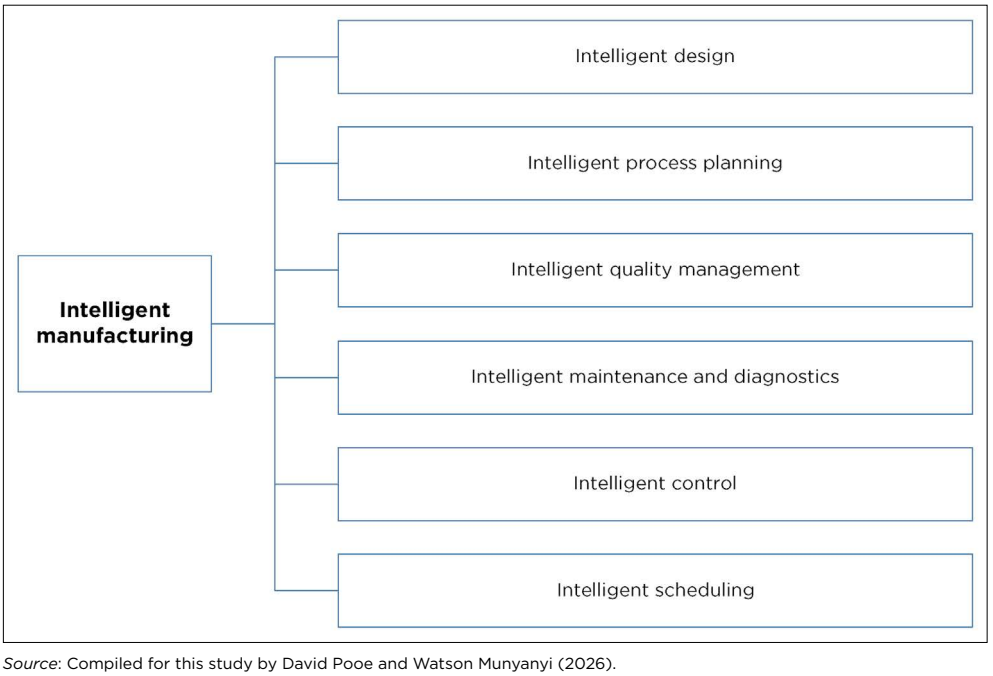
Intelligent manufacturing predominantly leverages advanced information and manufacturing technologies to enhance the flexibility of manufacturing processes. Certain technologies underpin IM, enabling smart devices or machines to be integrated into decision-making through their learning capacities. These technologies communicate directly with the firm's manufacturing systems, so that the problems that arise can be resolved in

a timely manner through adaptive decisions. Some of the technologies that underpin IM are powered by AI, thereby allowing manufacturing systems to learn from experience and to use that knowledge to resolve distortions as they arise. Intelligent manufacturing entails advanced and efficient manufacturing technologies, as well as management and procedures. This component of Industry 4.0 enables manufacturers to convert their traditional resources into intelligent objects that can sense, act and respond to commands from the smart environment. In addition, critical technologies such as the Internet of Things (IoT), cyber-physical systems (CPSs), cloud computing, big data analytics and ICT enable IM.

Intelligent manufacturing along the production line

The manufacturing workshop is the core of the company's product production. The discrete manufacturing workshop is engaged in multi-variety and small-scale production; the production process is complex, production scheduling is difficult, and the monitoring and management of the workshop have always been a problem that plagues the enterprise.

As illustrated in Figure 4.3, through information technology, enterprises can realise real-time control of the workshop production process, adjust production plans in timely response to market changes or customer needs,



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 4.3: Intelligent manufacturing activities.

improve market response speed, optimise manufacturing resources, improve production efficiency, reduce costs and enhance core competitiveness. Intelligent manufacturing is the core of Industry 4.0, and manufacturing IoT technology is the foundation of IM. It combines the technical means of IoT with the actual manufacturing process to drive production and transform traditional workshop management. Through the identification of work in progress, dynamic tracking of the in-process product and real-time collection of production data, real-time detection of status information can be realised, and the transparency of the shop's manufacturing process can be improved.

Dimensions of intelligent manufacturing

Perhaps the greatest development in this industrial revolution has been the integration of IoT technologies such as machine learning (ML), AI and big data into the manufacturing process (Nikiforidis et al. 2025). Incorporating these analytic technologies has provided a platform for developing reliable products that meet current customer demands. Remarkable insights into IM have led to the emergence and growth of certain dimensions.

Additive manufacturing

One of the dimensions of IM that is proving to be compatible with the requirements and expectations of SMEs is additive manufacturing (AM). Also referred to as three-dimensional (3D) printing or rapid prototyping, it is the manufacturing of parts layer by layer through computer-aided design (CAD) models. Unlike traditional machining processes characterised by drilling, milling and cutting operations, AM with 3D CAD models supports operational flexibility, offers shorter lead times, reduces inventory and increases product customisation. Over the years, AM techniques have been perfected, enabling firms to leapfrog some of the obstacles inherent in traditional manufacturing. It can be argued that manufacturing SMEs in South Africa benefit more from adopting AM because the systems assist decision-makers by producing prototypes or layers at a time. This sustainable manufacturing approach is likely to improve SME performance and competitiveness. When applied correctly, AM provides a perfect solution to the scalability, performance and complexity challenges that SMEs in South Africa face. As a result, several advantages await those willing to embrace AM actively.

Simulation and modelling

Simulation and modelling technology is a relatively new phenomenon that has evolved over the past six decades into another essential means

of transforming manufacturing. In manufacturing, simulation relates to the representation of a manufacturing operational system model on a digital computer. The application of simulation and modelling has not been limited to manufacturing but has extended to almost all aspects of the economy, society and the military. The areas where simulation and modelling have been applied include aerospace, medical treatment, energy, agriculture and education. This dimension of IM has been described as highly complex, with one system exhibiting both quantitative and qualitative, continuous and discrete characteristics simultaneously. Analytical simulation and modelling of processes is based on knowledge of the underlying process physics and validated by experimental results. This has become a powerful tool for optimising unit processes in manufacturing. Simulation and modelling technologies in IM offer unique advantages for solving the practical problems faced by SMEs in South Africa (Pingilili et al. 2025). For instance, in new product development, the product process design can be simulated before production. This helps in guaranteeing the feasibility and effectiveness of the designed process plan. Most of the costs associated with product design and process planning are reduced through simulation and modelling.

Automated intelligent product management

Automated intelligent product management refers to the ability to monitor, assess and reason about a product's current or future state of development using built-in automated processes. The automation of the product management process is a significant dimension of IM that allows manufacturers to track product activity accurately and to monitor and manage inventories using real-time product data (Ugbebor et al. 2024). Automated intelligent product management enables SMEs to develop self-organising production, distribution and inventory systems while customising products rapidly. The long-term result is a paradigm shift in the manufacturing process. An automated intelligent product management system is based on assigning a unique identification to the product and collecting and processing data on product features and production requirements. Unlike traditional product management systems, these intelligent systems enable quick, precise decision-making in production planning and control (PPC). Traditional PPC systems have failed to capture product events in real time, and feedback mechanisms have failed to handle the real-time events associated with products.

Intelligent factories and warehousing

Many manufacturing companies worldwide are already using IM across certain industries: semiconductor, electronics and medical devices,

automotive and aviation, equipment manufacturing, pharmaceuticals, chemicals, metals and mining and consumer packaged goods. This has led to the emergence and growth in the development of smart factories and smart warehouses.

Smart factories

A smart factory is a highly digitised and connected production facility with a fully integrated, collaborative manufacturing system, capable of responding in real time to changing demands and conditions across factories, supply networks and customer needs (Jenkins 2025). Smart factories utilise interconnected machines and tools to improve manufacturing performance and to optimise energy and workforce requirements by implementing big data processing, AI, advanced robotics and interconnectivity. The integration of CPS, IoT and cloud computing forms the building blocks of smart factories, and ongoing research has emphasised the importance of adopting emerging communication and technological advancements. Various intelligent technologies for a smart factory include digital enterprise-level planning and control and cloud-enabled prognosis. Smart factories achieve this high level of automation and efficiency through a myriad of technologies, including AI, the IoT, machine-to-machine communication and more. Smart factories use AI and ML to perform real-time data analysis during the manufacturing process (Husain 2025). The result of this integration of data analytics will significantly assist in achieving manufacturing optimisations. In addition, these factories are equipped with sensors that collect and process real-time data. This enables manufacturers to obtain a complete, 360-degree, high-fidelity, virtual data-driven integrated view of all operations from suppliers and supply chains, through equipment, processes and manufacturing practices, to final product testing and customer satisfaction.

To make modern manufacturing more cost-efficient, production lines should be smarter and more flexible, which is the fundamental idea of a smart factory. With advancements in technology, factories have become increasingly dependent on network connectivity, thus becoming more intelligent, flexible and dynamic, powered by devices and autonomous systems (Chidiebube, Chikwendu & Obiuto 2025). Smart factories bridge the gap between control systems and their on-premises implementation by bringing together physical and digital systems. In particular, manufacturers of machine tools are concerned with how machine tools and their digital counterparts are used to satisfy the needs of users effectively. By processing real-time data from machine sensors and applying AI and ML, it is possible to predict critical events and take preventive action to avoid problems. A smart factory can monitor streaming sensor data using

business rules and ML models to assess the health of its equipment and processes. A wide range of solutions can be used to understand equipment, processes, products, operations, customers and sales better and then to help act on the insights gained.

Smart warehousing

The technological transformation that is sweeping across various sectors has spilt over into storage and warehousing facilities. To keep up the rapid pace, warehouses have begun equipping themselves with technologies to contain manufacturing, production and consumer demand. Old warehousing methods have been transformed, giving rise to what is now known as a smart warehouse. A smart warehouse is a collection of automated components, and, like smart homes, it is enabled by several automated, interconnected technologies (Min 2023). These technologies work together to increase warehouse productivity and efficiency, minimising the number of human workers while reducing errors. It is automated for improved productivity, efficiency and accuracy, and the solutions that are implemented give flexibility and capability to the employees and their processes. The approach in smart warehousing is to connect operations, processes and resources to lower costs and reduce lead time. The advice for SMEs is to invest in new technology that makes their warehousing smarter. Smart warehouses will provide SMEs with substantial competitive advantages by reducing the demand for human labour and optimising the limited human labour needed. This also lowers operating costs, and the resulting cost savings can translate into lower prices for consumers.

Benefits of intelligent manufacturing system

Generally, manufacturers today face significant challenges, including customer demand for more product customisation, reduced supply lines and an increased need to outsource services. These have meant that the whole manufacturing process must be altered, smaller production batches adopted, and frequent changes made to the product lines. There is also the problem of increased waste that manufacturers must deal with constantly. Nowadays, the competitiveness of manufacturing firms depends largely on their agility, efficiency and responsiveness to customer preferences, product quality and legislative compliance. As such, manufacturers are seeking to enhance their competitiveness by implementing a framework of diverse data acquisition and handling systems and decision-making, by merging IoT and ICT at the manufacturing process level.

To compete effectively, manufacturing SMEs will require effective mechanisms to optimise productivity and yields while reducing cycle times

and waste. The Industry 4.0 context presents new capabilities that enable the utilisation of big data, ML and AI to shift to more effective, reactive processes, products and factories. The ultimate reason for incorporating CPS into the manufacturing process is to automate decision-making with AI. Specialised manufacturing through production system technologies embedded with IM processes is becoming a decisive element in acquiring, transforming and integrating production processes. In intelligent manufacturing, processes related to design, production and product life cycle management are upgraded continuously. Adaptive decision-making models, advanced materials, intelligent devices, smart sensors and data analytics are used to manage the product life cycle as part of IM. To implement IM successfully, four key components are significant: CPS, the IoT, the Internet of Services and the smart factory.

The scope of manufacturing is significantly different now than in the early days of the First Industrial Revolution (1IR). Modern production focuses not only on quantity and quality but also on resource conservation and the sustainability of processes. The intelligent manufacturing system is a modern manufacturing system that integrates the capabilities of humans, machines, and processes to achieve the best possible manufacturing outcomes. A manufacturing system refers to the entire process of gathering inputs, arranging them and transforming them into the desired output. The intelligent manufacturing system seeks to maximise manufacturing resources, minimise wastage and add value to the business. The intelligent manufacturing system emerged from the realisation that the future of manufacturing lies in adopting novel methodologies to transform traditional manufacturing systems into smart systems. The use of intelligence in traditional manufacturing systems means introducing flexibility into production processes, analysing existing processes and their shortcomings, collecting information on them and using that information to formulate better processes. While traditional manufacturing builds on operators' existing knowledge and experience, IMS requires those involved in the process to learn from past production data, understand all complexities, forecast production outcomes and find better alternatives. Through IM, producers aim to keep up with the industry's continuous evolution and the ever-growing demand of consumers.

Prospects for small and medium enterprises in intelligent manufacturing

The current technological developments, particularly mobile technologies, have offered remarkable opportunities for SMEs to improve their manufacturing capabilities. Empirical evidence shows that SMEs can enhance competitiveness and profitability by adopting emerging manufacturing

technologies. The literature on technology has also shown that incorporating technology into the manufacturing process is essential to the firm. Because SMEs have become a significant component of South Africa's supply chains, there is a need to ensure competitiveness by integrating new technologies such as manufacturing robots, advanced solutions and other low-cost, high-capability 4IR technologies. Also, mainstreaming science, technology and innovation will allow SMEs to embrace and to benefit from the realities of the emerging technological paradigm. Hence, the 4IR prospect for SMEs will lead to certain advantages, discussed in the next sections.

Operational excellence and manufacturing quality

In management studies, operational excellence refers to the ability to execute operational business processes more effectively and consistently than competitors. This usually occurs when the organisation ensures that value flows to the customer by creating an uninterrupted value stream that continuously meets their needs, even as those needs change. In this regard, large, more resourceful corporations have, to a greater extent, managed to orient their manufacturing operations towards capacity maximisation, planning efficiency, innovation and cost reduction, resulting in operational excellence. At its most basic level, manufacturing quality is about conformance to specifications in a manner that ensures a competitive edge. Manufacturing quality has always been the purview of large corporations, which have demonstrated significant compliance with international standards. To match the levels attained by large corporations, SMEs in South Africa may need a significant investment in new technology. These SMEs can successfully compete with large manufacturing corporations by adopting and advancing their innovative, efficient and cost-effective manufacturing techniques. Hence, SMEs in developing countries must consider supporting digital connectivity, skills and capacity building, and must address the use of standards for interoperability and ways to strengthen governance. The transition to IM provides a fulcrum for the revolution of product life cycles such as design, manufacturing and maintenance, and it does so for process planning. This is regarded as a new means of implementing IM as a basic unit.

Value chain transformation

In general, SMEs in South Africa have failed to grow owing to a lack of the prerequisite skills, knowledge and personnel, which are sometimes unaffordable for SMEs. In the era of the data-driven economy, advances in information technology can transform these circumstances in

countless ways. One of the opportunities that lies ahead of SMEs owing to IM is value chain transformation (VCT). A value chain describes the complete set of business activities undertaken to create a product.

Value chain transformation refers to the many business changes that result from modifying a company's value chain. It occurs when companies make efforts to develop and implement an effective value chain management process that assists the organisation in achieving smoother operations, increased profitability and more sustainable growth. It is acknowledged broadly that the integration of information technology has induced modern manufacturing systems to become more digitised, networked, collaborative, personalised, service-oriented and intelligent. In the SME context, VCT initiatives should be driven by the need to align strategic, operational and financial needs and to help clients improve their business models. This sometimes involves relocating and redesigning business activities to lift, shift and improve the value chain. To facilitate the VCT, SMEs must put in place multi-disciplinary teams that integrate emerging IM technologies uniquely into existing processes to increase value addition. This will ensure that SMEs produce value chain transformed businesses that deliver optimised operational performance and create a robust base for efficient growth.

Business models innovation

Since the manufacturing sector is undergoing a remarkable transformation enabled by ICT and smart technologies, SMEs in South Africa have an opportunity to reinvent their business models. Intelligent manufacturing has provided SMEs with on-demand, real-time, high-quality data in this digital era. Although there are concerns about the reliability, scalability and availability of IM among SMEs in South Africa, this technology is expected to become a significant enabler for SMEs to transform their business models. One of the positive outcomes of IM is helping businesses to align product innovation with business strategy. The creation of smart factories and networks encourages effective collaboration. Small and medium enterprises can collaborate and implement necessary measures to deliver their products and services profitably despite a lack of experience, knowledge and outright confusion about technology.

Material planning and management

Material planning and management is a critical process in every manufacturing company. With the increasing exploitation of data, information technology has necessarily become more efficient. Material planning and management incorporates production planning, facility

and/or manufacturing layout design, production control and monitoring, manufacturing resource allocation and assignment, production scheduling, fleet and transhipment operations. This high level of human–machine cooperation helps to establish an integrated ecosystem in which numerous manufacturing elements are combined. This works better for the organisation at both the managerial and technical levels because resource allocation and planning become more manageable when these levels are combined seamlessly. Human involvement in an IMS can be minimised with AI, and materials and production compositions can be automatically arranged. In addition, these production processes and manufacturing operations can be monitored and controlled in real time.

Customer insights

Customer insights refer to the interpretation of trends in consumer behaviour to improve the consumer fit of a product or service, thereby increasing the likelihood of financial benefits from it. Collecting and analysing consumer insights helps you to identify purchasing patterns that reveal the values of your customer base. Customer insights help to build the most robust relationship with a customer, deliver relevant product and service recommendations, and drive the bottom line. Finally, customer insights can also enhance your overall marketing strategy by providing a tailored brand experience that focuses on what your customers truly value. Conventionally, customer insights can be obtained from formatted customer survey data, and some researchers have developed models to identify them. Intelligent manufacturing provides the organisation with critical insights that help predict consumer preferences. Intelligent manufacturing is believed to enable the advancement of big data and analytics, making it easier for businesses to unearth consumer insights. The business can then use these actionable customer insights to craft personalised and targeted product offers. The general understanding is that successful product differentiation is a by-product of objective information about consumer preferences and, as such, IM is useful.

Challenges with intelligent manufacturing

The benefits of digital technologies, including advanced data analytics techniques, are well trialled by technology vendors, promising to reduce costs, improve maintenance and efficiency, and transform logistics across a wide range of sectors, including automotive, manufacturing and processing, security and utilities. Although it is evident that IM plays an essential role in enabling the use of data and information for planning and resource allocation, it is mainly limited to large enterprises.

Underdeveloped Industry 4.0 infrastructure

To implement IM technologies successfully among SMEs, associated technologies such as AI, CPS, big data processing, augmented and virtual reality, IoT and robotics technology need to be developed adequately. Small and medium enterprises generally lack the resources to collect large amounts of data or the know-how to process and exploit it. Moreover, SMEs often fail to implement advanced techniques such as optimisation tools or enterprise resource planning (ERP) initiatives, owing to the cost and a lack of specific knowledge and personnel. As such, these SMEs find it challenging to focus on the effectiveness of their production planning. Since manufacturing is a midstream activity in the supply chain, it involves centralising the flow of goods and information from and to other stakeholders. The process itself also comprises numerous sub-processes, resources, stakeholders and materials, making manufacturing activity complex and uncertain. The complexity of the system, the interaction of machines and their inter-relation, the roles of each subsystem, and their working mechanisms and interdependencies make it difficult for most SMEs to comprehend.

Lack of prerequisite technical skills

Skilled workers are a crucial asset for competition in a knowledge-based economy. The rapid digital transformation, growing globalisation and emerging skills shortages worldwide will most likely put further pressure on labour markets and intensify competition for skills, placing SMEs at an even greater disadvantage. To advance the Industry 4.0 agenda fully, SMEs must engage in deliberate cyber-physical technical training to equip their employees with the skills needed for critical aspects such as IM. With pressure to introduce Industry 4.0 technologies in companies, there is also a shortage of skilled workers with the appropriate knowledge. Furthermore, there is a need to develop proper Industry 4.0-informed strategic initiatives to transform the manufacturing processes of these SMEs. With the 4IR already underway, SMEs in South Africa are facing the need to reshape production processes, which, in turn, requires new skills and knowledge from employees in the ‘factory of the future’. To do that, SMEs need adequate training tools that provide technical knowledge on Industry 4.0 and innovative training approaches that enable them to nurture the necessary skills in their current and future employees. However, SMEs typically have more difficulty attracting and retaining skilled employees than large firms because they lack the capacity and networks to identify and access talent. More importantly, they tend to offer less attractive remuneration and working conditions than larger firms and therefore have difficulty competing for highly skilled workers.

Initial cost of implementation

Some leading countries that impact the global market significantly are moving towards IM technologies and have already announced initiatives for next-generation industries. A big downside to IM is the initial cost of implementation. As such, many small to midsize companies will not be able to afford the considerable expense of the technology. These organisations must plan for the future even if they cannot implement smart manufacturing immediately. As with all IoT deployments, financing is critical, and pro-IoT advocates in the company are asking management to fund trials and, ultimately, full deployments. Convincing management to fund projects based on theoretical benefits that have not yet been demonstrated in the actual facility is challenging. Quantifying benefits must always demonstrate the correlation between operational improvements and the bottom line. In addition, when shifting to another advanced technology in an existing manufacturing system, the financial analysis and return on investment are evaluated carefully. The additional investment required to adopt newer technology should be weighed against production losses during an upgrade, and the time needed to recover the investment through income from the existing system influences such adoption.

Small and medium enterprises' access to intelligent manufacturing technologies

While SMEs are central to industrial upgrading, they face persistent structural constraints in accessing IM technologies such as AI, CPS, advanced robotics, IoT, digital twins and data-driven production planning. Studies indicate that SMEs rarely adopt these technologies independently; rather, adoption is mediated through institutional ecosystems comprising manufacturing hubs, innovation incubators, digital service providers, targeted public subsidies, fiscal incentives, public–private partnerships (PPPs) and university–industry collaboration mechanisms (Mosupye-Semenya 2024; Nel-Sanders & Thomas 2022). These intermediaries reduce capital intensity, knowledge asymmetries and technological risk, enabling SMEs to engage incrementally with Industry 4.0 technologies rather than through full-scale in-house investment (Kalishina 2023).

Manufacturing hubs

Manufacturing hubs, centralised ecosystems that provide shared infrastructure, often structured as industrial parks, technology stations or smart manufacturing centres, have emerged as critical access points for SMEs pursuing advanced manufacturing technologies (Atieh, Cooke & Osiyevskyy 2023). The hubs lower entry barriers to IM for SMEs, enabling

SMEs to experiment with digital fabrication, robotics and data-driven production systems without prohibitive capital expenditure (Alkhodair & Alkhudhayr 2025). In South Africa, the Technology Station Programme is coordinated through universities and supported by the Department of Science and Innovation, in collaboration with the Council for Scientific and Industrial Research (CSIR). Technology stations in sectors such as textiles, tooling, AM and automation enable SMEs to experiment with IM tools, including digital design, automation integration and data-enabled quality control, without bearing full capital costs (Sihlobo 2023). Empirical evaluations indicate that SMEs participating in these hubs demonstrate improved productivity, shortened product development cycles and enhanced export readiness (Dhlamini 2024). Comparable international models include Germany's Mittelstand 4.0 Competence Centres, which provide SMEs with access to demonstrators, testbeds and applied training in digital manufacturing, and manufacturing USA institutes, which operate as pre-competitive collaboration spaces linking SMEs to advanced manufacturing research and infrastructure.

Innovation incubators

Manufacturing-oriented innovation incubators and accelerators operate as critical intermediaries between emerging technologies and SME commercialisation pathways. Unlike general-purpose business incubators, these entities emphasise prototyping, process innovation and technology validation in production environments (Comins & Kraemer-Mbula 2016). In South Africa, incubators linked to CSIR facilities and regional innovation hubs in Gauteng and the Western Cape support SMEs working in advanced materials, smart sensors and digitally enabled production systems. These incubators provide access to laboratories, industrial-scale testing facilities and applied researchers, significantly accelerating early-stage adoption of IM technologies (Bolo 2020; Dhlamini 2024). Evidence from comparative studies in Africa and Asia suggests that incubators embedded in national innovation systems – rather than operating as isolated start-up spaces – are more effective in enabling SMEs to transition from low-technology manufacturing to digitally augmented production (Brunschwig 2019; Nel-Sanders & Thomas 2022).

Digital service providers

A rapidly expanding pathway for SME engagement with IM technologies is through digital service providers offering modular, cloud-based and pay-per-use solutions (Dyba & De Marchi 2022). In addition, SMEs can access manufacturing execution systems, predictive maintenance platforms, AI-enabled quality inspection tools and digital supply chain

(DSC) systems delivered 'as a service'. For SMEs, this service-based model reduces upfront capital requirements substantially and enables gradual capability accumulation. Studies suggest that SMEs are more likely to adopt IM when technologies are embedded in service platforms rather than offered as standalone capital assets (Jang, Chung & Son 2022). In South Africa, DSPs operating in partnership with universities and science councils assist SMEs with data analytics, integration with automation and process optimisation without requiring extensive in-house ICT capacity (Sihlobo 2023).

Fiscal incentives

Direct government subsidies remain a critical enabler of SME access to IM, particularly in capital-intensive and high-risk technological domains. These instruments typically take the form of matching grants, innovation vouchers and co-funded pilot projects (Alexander 2021; Nel-Sanders & Thomas 2022). In South Africa, support schemes administered through the Department of Trade, Industry and Competition and the Department of Science and Innovation fund SME investments in automation, advanced manufacturing equipment and digital upgrading. Evidence points to the fact that subsidy effectiveness is highest when financial support is coupled with technical assistance from institutions such as the CSIR or universities, rather than provided as stand-alone funding.

Public–private partnerships

Public–private partnerships (PPPs) are particularly effective where SMEs lack both financial resources and absorptive capacity (AC). The Council for Scientific and Industrial Research functions as a central technology intermediary in the manufacturing innovation system of South Africa, translating advanced research into SME–accessible applications through collaborative development projects, shared research facilities and pilot manufacturing lines (Bolo 2020). Studies from Japan and the United Kingdom (UK) on aerospace components, AM and industrial IoT show that SMEs participating in government-led PPPs gain access to IM capabilities far earlier than would be feasible through market-based adoption alone (Kiani 2025).

University–industry collaboration

The university–industry collaboration is a critical mechanism for knowledge diffusion and technology transfer. Academic institutions contribute research expertise, talent pipelines and technology prototyping capabilities,

while industry partners provide practical insights and pathways to commercialisation (Baleeiro Passos et al. 2023). In the UK, Russia and Italy, university-linked technology stations and collaborative research initiatives have enabled SMEs to adopt digital design tools, automation systems and data analytics in production environments. Outcomes reveal that SMEs engaged in long-term university partnerships develop stronger learning capabilities and greater resilience in successive waves of technological upgrading (Sarpong & Attakora 2025).

Conclusion

In conclusion, adopting IM practices presents significant opportunities for SMEs to revolutionise their operations and stay competitive in a rapidly evolving landscape. By embracing technologies such as automation, data analytics and IoT within the Industry 4.0 framework, SMEs can enhance productivity, improve product quality and increase operational flexibility. However, to capitalise fully on these opportunities, SMEs must address critical challenges such as technological readiness and workforce upskilling. Achieving technological readiness involves investing in the necessary infrastructure, software systems and expertise to implement IM solutions effectively. This may require SMEs to assess their current technological capabilities, identify areas for improvement and allocate resources strategically to bridge gaps. In addition, fostering a culture of innovation and agility in the organisation is essential for adapting to the rapidly changing technological landscape. Furthermore, workforce upskilling ensures that employees possess the skills and knowledge to operate and maintain advanced manufacturing technologies. Small and medium enterprises must invest in training programmes, continuing education initiatives and skill development opportunities to empower their workforce for the digital age. By equipping employees with the necessary technical competencies and fostering a culture of lifelong learning, SMEs can leverage IM practices to drive innovation, efficiency and growth. While adopting IM practices may pose challenges for SMEs, the potential rewards are substantial. By addressing barriers, embracing innovation and investing in human capital, SMEs can unlock the full potential of IM and position themselves for long-term success in the digital economy.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and W Munyanyi; *methodology* (*desktop-based literature review and conceptual synthesis*), D Pooe and W Munyanyi; *validation*, D Pooe and W Munyanyi; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and W Munyanyi; *resources*, D Pooe; *writing – original draft preparation*, D Pooe; *writing – review and editing*, W Munyanyi and D Pooe; *visualisation*, W Munyanyi; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 5

Blockchain technology and small and medium enterprise supply chains

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Introduction

With the exponential rise in the adoption of Fourth Industrial Revolution (4IR) technologies, blockchain has emerged as a prominent buzzword. This innovative technology promises to revolutionise service delivery, enhance end-to-end value and boost operational efficiency for both large and small firms. Widely hailed as ground-breaking, disruptive and foundational,

How to cite: Munyanyi, W & Pooe, D 2026, 'Blockchain technology and small and medium enterprise supply chains', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 109–128. https://doi.org/10.4102/aosis.2026.BK572.05

blockchain has redefined the landscape of economic and social systems. Its transformative potential spans diverse industries, with supply chain management (SCM) being a primary beneficiary. In this chapter, we delve into the applications of blockchain technology (BCT) in the supply chains of small and medium enterprises (SMEs). We explore the multifaceted capabilities of blockchain, ranging from its ability to provide transparency and traceability to its potential to automate processes and reduce costs. In addition, the chapter examines the myriad benefits of blockchain to SME supply chains, including improved trust among stakeholders, streamlined transactions and enhanced data security. It provides an analysis of the critical success factors essential for the effective implementation of blockchain in SME supply chains. This involves technological infrastructure, regulatory compliance, stakeholder collaboration and strategic planning. By understanding these factors and harnessing the potential of BCT, SMEs can position themselves at the forefront of innovation, driving sustainable growth and competitiveness in an increasingly digitised marketplace.

Understanding blockchain technology

As digital innovation continues to gain momentum, blockchain and other enabling technologies are set to transform SME supply chains and their capacity to coordinate business functions systematically and strategically (Chowdhury et al. 2023; Wang, Chen & Zghari-Sales 2021). According to Tapscott (2023), one of the leading authorities on technological transformations, blockchain is expected to revolutionise several key industries that depend on third-party validation by offering a secure, direct method for exchanging money, intellectual property and other assets, bypassing traditional intermediaries such as banks, utility companies and governments. Evidently, there is increased interest in blockchain as a possible disruptive technology in SCM. However, SMEs still lack knowledge of blockchain and its effect on the supply chain. These SMEs have specific characteristics that are likely to require a different perspective from that obtained from studies conducted in the large-firm context. Against this background, there is a need for a nexus for BCT and SCM among SMEs, which has been neglected generally in existing literature despite its relevance. It is critical to inform SMEs about the potential enabling characteristics of blockchain across SCM dimensions. However, despite the significant growth in the development and adoption of blockchain applications in supply chains, SMEs in South Africa still lag in understanding it. Moreover, the subsequent disruptions to SCM by blockchain are not yet exhaustive, and there are still significant potential applications and implications, especially in emerging economies such as South Africa.

Emergence of blockchain technology

Blockchain technology emerged in about 2008 with a pseudonymous figure named Satoshi Nakamoto, a cryptographic pioneer who published a White Paper on Bitcoin, demonstrating how digital currencies could challenge the central banking system. The paper outlined how a cryptographically secure, peer–to–peer (P2P) electronic payment system could place significant financial control ultimately in the hands of individuals, in a transparent and censorship-resistant manner. According to Satoshi Nakamoto:

> [...] the root problem with conventional currency is all the trust that's required to make it work. The central bank must be trusted not to debase the currency, but the history of fiat currencies is full of breaches of that trust. (Nandi et al. 2021, p. 335)

This led to the development of Bitcoin, an electronic payment system based on cryptographic proof that allows parties to transact directly with each other without an intermediary such as a central bank. The fundamental technology behind this cryptocurrency is BCT.

Defining blockchain technology

As it is currently being applied:

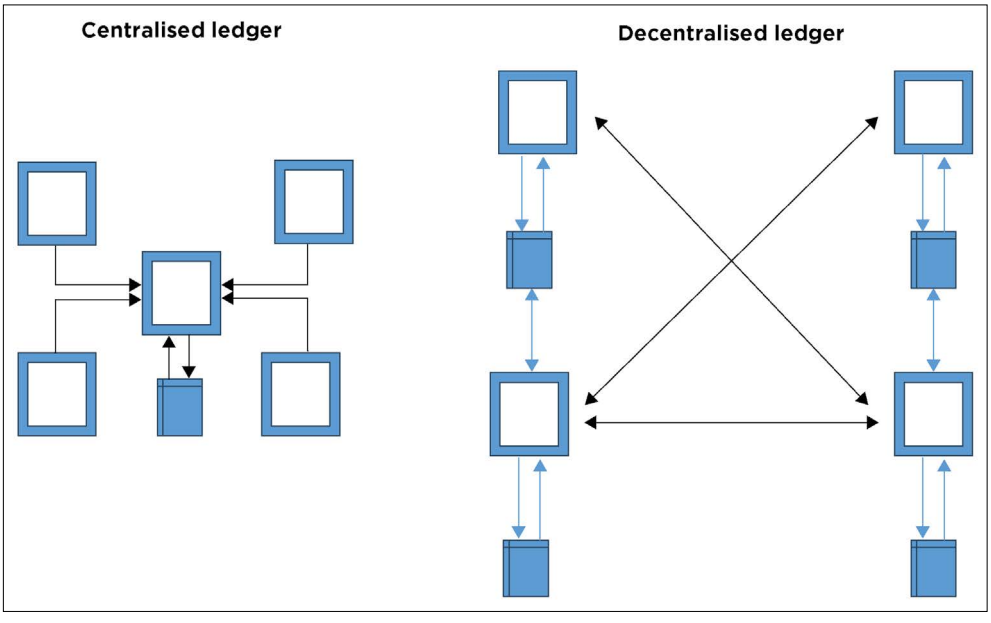
> [*blockchain*] is a tamper-resistant database of transactions consistent across a large number of nodes and is cryptographically secured against retrospective manipulations, and it uses a consensus mechanism to keep the database consistent whenever new transactions need to be validated. (Beck 2018, p. 55)

Initially developed for Bitcoin, blockchain allows participants to store and exchange value without the involvement of traditional intermediaries. A formal definition of BCT has been provided by Treiblmaier (2018, p. 547), who stipulates that it is 'a digital, decentralised and distributed ledger in which transactions are logged and added in chronological order to create permanent and tamper-proof records'.

Decentralised ledger

A decentralised ledger in BCT, shown in Figure 5.1, is a record of transactions or contracts maintained across different locations and people, removing the need for a central authority.

Powered by information and communications technology (ICT) capabilities, BCT enables payment clearing and settlement, authenticity verification and asset ownership recording. The distributed ledger is created by blocks containing transaction details, connected in chronological order to form a chain. In this distributed ledger, participants in a blockchain P2P network generate blocks without the interference of a central



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 5.1: Centralised vs decentralised ledger.

administrator or a trusted third-party service provider (Sarode & Chillarge 2021). Its file system keeps copies of changes made through mutual consensus, and the corresponding algorithms act as an online intermediary, increasing the security of payments.

Data flow in a blockchain network

Each participant in a blockchain transaction holds a copy of the synchronised ledger, ensuring that no data are lost. When changes occur, such as the addition of a new block, all copies across the network are updated in real time and recorded permanently in every ledger. Unlike other ledger approaches, BCT has ensured tamper-proof storage of approved transactions without the involvement of intermediaries (Habib et al. 2022; Sarode & Chillarge 2021). The network participants simply create, record, store and verify transaction information jointly, using security technologies such as hashing, digital signatures and cryptography (Bahga & Madisetti 2016). Jaiswal (2026) notes that the distributed ledger consists of transaction records that are arranged chronologically, signed cryptographically and immutable, accessible to all participants in the network. As copies of the blockchain are distributed globally, historical records cannot be altered without the consensus of most of the network. This inimitable distribution enhances trust in the network, as transactions can be monitored and traced by all participants.

Basic blockchain architecture

To incorporate BCT successfully into business operations, SMEs must understand the components of blockchain architecture. There are four main components in this architecture.

Node

According to Banurekha (2026), a node is any device, computer or user connected to a blockchain ecosystem and is updated continuously whenever there is a change to the blockchain ledger. This makes the node a critical component of the whole blockchain infrastructure. These nodes act as validation and communication points whenever authorisation or changes to the ledger are required. Any computer or device connected to a blockchain ecosystem can communicate with each other using the P2P protocol. The decentralised blockchain system relies largely on these nodes to manage network access and to secure its operation (Dong et al. 2023). The nodes secure the system by keeping copies of the database and verifying transactions and blocks in accordance with a set of rules.

Transaction

In blockchain technology, transactions are the smallest building blocks of a blockchain system, and each new transaction creates a new block. Details of each new transaction, such as price, asset and ownership, are recorded, verified and settled within seconds across all nodes in the blockchain system (Dong et al. 2023). To enhance authenticity and security, details such as the sender and recipient addresses and the value are updated whenever they change. The recording of transactions in a blockchain system follows the standard credit card statement, except that the details of a transaction are publicly announced to the network (Habib et al. 2022). Consequently, all the nodes independently process each transaction as it appears in the blockchain. As part of the security protocol, each transaction is time-stamped and digitally signed to ensure its genuineness. Before the block made up of new transactions is added to the network, it must be verified by the nodes on the system.

Block

A block, which forms the nerve of BCT, is a data structure used to aggregate transactions for inclusion in the public ledger, the blockchain. A block is essentially a bundle of transactions, and the order in which the transactions occur is determined by the order of the blocks. This means that all transactions in a single block co-occur, while all other transactions are classified as unconfirmed. A block fundamentally consists of a unique identifier for the block, a previous block reference and a list of transactions (Sarode &

Chillarge 2021). The purpose of blocks is to bundle transactions and replicate them to all the nodes in the network. Information is stored in a block in the form of block headers and transactions. Banurekha (2026) adds that the term block header refers to metadata that helps verify the validity of a block, while the rest of the block contains transactions. There are three types of blocks: the main branch block, the side branch block and the orphan blocks. The main branch blocks are the ones that directly extend the main blockchain and are usually the longest chains in the network. A side branch blocks reference a parent block that is not on the longest blockchain, while an orphan block references a parent block that is not known to the node processing it.

Chain

In the blockchain ecosystem, blocks built from transactions are arranged into a chain. A chain is, therefore, a sequence of blocks set in a particular order. In blockchain technology, blocks are always linked in a backward order, such that each block links to its previous block (Sarode & Chillarge 2021). In essence, blocks form a chain by referencing a previous block, known as the parent block. Blockchain gets its name because blocks are chained together cryptographically, and this chain grows as new blocks are added. To maintain ledger security and consistency, asymmetric cryptography and distributed consensus algorithms are implemented throughout.

Major components of a blockchain ecosystem

Due to its unique characteristics, BCT has received immense attention from both practitioners and scholars. However, businesses have tended to focus on transactional features, overlooking the critical components of the blockchain ecosystem. Specifically, with SMEs in mind, it is essential to provide an in-depth understanding of the logical components that make up the blockchain ecosystem, so that the transactional aspect is accurately understood. At first glance, the whole blockchain space may seem complicated to SME owners, managers and employees, but once the components are explained, it becomes easy to understand. Although blockchain networks are created differently to cater to users' diverse needs, they all follow a similar basic foundation. The four main blockchain ecosystem constituents are discussed next.

Node application

In blockchain technology, a node is a participant in the network that engages in transactional activities and holds a full, permanent copy of the ledger, including all historical transactions. The node application is typically the computer from which a node or participant accesses the blockchain (Al Ahmed et al. 2022). The gateway to the blockchain ecosystem can be

understood as the hands and legs of blockchain, just as Internet Explorer is the gateway to the internet. Each participant in the blockchain network must run a node application specifically related to the blockchain ecosystem in which they wish to participate. For instance, each participant must run the Bitcoin wallet application to participate in the Bitcoin ecosystem. The Bitcoin client will operate within the Bitcoin ecosystem, adhering to the rules defined in the program code of the Bitcoin node (Cooper 2022). Like most applications currently being developed, one can successfully participate in a blockchain node application in their respective blockchain ecosystem with limited training or experience. This is an advantage for SMEs wishing to incorporate blockchain applications into their operations, as they can do so without recruiting specialised personnel.

Decentralised network architecture

Blockchain consists of a distributed ledger created by transaction blocks connected chronologically to form a chain (Oh & Shong 2017). As such, BCT provides a decentralised P2P network architecture that allows participants to transact more securely, transparently and reliably. The decentralised blockchain ledger is stored in all individual stakeholder databases of the network, called nodes. This ensures that the system is fault-tolerant and that failure at the central infrastructure point is impossible. There is ongoing, massive replication of the ledger across all nodes, making the system more robust and improving service quality, reliability and availability. According to Iansiti and Lakhani (2017), the decentralised P2P connectivity in blockchain networks enables high computational power, reducing friction in transaction processing and costs. The distributed ledger is controlled in the node application, and once a participant has the corresponding node application running, they can access the ledger and blockchain contents of that ecosystem (Banurekha 2026). For example, if a participant runs an Ethereum node, they can view the Ethereum ecosystem's ledger and interact with other participants according to the rules of that ecosystem. Participants are allowed to run several node applications, each of which relates to a specific blockchain ecosystem. While many node applications may be utilised across blockchain systems, and regardless of the number of ecosystems in which one participates, there is only one shared ledger per ecosystem (Sarode & Chillarge 2021). Given the size of the SME sector and the prevalence of system failures among participants in their supply chains, the decentralised network architecture is likely to be a significant characteristic.

Consensus algorithm

The consensus algorithm is probably the most critical component of the blockchain ecosystem, often referred to as the 'brain' of the chain, which

forms the core of blockchain architecture (Nodehi et al. 2022). It is responsible for ensuring that a single ledger is synchronised by keeping all copies of that party consistent and up to date. Consensus in BCT refers to the agreement among nodes in a blockchain network regarding the submission of transactional information. Implementing this algorithm forms part of the node application, providing the 'rules of the game' on how the blockchain ecosystem will synchronise the ledger view (Al Ahmed et al. 2022; Oh & Shong 2017). Therefore, a consensus algorithm is the mechanism that allows users or machines to coordinate in a distributed setting. It is the process by which all peers in a blockchain network reach consensus on the current state of the distributed ledger. This procedure enables consensus algorithms to achieve a level of reliability in the blockchain network and to ensure trust among peers. Different ecosystems use different methods to reach this consensus, but there are three standard methods for consensus building: proof-of-work, proof-of-stake and proof-of-elapsed-time.

Virtual machine

In blockchain technology, the virtual machine is the final logical component that every participant in the ecosystem runs as part of the node application. The way virtual machines work can be understood by looking at how general-purpose computer programs work. When a physical computer runs a computer program, the instructions of the computer program tell the computer to change its 'state' (Samantray & Reddy 2025). The information displayed on the computer screen informs us that there has been a computer state change. This display may take the form of information and graphics, or sound sent to the speakers. In this regard, a virtual machine is a machine created by a computer program and operated according to instructions embodied in a specific language. A computer program creates a virtual machine where instructions are expressed in a programming language (Saraswat, Manchanda & Jasola 2024). In the Ethereum blockchain environment, the virtual machine is contained in the Ethereum node application known as a wallet (Samantray & Reddy 2025). Several blockchain platforms exist worldwide, each developed with different consensus algorithms, tools and programming languages. Companies worldwide have embraced blockchain, ushering the business world into a new era of collaboration and innovation. Notably, IBM, the leading multinational technology company, has created a separate division, IBM Blockchain, focused primarily on developing blockchain applications. Isolating BCT into these four essential components makes it easier for non-technical users in SMEs to understand BCT ecosystems and the latest market developments.

Power of blockchain technology

Blockchain technology's unique characteristics and power have made it arguably one of the most rapidly rising technological solutions. It is a digital

approach that has reinforced the goodness of 4IR through data integrity and tamper-proof transactions. Although many concepts are still being developed and tested, it is becoming increasingly apparent that the prospects for employing this technology across diverse industries are high. Blockchain technology has stood out from other technologies because of its incomparable technical architecture, which enables adaptation across various activities (Saraswat, Agrawal & Rane 2025). Several unique characteristics have been associated with BCT, including its ability to provide a secure, verifiable, immutable and transparent distributed ledger. Against the background of other emerging 4IR technologies and their potential shortcomings, attention is shifting increasingly towards blockchain (Nodehi et al. 2022). Certain characteristics, discussed next, have made BCT the preferred emerging technology.

Distributed governance and control

Since there is no specific regulatory entity that controls blockchain networks and no need for trusted intermediaries to verify transactions, distributed governance and control are achieved. These characteristics of BCT have led to a shift from the 'internet of information' to 'the internet of value'. This distributed governance and control obtainable without central authority interference increases efficiency, promotes the seamless exchange of data across entities and improves process integrity (Oh & Shong 2017). In addition, because transactions are verified in real time by all network participants, audit compliance is enhanced. The power of blockchain lies in the fact that everyone influences decisions on the platform, while maintaining a delicate balance of control. However, some have argued that the openness of BCT is both its strength and its vulnerability, since decision rights are 'up for grabs' to anyone who can make time to write code.

Transparency and pseudonymity

Blockchain technology uses a distributed database ensuring that secure, validated data are available to all participants in the network at the same time (Al Ahmed et al. 2022). It offers full transparency across the entire transaction chain, enabling swift and efficient transfer of assets and information between multiple organisations. As noted earlier, blockchain ledgers allow direct connections between individual consumers and organisations, eliminating the need for a central authority. In the blockchain's P2P network, digital transaction data are shared in real time. Each network member maintains a local copy of the ledger and communicates updates to other nodes. Notably, as stated by Stanešić et al. (2025), each node is assigned a digital signature, known as a private key, which confirms its identity, and it is used to validate transactions. The network operates using a consensus protocol that organises transactions and blocks in the correct

order to preserve the ledger's integrity and consistency. This also helps to enhance trust between stakeholders or nodes in the long term. These characteristics make the blockchain-enabled transaction system highly transparent and make illegal transactions very difficult to execute.

Modern cryptography and programmable logic

Modern cryptography is a technique used in coding that manipulates traditional characters, such as letters and digits, directly, operating on binary bit sequences. Cryptographic systems are a fundamental component of standard protocols used to protect data at rest and in motion (Hazra, Ghosh & Jash 2024). Most notable has been the Transport Layer Security protocol, which enables the use of strong encryption across a wide range of applications. Blockchain technology utilises public-key cryptography and digital signatures to authenticate node identities and ensure data security. Based on the notion of 'security through obscurity', cryptography has become an indispensable tool for protecting information in computing systems. This approach helps to protect identities and prevent hackers from tampering with data, reducing the risk of fraud or theft. In addition, by eliminating the need for a centralised authority, BCT guards against a single point of failure and compromise. It has been argued that cryptography-based blockchain systems are more secure and satisfy the primary security properties. This, coupled with programmable logic, has enabled blockchain to achieve greater usability and application (Saraswat, Manchanda & Jasola 2024). Programmable logic has been credited with providing a viable alternative to the computationally intensive functions of digital signal processing (DSP). Its capacity to deliver increased DSP system performance at lower cost, along with greater flexibility, speed and density in implementation, has also been acknowledged.

Data transparency and security

The power of BCT is also manifested through its ability to make data more transparent than before in financial systems. Experts have argued that blockchain could be used eventually as the new benchmark for transparency. Blockchain technology is configured so that network participants can access the holdings and transactions of blocks, including their contents and details, making data more transparent (Singh et al. 2023). In the BCT ecosystem, every transaction and its corresponding values are visible to anyone accessing the system. A unique 30-plus-character alphanumeric address is assigned to each node or user as an identity, also aiding in providing a secure and efficient platform for transacting. This feature of blockchain can benefit SMEs by facilitating the registration of intellectual property transactions, verifying the origin of goods and services, and asserting ownership of assets. In the wake

of increased cybercrime and cybersecurity concerns, attention to BCT has shifted dramatically (Singh et al. 2023). Blockchain technology has grown in significance because of its ability to enhance data security and the inherent immutability and irreversibility of records. It has been introduced across many spheres as a new way to store information, conduct safe transactions and build trust.

Blockchain technology relies on several computers connected for record-keeping and data storage, and as such, hackers cannot target a specific single computer (Nodehi et al. 2022). This proves beyond doubt that blockchain is changing the approach to cybersecurity, and SMEs in South Africa can take advantage of these developments to enhance their data security and prevent malicious cyber-attacks. Immutability, which relates to how data remains unchangeable once recorded and processed on the blockchain, is another critical blockchain property. Blockchain technology has also been configured so that data cannot be altered in any way once it has been entered, and the blockchain encryption provides proper validation. In fact, the term 'chain' comes from the concept of record irreversibility, stemming from the fact that data are linked to every transaction record that came before it. Any blockchain record cannot be changed once it is entered. The computational algorithms and approaches in BCT ensure that the recording is permanent, chronologically ordered and available to all others on the network. These algorithms and techniques enhance data security and record irreversibility, both of which could benefit SMEs in South Africa.

Fields of blockchain technology application

After implementing BCT successfully in Bitcoin and recognising its striking features, blockchain has been deemed useful in various applications. Globally, ground-breaking applications of blockchain are currently being explored across sectors ranging from agriculture to energy, health and banking.

Banking and finance

In the financial services sector, significant inroads have been made towards adopting and applying BCT. Seemingly, the financial services sector stands to benefit most from the blockchain revolution and its integration into business operations. Perhaps the most significant benefit of this underlying technology for the banking and finance industry is that it will enable the movement of funds with confidence that transactions are secure and reliable (Khatwani et al. 2023). In addition, as a ground-breaking technology for record-keeping, BCT is poised to transform the future of finance across

securities trading, asset and collateral management, payments and payment records. The peer–to–peer functionality in blockchain transactions eliminates while increasing transparency, which has proven helpful in banking and finance. The reduction in 'layers' will lead to instant settlements of payments among banks, thereby promoting functionality and efficiency in banking and payment systems. If implemented in cross-border payments, blockchain systems can facilitate the instantaneous transfer of funds (Mishra & Kaushik 2023). This distributed, permanent and irreversible ledger technology can revolutionise receivables, payables and intercompany accounting and consolidations.

Health sector

There have been significant inroads to transform the delivery of services in the health sector through BCT. Evidence shows that BCT can transform health care, position the patient at the core of the health care ecosystem, and enhance the security, privacy and interoperability of health data. One of the benefits of BCT relative to traditional health care database management systems includes decentralised management, unchangeable databases, data provenance, traceability, robustness and data availability to authorised users (Bali et al. 2023). Over the years, there has been an increase in data regulations, such as the General Data Protection Regulation, which promote privacy in the handling of patient health information. While this technology may not be a panacea, the health sector can leverage blockchain capabilities to securely store patient medical records. In a blockchain ecosystem, a medical record can be created, signed and the patients provided with the proof and confidence that the record cannot be changed. The private key used to encode and store the documents ensures patient privacy. Blockchain's capacity to maintain an incorruptible, decentralised and transparent log of data makes it unparalleled (Singh et al. 2023). On the other hand, the decentralised nature of blockchain will allow patients, doctors and health care providers to share the same information instantaneously and safely.

Food safety

The coronavirus disease 2019 (COVID-19) pandemic, which has besieged the world since 2019, has altered how consumers access essential commodities and foodstuffs. Since the outbreak of COVID-19, grocery demand has spiked owing to restrictions on movement and strong consumer preference for contactless shopping. This, coupled with the fact that, over the past few years, the United States and other countries have witnessed a dramatic increase in food recalls, has made traceability

paramount for food and beverage distributors and manufacturers. Consumers have increasingly demanded that information relating to the source or provenance of products be displayed on products to enable buying decision-making (Sri Vigna Hema & Manickavasagan 2024). The result has been an increase in the need for traceability and agility in the food supply chain. There is remarkable empirical evidence of developments in BCT that could solve the fragility in food supply chains, where a lack of end-to-end visibility is causing severe disruptions. The distributed nature of the blockchain ledger technology has proven to provide appropriate identification and location of products throughout the chain, enhancing traceability.

Government and public services

According to Luthra et al. (2023), BCT has also enabled the emergence of what has grown to be known as the blockchain-based digital government. In this environment, individuals, businesses and governments can share resources over a cryptographically secured distributed ledger. This is a structure that does not only inherently secure sensitive government data by eliminating a single point of failure but can also be leveraged to support an array of public sector applications. It has been noted that BCT can improve efficiency in government payments, registrations, identity management, taxation and voting (Dong et al. 2023). Security and identity are ever-evolving concerns in government systems, and blockchain can be the solution to concretising the concept of e-government. Because of its ability to modernise public administration through user-centric, agile and innovative public services, BCT must be prioritised if governments are to achieve the desired paradigm shift in policymaking and service delivery. Blockchain technology has also been credited with fostering compliance by eliminating the need for intermediaries in areas such as tax collection. Blockchain can also help to reduce government costs by enabling government agencies to transact directly with buyers and sellers in procurement.

Blockchain technology and small and medium enterprise supply chains

As a system of organisations, people, activities, information and resources involved in moving a product or service from supplier to customer, the supply chain has responded to global changes. There is evidence of a supply chain transformation in response to Industry 4.0, leading to the emergence of what has become Supply Chain 4.0 (Akbari et al. 2024). With growing interest in blockchain adoption and use, it is crucial to consider the potential benefits of BCT for businesses in general before

narrowing it to SCM. For instance, the blockchain's immutable ledger makes it well suited for real-time tracking of goods as they move and change hands throughout the supply chain. Blockchain technology has been described as the 'next-generation internet' (Shermin 2017, p. 500), a new 'foundational technology' (Iansiti & Lakhani 2017, p. 119) with the potential to reshape financial transactions and influence how people interact in both economic and social life. The emerging BCTs are changing drastically how inter-organisational processes are managed. It is clear that the BCT characteristics mentioned allow developers to develop numerous applications that disrupt and create new business processes, and SMEs cannot afford to ignore this trend.

Supply chain resilience

Supply chain resilience (SCR) is the ability of the supply chain to prepare for unexpected risks, respond and recover quickly to potential disruptions, and return to its original state or grow by moving to a new, more desirable state. When cost control is critical, a reimagination of supply chains can deliver the resilience and efficiency that businesses need for the next normal, if leaders make smart investments to minimise costly disruptions before they occur. The concept of organisational resilience is not a recent development; an organisation's ability to effectively respond to unexpected challenges has long been key to its success. However, with an increasing variety and frequency of threats facing supply chains today, resilience has become even more critical in SCM. Consequently, industry leaders have intensified their efforts to explore the factors that contribute to resilience, leading to a growing body of knowledge that other organisations can learn from and apply.

As detailed in Chapter 10, companies need an understanding of their exposure, vulnerabilities and potential losses to inform resilience strategies. Supply chain resilience today goes beyond just managing risk; it now involves leveraging that capability as a competitive edge. Organisations that can effectively handle disruptions are not only better prepared but also better positioned to capitalise on them compared to their competitors.

Deploying blockchain technology in small and medium enterprises supply chain

The advent of Industry 4.0 saw blockchain being adopted in various supply chain applications, marking the emergence of blockchain-enabled supply chains. These technologies have already been recognised for enhancing processes and boosting efficiency in various areas. The disruptive integration of blockchain and the Internet of Things (IoT) has positioned this combination as one of the most promising technological advancements

in recent times. Together, they enable companies to reinforce connections with key stakeholders, particularly existing customers, while also attracting new ones**.** The current setup, where supply chains have remained largely centralised, has exposed them to corruption, fraud and tampering. In this regard, BCT gives rise to a novel and distributed approach in supply chains, where visibility and transparency of product flows are at the core (Iansiti & Lakhani 2017). The integration of blockchain into the supply chain architecture enables the creation of a reliable, transparent and secure system that supply chain actors, especially SMEs, would appreciate. Of particular interest is that blockchain is premised on removing intermediaries in the business ecosystem and prioritising security over performance. Having easy access to verifiable records will be of significant value to all businesses, as will the ability to track business assets.

In this context, BCT can offer businesses a compelling reason to rethink how they manage their business processes. In addition, most SMEs are losing money owing to bureaucratic delays, human error and fees paid to intermediaries, and blockchain has the potential to eliminate mistakes, bypass infernal intermediaries and make transaction authentication easier. Blockchain has been adopted in the banking and finance sector because it enables direct transactions between parties, eliminating the need for reconciliation and intermediation (Khatwani et al. 2023). Banks can also track financial assets continuously and settle transactions autonomously in a secure, reliable and resilient manner. These features highlight how BCT can support organisations in executing business processes across different entities, even in the absence of a mutually trusted third party. This affects the business processes significantly that SMEs in all industries must prioritise.

Achieving supply chain resilience

In today's dynamic and turbulent business environment, with the prominent role that supply chains play, there is a need to develop measures to mitigate the adverse effects of threats to business operations. There has been an increase in threats to supply chains, such as natural disasters, accidents and intentional disruptions, driven by the growth of global supply chains, the shortening of product life cycles and market volatility (Akbari et al. 2024). In addition, the management of product and process integrity in multi-stakeholder supply chains has become increasingly significant. Most existing solutions have struggled to deliver true SCR owing to fragmented data, unreliable provenance and inconsistent protocols across processes and distribution channels. In contrast, BCT stands out as a comprehensive solution, offering a cost-effective way to ensure secure product traceability, data immutability and the establishment of trust among all stakeholders.

According to Duong et al. (2025), resilience has become a concern in supply chains owing to globalisation and the rise in diverse disturbances. By definition, SCR refers to a supply chain's capacity to anticipate unexpected risks and respond quickly to potential disruptions. This enables the actors in the chain to safeguard their customer bases, market share and financial performance. As such, resilience is at the core of SCM and investing in it can lead to efficiency and productivity (Mishra & Kaushik 2023). To remain competitive, each player along a supply chain must forecast customer demands appropriately and timeously. This will enhance the proper management of production planning, inventory and material requirements planning activities. With each transaction along a supply chain, rights and obligations are created among the stakeholders, and information must be recorded accurately to reduce ambiguity. For SCR to be achieved, chain actors need a holistic approach to ensure accurate alignment of chain processes to the identified risks (Khatwani et al. 2023). For resilience to be achieved in supply chains, both resistance and recovery capacity must be present. Resistance capacity refers to the ability of a supply chain to minimise the impact of disruption, either by avoiding it entirely or by containing it. Recovery capacity, on the other hand, is related to the ability of a chain to return to normalcy and functionality after a disturbance has occurred.

The numerous characteristics of blockchain, such as transparency and decentralised, immutable record-keeping, which prevent single-point failures, have proven that BCT is the solution for resilience in supply chains. Because BCT increases transparency in transactions, it can help to reduce fraud along the supply chain. Transparency also helps in reducing counterfeit and grey-market trading, thereby boosting confidence along the supply chain (Mishra & Kaushik 2023). It should also be noted that BCT can streamline administrative processes and reduce costs by eliminating the need for intermediaries. This also enhances effective audit of supply chain data, improves compliance and accelerates information flow through the distributed ledger. Identification and execution errors in inventory data, shipments and payments can also be detected in real time with the adoption of BCT, a feature lacking in current centralised architectures.

Blockchain payment systems

Blockchain payment systems facilitate, process and verify transactions on a blockchain or distributed ledger system. Depending on the use case, these tools may be designed for individuals, businesses or financial institutions and will have different features. These payments are also secure, as BCT allows tracking from beginning to end while protecting user privacy: only network participants are notified of the transactions, and the identities of the transacting parties are not revealed. One of the most widely used

blockchain payment platforms, Coinbase, allows users to buy, sell and store over 150 cryptocurrencies and to convert their earnings into fiat currency. In addition, the platform houses a variety of tools for individuals and businesses to expand their reach into the crypto sphere. Small and medium enterprises may opt for blockchain-based payment solutions for several reasons.

Certain platforms enable the creation of smart contracts, self-executing protocols that facilitate, verify and enforce transactions automatically, enhancing both efficiency and trust in financial operations (Khatwani et al. 2023). By leveraging BCT, enterprises can automate their business processes while maintaining high security and transparency. Among many industries that blockchain has transformed so far, the payments and finance industry has been behind the hype (Mishra & Kaushik 2023). Lately, as the world undergoes digital evolution, the payments industry has adopted many ingenious technologies to streamline payment processes. These contracts are well documented and provide greater traceability. These forms of payment are also quicker than traditional tools as they do not require a financial institution and allow transactions to be completed efficiently across country borders.

Critical success factors for small and medium enterprise supply chains

In materials science, resilience is the capacity of a material to return to its original form after being deformed. In the business context, resilience describes a company's ability to recover from significant disruptions, such as how quickly it can restore normal operations, including production, service delivery or order fulfilment. As outlined in Chapter 2, businesses can strengthen their resilience through three key strategies: adding redundancy, enhancing flexibility and transforming corporate culture. While redundancy has its limitations, flexibility and cultural change are vital for true resilience.

Redundancy

In theory, a resilient company can be developed by incorporating redundancies across its supply chain, such as holding surplus inventory, operating below full capacity, or relying on multiple suppliers (Akbari et al. 2024). While these buffers can help a business to stay afloat during disruptions, they are usually short-term solutions and come with a high price tag. The company must bear the costs of extra inventory, capacity and personnel. In addition, this excess often leads to inefficient operations, diminished product quality and rising expenses. Leading supply chain approaches such as the Toyota Production System, lean manufacturing

and Six Sigma emphasise maximum efficiency and minimal inventory to ensure the timely delivery of high-quality goods. Prioritising redundancy can undermine these efficiency-driven models.

Supply chain flexibility

In contrast, enhancing supply chain flexibility enables a company not only to endure major disruptions but also to adapt more effectively to shifts in demand (Kamalahmadi, Shekarian & Mellat Parast 2022; Lücker, Timonina-Farkas & Seifert 2025). To embed flexibility into its operations, a company should take these steps:

Adopt standardised processes

Developing the capability to shift production across different plants is essential for flexibility. This can be achieved by using standardised, interchangeable components across products, implementing uniform plant designs and manufacturing processes, and cross-training employees. Such standardisation of parts, facilities and workforce enables a company to reallocate resources quickly in response to disruptions (Boonlua et al. 2023). For instance, Intel constructs its semiconductor fabrication plants with consistent layouts and processes, allowing it to transfer production seamlessly between facilities when necessary.

Use concurrent instead of sequential processes

Using simultaneous rather than sequential processes, especially in critical areas such as product development and production or distribution, can accelerate recovery significantly after a disruption while also enhancing responsiveness to market changes (Kamalahmadi et al. 2022). Companies have demonstrated that by operating a centralised supply chain organisation, they can integrate multiple functions, such as engineering and sales. This alignment allows the company to manage operations in parallel, offering real-time visibility into each function. As a result, organisations can evaluate the status of all key activities rapidly during a crisis and respond more efficiently.

Cultural change

What truly sets apart companies that recover swiftly and even thrive after a disruption is their corporate culture. Resilient organisations often exhibit common cultural characteristics, chief among them being ongoing, transparent communication among well-informed employees (Lücker et al. 2025). These companies ensure that everyone stays up to speed on strategic

objectives, operational conditions and the real-time flow of business activity. At Dell, for instance, employees have continuous access to data on manufacturing, shipping and various other operational metrics. This visibility means that when a disruption occurs, staff already understand what is selling, where materials are located and what the company was aiming to achieve before the interruption. Armed with this insight, they are better equipped to make smart, timely decisions in the face of the unexpected.

Distributed power

According to Dahmen (2023), another key trait of resilient companies is the distribution of decision-making power, which allows teams and individuals to take immediate action when necessary. For example, Toyota empowers its assembly-line workers to stop the entire production line by pressing a dedicated alarm button if they detect an issue. Similarly, on the United States of America's Navy aircraft carriers, any crew member has the authority to halt flight operations upon noticing a potential emergency. This level of empowerment ensures that those closest to the action, who often detect problems before they become visible to upper management, can intervene early. By acting swiftly, they can often prevent a minor issue from escalating into a significant disruption. In environments where speed and precision are critical, this kind of decentralised control not only boosts responsiveness but also builds a culture of accountability and trust across the organisation.

Conclusion

Introduced in 2009 as the foundation of Bitcoin, BCT has significant potential to benefit today's supply chain. It provides a decentralised platform that supports any transaction type and records information with an immutable, permanent historical trail. We believe it has a significant future in the supply chain, as it promises to deliver an efficient, transparent and collaborative network for organisations to share data quickly and securely across a variety of supply chain sectors and processes. This technology enables businesses to build a more flexible and responsible supply chain and to address new external and internal challenges robustly. Although BCT has been acknowledged broadly as a promising solution for the current supply chain challenges of SMEs, its applicability requires significant changes in both technological and cultural contexts. In addition, more comprehensive evaluations are needed to unveil and address its challenges before realising the full potential of this new technology. In summary, BCT offers SMEs unprecedented transparency, security and efficiency in managing their supply chains. By embracing blockchain solutions and addressing implementation challenges, SMEs can fortify their SCR and gain a competitive edge in an increasingly digitised marketplace.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and W Munyanyi; *methodology* (*desktop-based literature review and conceptual synthesis*), D Pooe and W Munyanyi; *validation*, D Pooe and W Munyanyi; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and W Munyanyi; *resources*, D Pooe; *writing – original draft preparation*, D Pooe; *writing – review and editing*, W Munyanyi and D Pooe; *visualisation*, W Munyanyi; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 6

Digital supply chain strategy implementation

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Introduction

Developing and implementing a digital supply chain strategy (DSCS) is essential for small and medium enterprises (SMEs) to remain competitive in the digital age. This chapter focuses on crafting and executing DSCSs, as well as examining the process, drivers and challenges associated with implementation. Currently, disruptions caused by rising tariffs, trade wars and the global pandemic have pushed supply chains into the spotlight of business discussions. Supply chain resilience (SCR), which was once the

How to cite: Munyanyi, W & Pooe, D 2026, 'Digital supply chain strategy implementation', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 129–149. https://doi.org/10.4102/aosis.2026.BK572.06

concern of only the manufacturing sector, has now evolved to become a widespread focus across various industries and is covered frequently in mainstream media. Moreover, in an increasingly digital world, consumers demand speed, convenience and accuracy. Technology has helped many businesses to keep up with these demands, particularly the rise of the digital supply chain (DSC), which has increased efficiency for manufacturers, improved visibility and cost reduction for all stakeholders, and increased customer satisfaction, among other benefits. However, many organisations are still struggling to keep pace with the onslaught of digital trends that are disrupting traditional supply chain management (SCM), slashing response times and raising customers' expectations. The speed of change can be overwhelming, especially for those who are not digital natives. Organisations need to accelerate investment in DSCs to ensure their continuity, but such investments yield sustainable results only when a DSCS is in place and implemented effectively. The literature shows that there is a difference between having a strategy in mind and actually executing it. Effective digital chain strategy implementation is the focus of this chapter, with a spotlight on the differences between a traditional and a DSC, followed by a DSCS, the components of successful implementation, key considerations, challenges that can occur during the process and, eventually, how to address them.

What is a digital supply chain?

A digital supply chain is a supply chain whose foundation is premised on web-enabled capabilities, for example, artificial intelligence (AI), machine learning (ML), predictive analytics, augmented and virtual reality, the Internet of Things (IoT), big data and three-dimensional (3D) printing to every aspect of the end-to-end supply chain. The Digital Supply Chain Institute (2017) defines a DSC as a customer-centric platform model that captures and maximises the utilisation of real-time data coming from a variety of sources, enabling demand stimulation, matching, sensing and management to optimise performance and minimise risk. We can also view a DSC as an intelligent, value-driven network that leverages new technologies and data analytics to create value and revenue for the organisation through digital planning, supply, manufacturing and logistics. On the other hand, Jenkins (2020) describes a DSC as a set of processes that use advanced technologies and better insights into the functions of each stakeholder along the chain to let each participant make better decisions about the sources of materials they need, the demand for their products and all the relationships in between.

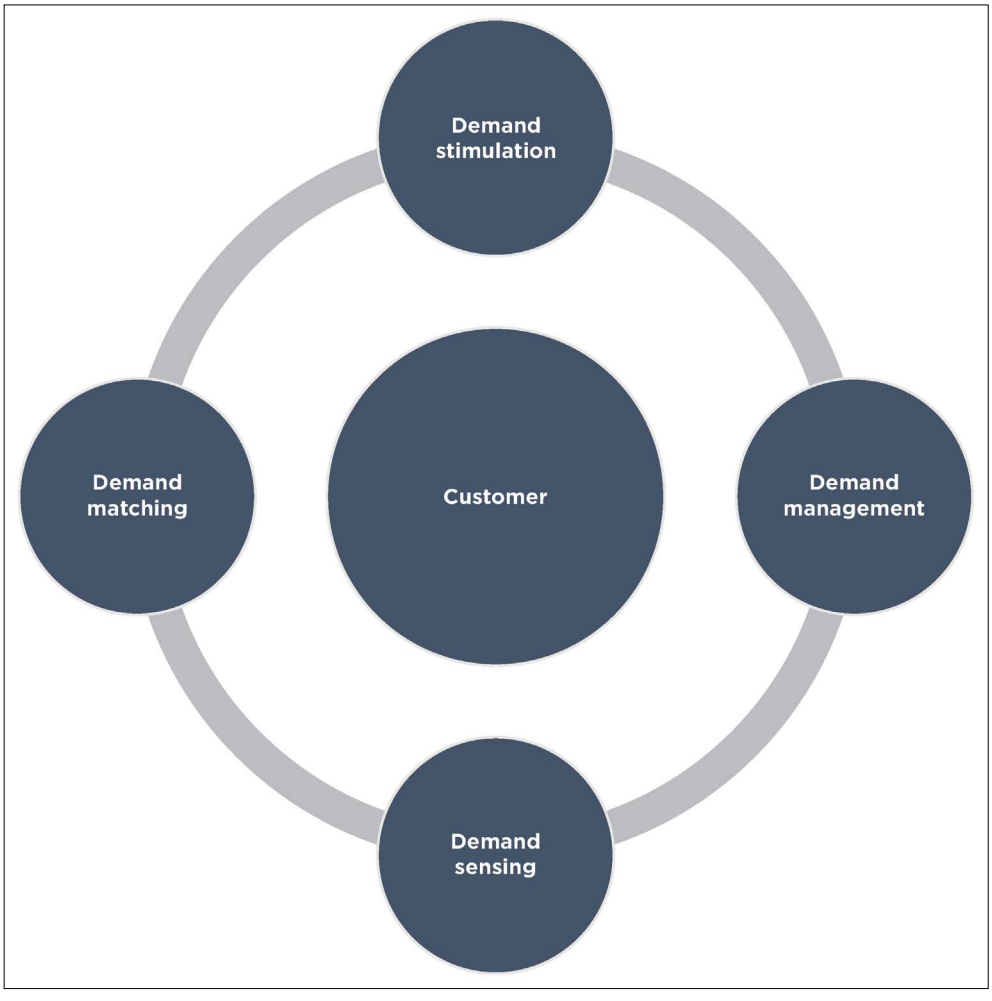
A digital supply chain involves the seamless integration of traditional SCM systems, such as demand planning, asset management, warehouse management, transportation and logistics, procurement and order fulfilment

(Badhera, Kushwaha & Gupta 2026). Yet, true digital transformation goes beyond integration; it requires extracting data from these systems and equipping equipment to generate real-time data. This is achieved through sensors and monitors, collectively known as the IoT, which are used primarily to track and manage manufacturing and logistics operations (Chaudhari et al. 2026). Using network gateways, this sensor-generated data can be shared across the supply chain with relevant stakeholders. Once aggregated, it allows them to evaluate supply reliability and make informed decisions. For example, a clothing retailer could gain visibility not only into the current inventory of shirts, categorised by colour, style and size, in a warehouse, but also into the number of shirts being produced and the status of their specific order in the manufacturing process. When data are collected across multiple suppliers, it enables the retailer to maintain optimal stock levels across all stores without overstocking.

The systems used to collect and analyse supply chain data operate in near real time, offering significantly improved visibility into supply chain activities compared to traditional methods. However, to extract meaningful insights from this vast amount of data, advanced analytics are required to model patterns and forecast outcomes. As supply chains grow more complex, with an increasing number of suppliers, components, distributors and customers, so does the challenge of managing them effectively. One powerful tool aiding this effort is the digital twin, a virtual replica of a physical product or process. This technology enables organisations to create a digital version of their entire supply chain, allowing them to simulate various 'what-if' scenarios. For example, in the context of the earlier clothing retailer, green shirts from one vendor may be 15% more expensive than those from another but fulfilling demand may still require sourcing from both. Figure 6.1 illustrates a typical DSC.

A digital twin would allow the retailer to ask, 'What if we stopped buying from our three most expensive suppliers?' Then immediately see whether demand would still be met. Machine learning enhances these capabilities further by enabling predictive modelling and generating actionable recommendations in response to dynamic supply chain conditions. In addition, blockchain technology (BCT), a secure, transparent and immutable digital ledger, offers significant potential to enhance global supply chain transparency and ensure accurate, real-time tracking of assets and transactions.

Transforming a traditional supply chain into a digital one involves several critical factors. At the forefront is the need to gain a deeper, more refined understanding of your customer and end consumer by leveraging data analytics and advanced technologies (Digital Supply Chain Institute 2017). Production will be driven by customer demand rather than by manufacturing



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 6.1: Digital supply chain.

efficiencies, resulting in better inventory management and a more effective response to customer needs. The supply chain will shift from a behind-the-scenes function to a key, integrated role alongside sales, marketing and product development, overseeing the entire process from procurement to delivery. In addition, leadership in the DSC will extend across all areas of the demand process, including demand stimulation, management, sensing and matching. This transformation will require greater internal collaboration and stronger partnerships with key stakeholders, including suppliers and customers. By utilising data analytics and advanced technologies, companies can gain improved visibility into supply chain risks, allowing them to prevent or mitigate negative effects more effectively.

Differences between digital and traditional supply chain

Many supply chains still rely on a combination of paper-based and information technology (IT)-enabled processes. However, a true DSC moves beyond this hybrid approach, fully leveraging connectivity, system integration and the data-producing capabilities of 'smart' components. While both digital and traditional supply chains involve functions such as product design, raw material procurement, demand estimation, product introduction planning, supply arrangements, sales channel selection, delivery support and customer order visibility, Jenkins (2020) highlights several differences between the two models.

Firstly, traditional supply chains focus on planning and reacting, while DSCs focus on predicting and prescribing actions. Secondly, traditional supply chains are often static and rely on historical transactional data, whereas DSCs operate in real time, are dynamic and can adapt to changing circumstances (Kaushik 2021). Thirdly, traditional supply chains are linear, whereas DSCs function as networks. Fourthly, traditional supply chains often use standalone systems, while DSCs integrate IT and operational technology systems. Instead of optimising for individual nodes, shipments or orders, DSCs balance profit and service levels. Fifthly, in traditional supply chains, identifying potential problems and predicting their effects requires significant effort, such as conducting regular resilience assessments of critical suppliers based on stock-keeping units. In contrast, DSCs, through shared quality and control data from suppliers, allow companies to address issues proactively without the need for labour-intensive preplanning.

Moreover, traditional supply chains involve humans making decisions based on machine inputs, while DSCs allow machines to drive decisions with human oversight. Traditional supply chains are linear, meaning that each step depends on the previous one. This can cause problems when a subassembly provider or shipper fails to perform as expected, resulting in delays and customer dissatisfaction. Digital supply chains, on the other hand, provide greater visibility into the process, enabling near real-time monitoring of supplier performance and customer needs. This transparency enables supply chain owners to develop more complex relationships with suppliers and to mitigate most disruption risks. Digital supply chains are more customer-centric and focus on achieving excellence in demand fulfilment across three key pillars: speed, personalisation and choice. The specific impact depends on the organisation's goals, but overall, DSCs integrate internal and external data – both structured and unstructured – facilitating two-way communication with suppliers and full visibility for all stakeholders. New technologies collect, monitor and analyse data to make real-time predictions and recommend actions. The differences between the traditional and DSC are summarised in Table 6.1.

TABLE 6.1: Differences between a digital and traditional supply chain.

Traditional model of the supply chain	Digital supply chain
Limited view of the supply chain	On the stage of preparation and implementation, flexibility and quick response are essential
When information passes through a whole section of a company, it is delayed. There is a lack of clarity across the whole chain, which makes meaningful communication difficult	Both supply chain partners have access to the same details at the same time
As info demand travels down the material path, the end user's need is blurred to the producer	The progress in partnership depth to capture the supply chain's importance
Delays and unsynchronised reactions at several levels owing to various planning phases	Flexibility and quick assessment of changes in consumer needs

Source: Compiled by David Pooe and Watson Munyanyi for this study (2026).

Advantages of digital supply chain

The digital supply chain model offers numerous benefits, including increased visibility and connectivity, supply chain sustainability, real-time tracking, better customer experiences and greater flexibility and agility.

Visibility and connectedness

The concept of complete supply chain visibility is not new, but in the context of a DSC, visibility equates to being connected. It is worth reflecting on how many of your supply chain partners you are digitally linked with and how many are involved in strategic planning collaborations. This connectivity should go beyond just material suppliers. Think more broadly, including logistics. Are your transportation providers integrated into your systems so that you can respond to disruptions and maintain timely deliveries? Consider your operational equipment as well. Are you leveraging IoT technologies to connect with manufacturers who can monitor asset conditions in real time, anticipate equipment failures and act preventively? Achieving this depth of connectedness is essential for full supply chain transparency. Yet, many organisations are only partially there. Significant efforts are still needed to link suppliers, logistics partners, equipment and other components across the entire supply chain. The upside is that the necessary technologies, such as IoT, predictive analytics, ML and cloud-based solutions, are already available to support this transformation and enhance business agility (Jenkins 2020).

Sustainability from multiple perspectives

Sustainability should be understood from both an environmental and a business perspective. While the urgency of climate change highlights the importance of environmental sustainability, companies often prioritise sustainable business growth to remain competitive. Fortunately, these two

aspects often go hand in hand. Reducing resource use and minimising waste leads to more efficient operations, which also reduces costs. Modern technologies enable innovative business models that support growth while reducing environmental impact (Böttcher et al. 2024). For instance, direct-to-consumer approaches eliminate the need for multiple distribution steps, lowering transportation emissions. Similarly, 3D printing allows production to be located closer to the end user, further reducing transport needs. Technologies such as predictive maintenance can extend asset life, while IoT and ML can improve energy efficiency across equipment fleets (Tanasuica & Roman 2024). A flexible DSC is essential for organisations looking to adopt and sustain these kinds of innovations.

Cost savings

The primary aim of a DSC is to generate insights that drive higher efficiency, eliminate waste and boost profitability. Organisations that embrace DSCs can allocate resources, personnel, assets and inventory more effectively where they are needed in real time (Tarannum & Hossain 2024). This agility enables them to address manufacturing and transportation risks proactively, resulting in cost reductions. When fully implemented, a DSC can deliver broad benefits, including savings in time, money and materials, while also helping lower environmental impact.

Real-time tracking

A complete deployment of DSC technologies would replace all paper use, eliminate all manual data entry and updates, and eliminate the need to request information by phone, for instance, because you would already have it at your fingertips (Ranjan, Chaudhari & Singh 2023). The deployment of electronic sensors and tracking capabilities will enable real-time tracking of product movement across all aspects of manufacturing, transportation and logistics processes that permeate any supply chain.

Flexibility

Digitising the supply chain offers the flexibility needed to create a truly demand-driven model. By leveraging real-time data on sales and consumer demand, businesses can make smarter, faster decisions about production and inventory (Nweje & Taiwo 2025). This allows them to concentrate resources on high-performing products while scaling back or discontinuing those with minimal demand, ultimately reducing waste and operational costs (Tarannum & Hossain 2024). In addition, this responsiveness improves customer satisfaction by ensuring popular items are always in stock. It also supports more agile marketing and supply strategies, allowing companies to adapt quickly to changing market trends and consumer behaviour.

Agility

A key advantage of technologies such as AI is the advanced automation they enable. Artificial intelligence-powered algorithms can identify and correct inefficiencies, enabling data-driven decisions to be made instantly without human intervention. This kind of intelligent automation enhances speed, accuracy and consistency across operations. In today's fast-paced and highly competitive business environment, such responsiveness is vital (Dalsaniya & Patel 2022). It empowers organisations to adapt quickly to changes, reduce operational bottlenecks and maintain a strong competitive edge. Moreover, automation through AI reduces the risk of human error, improves forecasting accuracy and allows employees to focus on more strategic, value-adding tasks rather than repetitive manual work. It also enables predictive capabilities, such as anticipating demand fluctuations, optimising inventory levels and addressing supply chain disruptions proactively (Attah, Ogunsola & Garba 2023). As businesses continue to embrace digital transformation, AI-driven automation will play a central role in driving efficiency, resilience and innovation across the supply chain.

Better customer experiences with digital supply chain

Total supply chain visibility, combined with a commitment to both environmental and business sustainability, plays a vital role in enhancing the overall customer experience. While it is often underestimated, visibility into the supply chain is critical for ensuring smooth, reliable service delivery. Any issues that arise after a customer has made a purchase, such as delays, damaged goods or lack of tracking, can undermine an otherwise positive interaction with your brand (Agrawal et al. 2024). Furthermore, a rigid or unresponsive supply chain can prevent companies from adapting to market trends, prompting customers to seek more agile competitors. Today's consumers also value innovation that supports sustainable growth. Whether it is a mobile app that streamlines service delivery, a subscription model that spreads costs and reduces waste, or an 'as-a-service' offering that provides access to ongoing production or specialised facilities without ownership, these business models align with modern expectations. Customers increasingly prefer solutions that are flexible, efficient and environmentally responsible – making supply chain innovation not just a back-end upgrade, but a front-line strategy for customer satisfaction (Al-Omoush et al. 2026).

Analysts acknowledge widely that the path to achieving the benefits of DSC is not straightforward. A Hinds (2019) report on Supply Chain 4.0 for McKinsey & Company suggests that for leaders to drive digital transformations effectively in their supply chains, they must combine

TABLE 6.2: Real-world examples of digital supply chain advantages.

Advantage	Example	Source
Visibility and connectedness	Maersk uses IoT-enabled smart containers to monitor the location, temperature and condition of cargo in real time, providing end-to-end visibility across its global shipping network.	Drozhzhyn (2024)
Sustainability (environmental and business)	Walmart Route Optimization system cuts millions of driver miles, reducing CO_2 emissions and improving logistics efficiency as part of broader sustainability goals.	Walmart (2024)
Cost savings	Oracle implementation in manufacturing, where IoT sensors enabled real-time monitoring of equipment performance, led to a reported 30% reduction in unplanned downtime and increased production efficiency.	Ayoub et al. (2025)
Real-time tracking	Walmart ambient IoT sensors on pallets (planned rollout across 4,600 stores) provide real-time tracking of inventory location, temperature, humidity and dwell time, reducing manual checks.	Nayak et al. (2024)
Flexibility	Zara RAIN RFID system tracks inventory across >2,000 stores globally every two hours, enabling flexible production and distribution decisions based on near-real-time stock data.	Wang (2017)
Agility	Hyundai Motor Group Metaplant integrates digital twins and AI robotics across factory operations, enabling rapid adaptation, real-time defect detection and swift quality response.	Lee (2024)
Customer experience	Companies such as Coca-Cola, DHL, FedEx and Amazon leverage IoT tracking and digital platforms that share delivery status with customers, improving service transparency and reliability.	Didwania, Verma and Dhanda (2024)

Key: IoT, Internet of Things; AI: artificial intelligence.
Source: Compiled by David Pooe and Watson Munyanyi for this study (2026).

traditional supply chain expertise with new technical skills, while also understanding how technological advancements support business objectives. Table 6.2 outlines the real world examples of digital supply chains. Information technology involvement is critical, but it is essential that all efforts are guided by functional knowledge and requirements. McKinsey & Company emphasise the importance of first ensuring strong performance in core supply chain functions, such as strategy review, demand and order management, forecasting, inventory management, production planning, supply chain planning, operational logistics and performance management, to identify areas for improvement. Building a DSC requires a holistic strategy that integrates organisational structure, operations, systems and physical assets, including processes like procurement and payments (Tanasuica & Roman 2024). In contrast, piecemeal efforts are likely to result in silos, redundant data and inefficiencies.

Digital supply chain strategy

Strategy

According to Ilkka (2014, p. 8), the notion of strategy stems from the Greek word *strategos*, meaning 'a general' and is a derivative of *stratos*, which refers to 'army' and 'to lead'. The concept of *strategos* meant both a military general himself and his skills of warfare, 'the art of the general'. Strategy is a well-defined roadmap of an organisation. It defines an organisation's mission, vision, goals, objectives and direction. The objective of a strategy is to maximise an organisation's strengths and to minimise the weaknesses of the competitors. A strategy can be understood as a guiding framework that helps a company and its components to reach a desired future state. It originates from a detailed strategic planning process that aligns organisational activities, and utilises and allocates limited resources efficiently to achieve current objectives. When formulating a strategy, it is crucial to recognise that decisions do not occur in isolation; any action taken by the organisation is likely to provoke a response from stakeholders such as competitors, customers, employees or suppliers (Narne et al. 2024). A strategy serves as a comprehensive roadmap for decision-making in an organisation, outlining its objectives and goals, streamlining key policies and detailing plans to achieve them. It also defines the nature of the business, the type of economic and human organisation the company aims to be, and the contributions it intends to make to its shareholders, customers and society at large.

Features of strategy

A strategy is crucial because it acknowledges the inherent uncertainty of the future. Given that perfect foresight is not possible, companies must be prepared to navigate the unpredictable events that shape the business environment. A strategy focuses on long-term developments rather than on day-to-day operations, addressing potential innovations, new products, production methods or markets that may emerge in the future. Moreover, it is designed to account for anticipated customer and competitor actions, with strategies related to employees also predicting their behaviour. In essence, a strategy involves allocating resources, establishing a distinct system of activities and pursuing specific goals. Ultimately, a strategy serves as the bridge between the organisation's current state and its desired future position.

Supply chain strategy

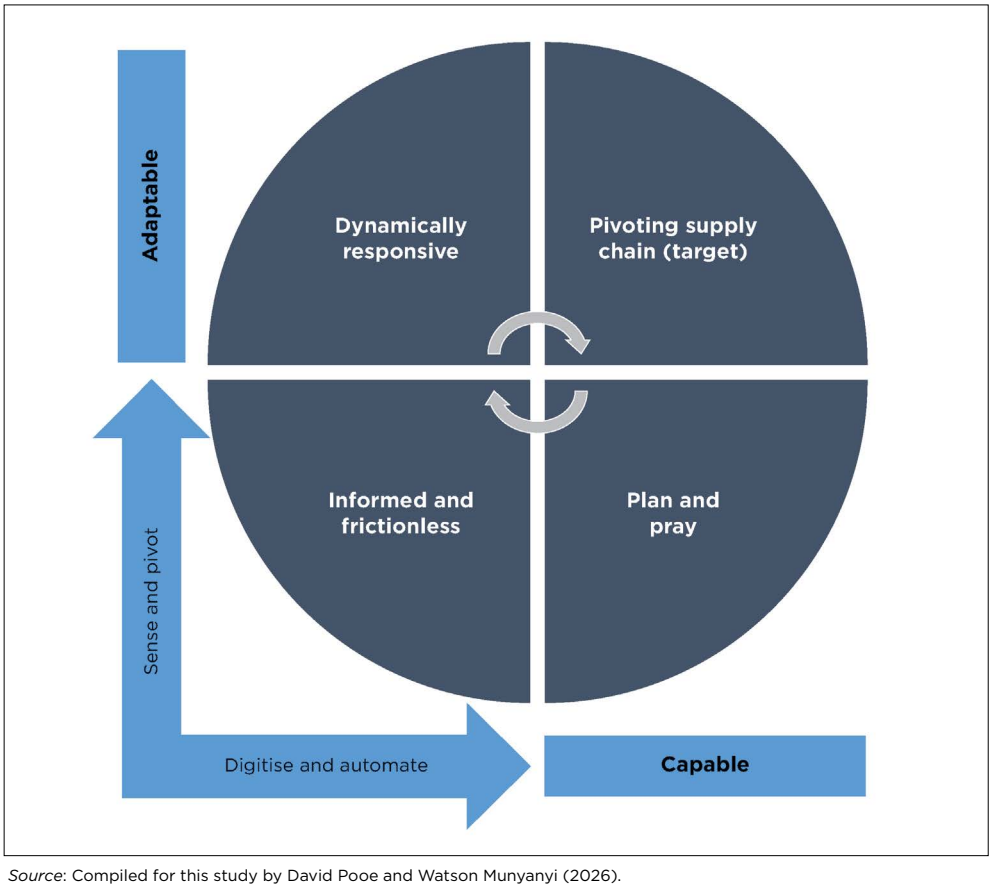
A supply chain strategy refers to a set of prioritised objectives and strategic priorities for SCM, along with the methods to implement and measure

them, aimed at leveraging logistics success factors to enhance overall business performance (Schnetzler, Sennheiser & Schönsleben 2007). It can be both a deliberate and an emergent process, serving as a conceptual framework that guides a company in involving its supply chain and stakeholders in efforts to achieve corporate strategic goals (Rose, Singh Mann & Rose 2012). For instance, a supply chain strategy may involve using IoT tools and advanced analytics to drive significant revenue growth, such as ZAR50 million within six months. A key question in such a strategy would be: how can we improve efficiency and decision-making across the supply chain? For example, a large consumer packaged-goods company, under constant pressure to deliver excellent customer service, identifies the need for substantial improvements in its supply chain network visibility. The existing, fragmented data systems of the company fail to link datasets, resulting in inconsistent reports that provide limited value for decision-making. Owing to a lack of accurate information, production or delivery problems are addressed by dispatching teams flown in expressly, a process that is both costly and slow. In this scenario, the key issue is how to access and analyse data quickly to enhance visibility, enable event management, foster cross-functional collaboration and support rapid root-cause analysis and predictive insights.

Digital supply chain strategy

The digital supply chain strategy, the well-defined roadmap of an organisation's DSC, is the new approach to operating a resilient and sustainable supply chain. Robinson (2020) notes that in the digital age of today, organisations face a changing demand curve and supply chain uncertainty. For operations teams, the challenge and ultimate competitive advantage have evolved to become: how well do we respond and execute against ongoing uncertainty? With the world so unpredictable, facing increased natural disasters, trade wars and pandemics, chaos is now the new normal. In the face of this upheaval, supply chains try to predict what will happen; then optimise performance against the plan. Most often, those plans are not met, and the path forward demands a bold leap in supply chain performance.

Chaos is the central challenge companies must contend with today. The demand pressure exerted on the supply chain is increasing exponentially, whereas supply chain performance used to be all about batch quantities, timetables and lead times. Times have changed, and presently, business transformation has become pertinent. As timetables and priorities are shifting constantly, suppliers are now finding themselves unable to deliver at the required time demanded by the market. In this upheaval, supply chains must respond accordingly. There have been attempts to predict what will happen with performance being optimised against the plan.



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 6.2: A digital supply chain strategy.

Companies are investing increasingly in supply chain capabilities. Yet, these have triggered non-productive finger-pointing and disappointing results; something is missing – a DSCS that befits the fast-paced digital era.

The digital supply chain strategy is the new approach to provide organisations with much-needed SCR amid numerous uncertainties, which alter demand patterns and, in turn, supply chains. It therefore ensures that supply chains are better informed, more frictionless, cost-efficient and capable of handling any demand changes (Robinson 2020). The digital supply chain strategy is best undertaken using a dual-prong approach, as shown in Figure 6.2.

Sense and pivot

In a DSCS, the concept of 'sense and pivot' emphasises the adaptability of supply chains to respond effectively to unforeseen events. By doing so,

organisations can enhance flexibility throughout their supply networks. This shift involves introducing new processes, governance models and ways of operating that capitalise on emerging technological advancements. Importantly, this approach enables planning, production, distribution and logistics functions to become more responsive to fluctuating demand, rising expectations for customised experiences and an increasingly unpredictable business landscape.

☐ Digitise and automate

The 'digitise and automate' strategy is another key pillar of DSC transformation, centred on enhancing the supply chain's ability to execute effectively against established plans. When implemented successfully, this approach leads to a more informed, streamlined, cost-effective and capable supply chain operation. By leveraging automation, advanced analytics and integrated digital platforms, organisations can reduce inefficiencies significantly, minimise manual intervention and enable real-time decision-making. This digital capability also facilitates better collaboration across internal functions and external partners by ensuring seamless data flow and visibility. As a result, inventory levels can be optimised, lead times shortened and disruptions managed proactively. In addition, with more accurate and timely data, businesses are better equipped to conduct strategic planning, supported by improved forecasting, scenario modelling and demand sensing. Over time, this creates a strong foundation for continuous improvement, agility and long-term competitive advantage.

■ Implementing digital supply chain strategy

Like any functional strategy, implementing the DSCS requires the organisation to follow the typical process for general strategy implementation. Implementing a DSCS still encompasses all the steps undertaken for a traditional supply chain. Strategy implementation refers to the process of putting plans and strategies into action to achieve an organisation's long-term objectives. In the context of a DSCS, it involves translating the chosen strategic direction into practical steps and initiatives across the organisation. In other words, it is the mechanism through which a company aligns and mobilises its structure, culture, resources, workforce and control systems to execute the strategy effectively. This alignment ensures that the organisation does not only follow through on its strategic vision but also gains a competitive advantage in the marketplace. Other definitions of strategy implementation are provided in Table 6.3. Implementing the DSC strategy is not the starting point; instead, it is the fourth stage of the strategic management

TABLE 6.3: Strategy implementation.

Author	Explanation
Aaker (2008)	The implementation stage involves converting strategic alternatives into an operating plan
Bonoma (1984)	Implementation is turning a drawing board strategy into a marketplace reality
Bryson and Bromiley (1993)	The implementation process is defined as a set of generic activities that occur across an entire problem-solving sequence
Cespedes (1991)	Implementation deals with organisational issues, the development of specific marketing programmes and the execution of programmes in the field
Flood et al. (2000)	Strategy implementation is the successful implementation of strategic decisions
Floyd and Wooldridge (1992)	Implementation is the managerial interventions that align organisational action with strategic intention
Hrebiniak and Joyce (1984)	Strategy implementation is a process by which large, complex and potentially unmanageable strategic problems are broken into smaller, manageable parts and addressed accordingly
Kotler (1984)	Implementation is the process that turns plans into action assignments and ensures that those assignments are executed
Laffan (1983)	During implementation, a policy decision must be detailed and resources allocated among programmes
Miller, Wilson and Hickson (2004)	Strategy implementation refers to all processes and outcomes once a strategic decision has been authorised and is ready for execution
Noble (1999)	Strategy implementation is the communication, interpretation, adoption and enactment of strategic plans
Nutt (1983, 1986)	Implementation is a set of steps by responsible organisational agents to effect planned change and put strategic decisions into action

Source: Compiled by David Pooe and Watson Munyanyi for this study (2026).

process, the other three being the determination of strategic mission, vision and objectives, environmental and organisational analysis, and formulating the strategy. Thereafter, strategy implementation is followed by strategic evaluation and control.

Determinants of strategy implementation

According to Holm, Kringelum and Anand (2026), several key prerequisites influence the long-term success of strategy implementation. These foundational elements serve as critical enablers in ensuring that a strategic plan can be brought to life effectively. At the core of successful implementation is the people factor – organisations must have not only a sufficient number of employees but also the right individuals with the necessary skills and competencies to carry out the strategy. Equally important are the financial and non-financial resources that support the

execution process. In addition, a well-defined organisational structure is essential. Clear lines of authority and accountability help to ensure that everyone understands their roles, responsibilities and reporting relationships. The systems and tools available in the organisation also play a vital role. These include the digital capabilities, processes and platforms that support day-to-day execution and enable teams to work efficiently and effectively. Finally, organisational culture must align with the strategic direction. Employees need to feel comfortable in their roles, have a strong grasp of the overarching goals of the company and feel aligned with the brand's values and mission. When these elements are in place, organisations are better positioned to translate strategic plans into meaningful action and sustained results.

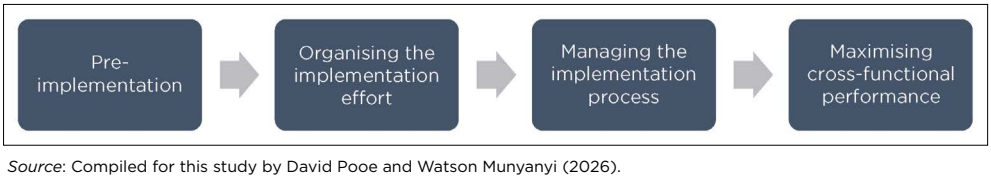
Process of strategy implementation

The diagnostic framework of strategy implementation has six levers of strategy implementation: organisation structure, control and information systems, reward systems, selection and socialisation, power and politics and organisation culture (Ilkka 2014). Strategy implementation communicates a willingness to overcome the barriers between the content and process paradigms, which consist of five managerial levers of strategy implementation: goals, organisational structure, leadership, communications and incentives. The model by Ilkka (2014) is centred on four major stages: pre-implementation, organising the effort, the ongoing management of the process and maximising cross-functional performance.

The process of strategy implementation builds on the strategy implementation model and involves the following steps.

Step 1: Establishing a structure that supports strategic execution

Before an organisation can implement a strategy successfully, it must first ensure that the right structural foundations are in place, as shown in Figure 6.3. This means defining clearly how various segments of the



Source: Compiled for this study by David Pooe and Watson Munyanyi (2026).
FIGURE 6.3: Strategy implementation model.

organisation connect and interact. Transparent roles, responsibilities and departmental relationships are essential. Moreover, cultivating a healthy organisational climate is key – this includes fostering collaboration, developing personnel and nurturing a strong sense of commitment and efficiency. Only when leaders and employees are aligned and driven can strategic goals be translated effectively into results.

Step 2: Allocating key resources to strategic priorities

To bring a strategy to life, the necessary tools, systems or platforms must be in place. This often includes investing in relevant software or infrastructure. In addition, providing staff with the appropriate training and upskilling opportunities is crucial. Strategy implementation depends heavily on resource availability, ensuring that teams are equipped to adopt new methods or technologies seamlessly.

Step 3: Crafting policies that reinforce strategy

As strategies are rolled out, supportive policies must follow. These guidelines provide teams with clear behavioural expectations aligned with the organisation's new direction. For example, if enhancing customer experience is part of the strategy, a policy could encourage employees to seek customer feedback consistently. Such tailored policies help to translate strategic intent into everyday actions.

Step 4: Implementing adaptive programmes for ongoing growth

Strategies must remain flexible to accommodate real-time needs. This calls for dynamic leadership capable of introducing relevant programmes or making policy shifts as required. Feedback loops and ongoing communication are essential to refine and enhance strategy execution. The ability to respond to changing conditions helps to sustain momentum and relevance.

Step 5: Leveraging rewards to drive desired outcomes

Strategic implementation often benefits from a well-designed incentive system. Recognising and rewarding behaviours that support the strategy can foster motivation and alignment. Rewards might range from public

acknowledgement to tangible benefits, and they help to reinforce the value of the strategy. Regularly sharing success stories linked to the strategy also boosts morale and engagement across the organisation.

Step 6: Conducting routine reviews of strategic progress

Implementation is not a one-time effort – it is an ongoing journey. Strategies should be assessed at intervals to determine their continued relevance and effectiveness. As internal or external circumstances evolve, strategies might need to be adjusted or, in some cases, rethought completely. A flexible approach allows organisations to remain responsive and resilient. Leaders should ask critical questions continually, such as: are adjustments necessary? Have our goals shifted? Such reflective practices are vital for sustaining long-term success. Table 6.4 shows the strategy implementation process.

Even the best-crafted strategies can fall short without proper implementation. It is also crucial to recognise that successful execution depends on aligning the strategy with key organisational elements, such as resource allocation, structure, work environment, culture, processes and reward systems. Only when these components are in harmony can effective strategy implementation truly be achieved.

TABLE 6.4: Strategy implementation process.

Stage	Implementation type	Purpose
Achieving strategies	Project implementation	To execute specific projects aligned with the strategy
	Procedural implementation	To implement structured processes and policies
	Resource allocation	To allocate necessary financial and non-financial resources
Managing change	Structural implementation	To align organisational structure with the strategy
	Leadership implementation	To guide and support change through leadership efforts
Achieving effectiveness	Functional implementation	To ensure that each department functions in alignment with strategic goals
	Operational implementation	To carry out daily operations effectively in support of the strategy
Evaluation and control	-	To monitor progress and provide feedback for continuous improvement

Source: Compiled by David Pooe and Watson Munyanyi for this study (2026).

Drivers of digital supply chain strategy implementation

The digital supply chain strategy implementation journey is about treading uncharted and unfamiliar territory. It is fraught with numerous questions, challenges and lessons. Research results from a study by Granà et al. (2023) on Capgemini strategy implementation indicate that successfully scaled DSCS implementation initiatives evolve in the following three areas.

Advocate and align

Ensure the DSCS implementation efforts are driven by the C-suite leadership and senior management. Supply chain digitisation is a complex process that spans planning, procurement, IT and human resources, and as such, it cannot be led solely by any one business unit; rather, the implementation process must be driven from the top to succeed. Leadership needs to advocate this transformation and provide a strategic focus on objectives and priorities. Similarly, implementing a DSCS is fundamental to achieving business objectives and must also be aligned with wider efforts; for example, to increase transparency and improve customer satisfaction so that the DSCS is not considered solely to be a cost-cutting exercise.

Build

For DSCS implementation to be successful, both upstream and downstream partners, such as suppliers and distributors and/or logistics providers, need to be brought in and made part of the digitisation efforts. Breaking the silos among the various supply chain functions, as well as the technology teams, is also critical to the success of DSCS implementation initiatives.

Enable

While the components discussed help in implementing the DSCS effectively, on the other hand, in order to sustain it, organisations also need to invest in key areas of building a customer-centric mindset and developing a talent base. Lack of awareness or the required skills are major barriers to successful implementation. There is a dire need for an organisation to conduct a realistic gap analysis between existing skills and those required to make progress throughout the implementation process. To this end, human resources management needs to devise approaches to attract, retain and upskill its employees effectively. Despite the benefits of a DSC, there are a few common challenges that come with implementing a digital strategy. It can be plagued by rivalry among subsidiaries, poor communication and a lack of understanding of overall aims, direction and support. Carpo (2023)

notes that numerous companies can remain stuck in mismatched legacy and analogue, or even pen-and-paper systems, whose history of minor, incremental improvements cannot keep pace with current digital business operations. Employee and supplier aversion to change, institutional knowledge gaps and unwillingness to turn over supply chain control to perceived 'robot masters' are common hurdles in the early DSC (SpendEdge 2018).

Managing the digital supply chain

A DSC comprises software applications, network systems and data integration that link customers to the technological infrastructure supporting e-commerce. Unlike traditional supply chains, which involve the movement of physical goods and raw materials between manufacturers, suppliers and retailers, the DSC focuses on virtual processes (Khojasteh, Mousavi Jahan Abadi & Ng 2026). As more business operations transition to cloud-based platforms, managing the DSC effectively becomes essential for driving revenue growth, controlling operational costs and safeguarding brand reputation.

Optimising integrated planning process

Optimising the integrated planning process in a DSC network is a complex task, largely because many organisations fail to utilise available data fully to achieve optimal planning outcomes. A common issue is that planners often override statistical forecasts or predefined plans with manual inputs, undermining the accuracy and efficiency of the process. To ensure that a DSC delivers the best possible results, there must be alignment in organisational structures, high-level integrated process optimisation, well-defined workflows, governance mechanisms and incentive systems – both internally and among external partners in the supply chain (Ageron, Bentahar & Gunasekaran 2020).

Building a balanced roadmap

Adopting a new market strategy that leverages a DSC network to drive growth can disrupt an organisation's existing, highly specialised supply chain. As a result, it is vital for management to ensure that the new supply chain design balances conflicting priorities while enabling seamless integration of innovative business models (Ahmed Khan et al. 2021). A well-structured, balanced roadmap can facilitate early achievements and provide the agility needed to adapt to emerging technologies and evolving future requirements.

Conclusion

Digital technologies are increasingly reshaping traditional supply chain frameworks, transforming them into collaborative, digitally integrated models that boost agility, visibility, flexibility and overall efficiency. A connected supply chain strengthens business process automation, enhancing security while also accelerating innovation and reducing operational costs. To capitalise fully on the benefits of DSC models, organisations must develop a comprehensive DSCS and embed it into their core business model and organisational structure (Byrne 2022). The goal of DSC implementation is therefore to ensure that the intended transformation practices are actioned collectively and expeditiously across the organisation and that the expected outcomes are achieved. An understanding of the most relevant factors, challenges and their solutions for effective strategy implementation is therefore of interest to both academics and practitioners. This chapter highlighted that, notwithstanding, DSCS implementation requires constant provision of administrative support, organisational leadership, employee buy-in and technical and fiscal support. Most importantly, to be effective, the DSCS implementation process involves continuous real-time data reviews, communication of these reviews and organisational flexibility to effect changes promptly as needed. Successful implementation of a DSC strategy requires strategic vision, organisational alignment and continuous adaptation. By managing the implementation process effectively and harnessing the drivers of digitalisation, SMEs can unlock transformative benefits and position themselves for long-term success in a digitally driven marketplace.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and W Munyanyi; *methodology* (*desktop-based literature review and conceptual synthesis*), D Pooe and W Munyanyi; *validation*, D Pooe and W Munyanyi; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and W Munyanyi; *resources*, D Pooe; *writing – original draft preparation*, D Pooe; *writing – review and editing*, W Munyanyi and D Pooe; *visualisation*, W Munyanyi; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 7

Pandemics, Industry 4.0 adoption and supply chain resilience of small and medium enterprises

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic has highlighted the critical need for supply chain resilience (SCR) and accelerated the adoption of Fourth Industrial Revolution (4IR) technologies by small and medium

How to cite: Munongo, S & Masakale, D 2026, 'Pandemics, Industry 4.0 adoption and supply chain resilience of small and medium enterprises', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 151–178. https://doi.org/10.4102/aosis.2026.BK572.07

enterprises (SMEs). Nevertheless, the emergence and spread of infectious diseases with pandemic potential have been a recurring phenomenon throughout history, significantly impacting the operations of SMEs (Takawira, Pooe & Samuels 2024). Humanity has already been afflicted by major pandemics and epidemics, including plagues, cholera, influenza, severe acute respiratory syndrome coronavirus (SARS-CoV) and Middle East respiratory syndrome coronavirus (MERS-CoV). Presently, the world is still battling the aftermath of the COVID-19 pandemic, which has had unprecedented adverse economic, social and health effects worldwide. The 24 months of disruption caused by the disease have shown the world what chief supply chain officers (CSCOs) have long known, namely that agile and resilient supply chains are key enablers of commerce and are essential for organisations that want to leapfrog their competition. Supply chain organisations cannot afford to let disruptions limit their effect, given that disruptions will always occur, whether from natural disasters, resource shortages, global trade conflicts or other inevitable yet unpredictable events. Despite their importance, SMEs are more susceptible to failure owing to resource constraints, leading to weaker resilience. Accordingly, addressing the COVID-19 pandemic does not only require protecting SMEs and supporting entrepreneurship, but also fostering innovative, productive entrepreneurship and resilient supply chain ecosystems that leverage 4IR technology. While the pandemic presented an unprecedented challenge for SMEs, it has also opened new market opportunities and created resilient supply chain prospects. While the pandemic was an unparalleled challenge for SMEs, it also ushered in new market and resilient supply chain opportunities. This chapter, therefore, examines the impact of pandemics on supply chains over time, various government response measures, their effectiveness and the role of 4IR technologies in enhancing SME resilience.

History of pandemics and effects

The transition from hunter-gatherer to agrarian societies over time contributed to the spread of infectious diseases across the global human population (Dobson & Carper 1996). Piret and Boivin (2021) report that the increased trade between communities heightened interactions between humans and animals, enabling the spread of deadly diseases. Subsequently, the growth of cities, expansion of trade networks, increased travel and the impact on ecosystems caused by a rising human population amplified the emergence and spread of infectious diseases, increasing the risk of outbreaks, epidemics and even pandemics (Khorram-Manesh, Burkle & Goniewicz 2024). Grennan (2019) describes the terms endemic, outbreak, epidemic and pandemic as referring to the occurrence of a health condition relative to its expected rate and geographical spread. From a granular perspective, an endemic is a health condition that occurs at a consistent and

expected rate within a specific population. In contrast, Vögele, Rittershaus and Schuler (2021) refer to an outbreak as an unpredictable increase in the number of people presenting with a health condition or in the number of cases in a new area. Conversely, an epidemic is an outbreak that extends across broader geographic regions, whereas a pandemic is an epidemic that spreads worldwide (Kaur et al. 2020; Stefański 2022). Table 7.1 shows the history of global pandemics.

Epidemics and pandemics leave a lasting impact on both the economy and society. For example, during the early 1830s, cholera affected France and other parts of central Europe severely. Hospitals were overwhelmed with patients suffering from mysterious illnesses that baffled doctors (Kaur et al. 2020; O'Sullivan 2021). The *Economist* (2021) reports that while the epidemic wiped out at least 3% of Parisians in the first month, it would contribute to an industrial revolution in France. Moreover, it increased political instability and social disparities, with the city's poor hit hardest by the pandemic. At the same time, the wealthier used their savings and resources to relocate from pandemic-affected towns and reduce their interactions with the community. Thereafter, the Spanish flu swept through much of Europe and the United States in 1918. The pandemic infected an estimated 500 million people, roughly one-third of the global population at the time, resulting in the deaths of 20–50 million individuals over four

TABLE 7.1: History of global pandemics.

Years	Pandemics	Pathogens	Vectors
541–543	Plague of Justinian	*Yersinia pestis*	Fleas associated with wild rodents
1347–1351	Black Death	*Yersinia pestis*	Fleas associated with wild rodents
1817–1824	First cholera pandemic	*Vibrio cholerae*	Contaminated water
1827–1835	Second cholera pandemic	*Vibrio cholerae*	Contaminated water
1839–1856	Third cholera pandemic	*Vibrio cholerae*	Contaminated water
1863–1875	Fourth cholera pandemic	*Vibrio cholerae*	Contaminated water
1881–1886	Fifth cholera pandemic	*Vibrio cholerae*	Contaminated water
1885–ongoing	Third plague	*Yersinia pestis*	Fleas associated with wild rodents
1889–1893	Russian flu	*Influenza A/H3N8?*	Avian?
1899–1923	Sixth cholera pandemic	*Vibrio cholerae*	Contaminated water
1918–1919	Spanish flu	*Influenza A/H1N1*	Avian
1957–1959	Asian flu	*Influenza A/H2N2*	Avian
1961–ongoing	Seventh cholera pandemic	*Vibrio cholerae*	Contaminated water
1968–1970	Hong Kong flu	*Influenza A/H3N2*	Avian
2002–2003	Severe acute respiratory syndrome	*SARS-CoV*	Bats, palm civets
2009–2010	Swine flu	*Influenza A/H1N1*	Pigs
2015–ongoing	Middle East respiratory syndrome	*MERS-CoV*	Bats, dromedary camels
2019–ongoing	Coronavirus disease 2019	*SARS-CoV-2*	Bats, pangolins?

Key: SARS-CoV, severe acute respiratory syndrome coronavirus.
Source: Piret, J and Boivin, G (2021). 'Pandemics throughout history' *Frontiers in Microbiology*, vol. 11, 631736. Creative Commons Attribution 4.0 International (CC BY 4.0).

consecutive waves (Vögele, Rittershaus & Schuler 2021). As a result, Beach, Clay and Saavedra (2020) found that businesses in Europe and the US were forced to shut down owing to so many employees being sick. Notwithstanding the socioeconomic losses incurred, some studies indicate that the Spanish flu pandemic gave rise to new businesses, with start-ups booming from 1919 onwards, in the middle of the pandemic.

Acquired immunodeficiency syndrome (AIDS), first identified in 1981, represents another pandemic with an extraordinary global economic impact. Since its emergence, the human immunodeficiency virus (HIV) has affected over 65 million individuals worldwide (Aborode et al. 2021; Eisinger & Fauci 2018). Although no cure has been discovered for this sexually transmitted disease, treatments are available to manage the virus, enabling individuals to live longer lives. Beyrer (2021) submits that developing countries, particularly low-income nations in Africa, have been heavily impacted as many economically active adults have succumbed to the illness. Furthermore, Africa has been plagued continuously by the Ebola virus since 1976, with the most prominent wave taking place during the period 2014–2016 in West Africa (Izudi & Bajunirwe 2024). Consequently, the Ebola outbreak led to restrictions on trade and transportation to prevent transmission of the virus in Sierra Leone, Liberia and the Republic of Guinea. This resulted in restricted and postponed movement of essential goods and individuals between countries. For example, Bedson et al. (2020) report that, in 2014, Sierra Leone implemented a three-day lockdown to reduce people's movement, allowing health care workers to detect new cases and raise awareness about the disease. The country also imposed quarantine measures on high-risk regions and enforced curfews, some of which lasted for several months in certain areas. As a result, circumstances such as these have a detrimental effect on economies that rely heavily on cross-border trade. According to Park, Lim and Murali (2022), informal cross-border trade accounts for 30–40% of total trade volume in Eastern and Southern Africa. The Ebola epidemic disrupted agricultural market chains significantly in three West African nations, especially affecting communities whose primary source of income is agriculture (Dramé, Ferrinho & Martins 2021; Liu 2022).

Coronavirus disease 2019 pandemic and effects

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is responsible for COVID-19, with the initial symptoms officially reported in Wuhan, China, in December 2019, followed by a widespread outbreak in 2020 (Thukral 2021). As noted by Downing (2020), on 11 March 2020, the World Health Organization declared COVID-19 a pandemic, reporting 118,319 cases across 114 countries and 4,292 global fatalities.

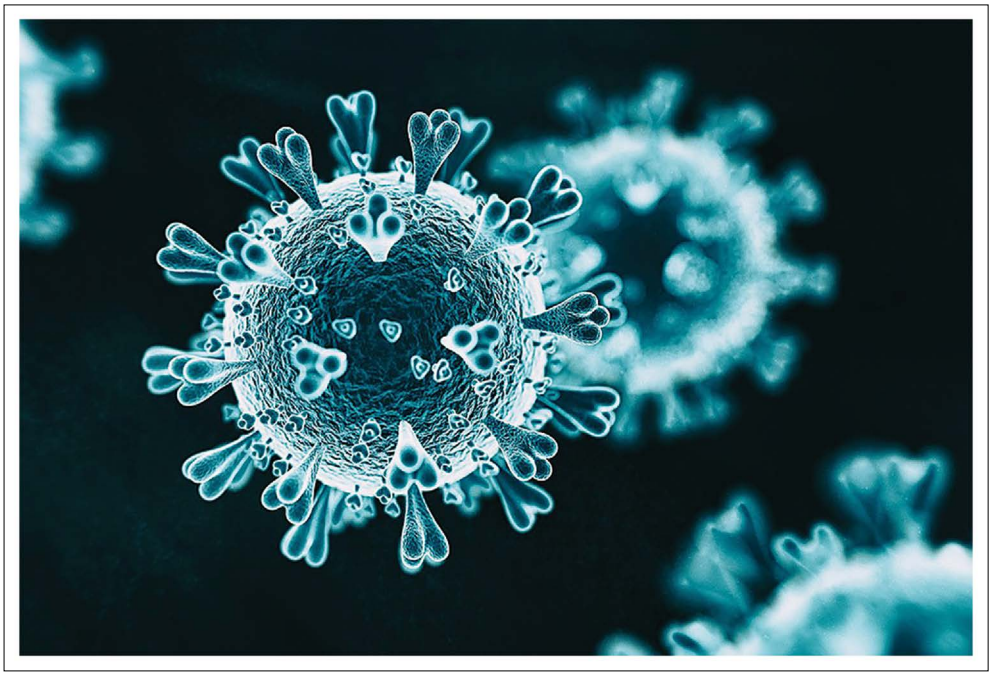
On 27 March 2020, the International Monetary Fund, as referenced by the United Nations Development Programme (UNDP Regional Bureau for Asia and the Pacific 2020, p. 2), declared that 'the world is now in recession', emphasising that the 'duration and severity of this recession depend on two factors: controlling the virus and implementing an effective, coordinated response to the crisis'. The COVID-19 pandemic has led to both a health and economic crisis, presenting numerous challenges for SMEs and global supply chains (Clemente-Suárez et al. 2021; Thukral 2021). It has also driven substantial changes in societal behaviour, as the virus continues to impose high human costs globally. With no cure in sight, measures such as social distancing and self-isolation became the 'new normal' to prevent the spread of the virus and to mitigate its effects (Ratten 2020).

Lockdowns

The coronavirus disease 2019 pandemic disrupted businesses worldwide significantly, owing to full or partial lockdowns and social distancing protocols, which are critical for controlling the spread of the virus. Industries that depend on social interaction, such as sports, travel, tourism, hospitality and manufacturing, were particularly affected (Susskind & Vines 2020). The pandemic led to workplace closures, disrupted supply chains and reduced production. Factors such as income loss, layoffs and the fear of infection contributed to decreased consumer spending, which, in turn, led to more job losses and business shutdowns (Borio 2020; Thukral 2021).

The coronavirus disease 2019 lockdown halted manufacturing units as the virus originated in China, home to many factories that supply goods to various countries. According to the United Nations Conference on Trade and Development (2020), the COVID-19 outbreak was projected to result in a global decline in foreign direct investment (FDI) by 5–15% owing to factory closures and reduced production. Some SMEs that rely on suppliers from countries with higher COVID-19 case numbers became severely vulnerable. However, in the second quarter of 2020, as shipments began moving from China, other challenges such as air and ocean freight disruptions – caused by flight shortages, container imbalances and rising freight rates – began to affect SME supply chains (Organisation for Economic Co-operation and Development [OECD] 2020). The coronavirus disease 2019 virus is shown in Figure 7.1.

The coronavirus disease 2019 pandemic posed an unparalleled challenge in several ways, with one of the most significant being the threat it posed to the lives of millions globally. As of June 2021, the World Health Organization (2021) reported that the global death toll stood at almost four million people. Meanwhile, the social distancing measures implemented to curb COVID-19 had a significant impact on the service sector, particularly since it often



Source: GOV.UK (2020). Coronavirus (COVID-19) – Updates and changes to services. <https://www.gov.uk/government/news/corona-virus-covid-19-updates-and-changes-to-services> Creative Commons Attribution 4.0 International (CC BY 4.0).

FIGURE 7.1: The coronavirus disease 2019 virus.

requires physical proximity. In addition, the service sector relies more on micro- and small-sized businesses than the manufacturing industry. The possible effects on SMEs included but were not confined to business closures, shorter operating hours, workforce reductions, disruptions in supply chains, hindrances to research and development activities, cessation of operations, alterations in business models, loss of important customers and limitations on products or services. As a result, COVID-19 had a greater direct effect on self-employed individuals than on salaried workers (Kritikos, Graeber & Seebauer 2020), and on small businesses more than on large corporations worldwide.

Effect on small and medium enterprises globally

The global pandemic has exacerbated an already dire situation for SMEs, especially for those from developing economies. Studies indicate that, before the COVID-19 pandemic, many SMEs faced difficulties such as limited finances, limited access to global markets and technological ineptness. In contrast to large enterprises, Munongo and Pooe (2022) found that SMEs were more vulnerable to the economic effects of the COVID-19 pandemic owing to their limited resources. They typically possess fewer assets, smaller cash reserves and lower productivity levels.

However, it should also be noted that, given their diversity, the severity of the pandemic impact on these SMEs varies significantly, depending on the economic sectors in which they trade.

The small and medium enterprises most affected by COVID-19 were primarily from the retail, hospitality, food services, entertainment and construction sectors (Munongo & Pooe 2022). A study by the National Bureau of Economic Research involving over 5,800 small businesses in the United States of America, reported by Bartik et al. (2020), found that 43% of these businesses were expected to close by December 2020. Panda et al. (2024) found that nearly all SMEs were affected by the COVID-19 pandemic, with an average decline of 20% in sales and 16% in customer base. Furthermore, the study highlighted that the journey of SMEs through the pandemic was a multifaceted and evolving process, involving various input factors, immediate outcomes, systemic outcomes, navigation strategies and the policy landscape.

The shocks caused by COVID-19 have negatively impacted SMEs worldwide across four main areas: demand, supply, financial stability and uncertainty. Subsequently, demand has declined in most industry sectors, driven by low consumer confidence, job layoffs and consumers prioritising essential items while postponing non-essential purchases (Cruz et al. 2020). The coronavirus disease 2019 pandemic led to reduced consumer spending on services such as travel, entertainment and dining, while demand from other businesses also declined, resulting in lower exports owing to disruptions in essential supply chains. On the supply side, Munongo and Pooe (2022) reported that COVID-19 reduced labour availability, leading SMEs to scale back production or face temporary closures. In addition, employees have been affected by the pandemic through illness and travel restrictions. Moreover, the study found that employee productivity decreased as workers struggled to adjust to new, shorter business hours and remote work arrangements. As a result, businesses faced underutilised capacity, with no clear timeline for a return to normalcy owing to ongoing uncertainties about the development of a cure for the virus.

The pandemic's restrictions on the movement of people and the movement of non-essential goods disrupted vital supply chains severely, resulting in significant shortages of raw materials. The coronavirus disease 2019 outbreak in major raw material-producing Asian states, including China, Japan and India, hindered the global flow of raw materials, disrupting international trade (Hayakawa & Mukunoki 2021). In addition, Asia's reduced production capacities further diminished global value chains for both raw materials and finished products. Similarly, Wei, Jin and Xu (2021) indicate that industries such as automotive and pharmaceuticals were among the hardest hit by supply chain disruptions,

primarily owing to their reliance on a single source for most of their needs. These global disruptions led to extended product cycles and increased financial liabilities for SMEs. In addition, reports highlighted that SMEs faced significant supply chain bottlenecks, severely affecting more than half of their production capacity.

In addition, the COVID-19 pandemic has affected the financial resilience of global SMEs. This is a result of their financial fragility; the acute shortage of financial reserves to draw upon to meet fixed overheads during the pandemic (Erdiaw-Kwasie et al. 2023). Consequently, financial fragility has led to inadequate working capital, inability to meet loan and operating obligations timeously, rushed business liquidations to avoid incurring further debts and widespread debt defaults. According to Munongo and Pooe (2022), the health protocols implemented to curb the COVID-19 pandemic reduced demand for non-essential goods and services, causing a drop in sales and cash flow for SMEs. Even more concerning, subsequent financial instability compelled many SMEs to lay off employees, leading to higher unemployment rates and contributing to both household and global poverty. Indeed, the pandemic led to business uncertainty owing to lower investments and reduced global funding for new start-ups. For instance, Thomas (2020) found that the unemployment rate in the United Kingdom (UK) reached its highest level since 2017 owing to the ongoing impact of the COVID-19 pandemic. In the long run, the COVID-19 pandemic is expected to serve as a cleansing mechanism and a significant reallocation shock for companies across sizes and industries (Gorecka 2023).

Effect on small and medium enterprises in South Africa

While all SMEs worldwide were affected by COVID-19, those in developing economies were the hardest hit, as they already faced significant operational challenges before the pandemic. The majority of developing economies are poor, landlocked countries with severe economic and regulatory challenges and a much higher cost of doing business (World Trade Organisation 2020). As for the South African SMEs, McKinsey & Company (2020) reported that, while already grappling with a shrinking economy downgraded to 'Junk' status, the additional shocks from COVID-19 further strained their organisational operations.

In addition, Mosiane et al. (2021) highlighted that the implementation of COVID-19 containment measures caused substantial supply chain disruptions, widespread job losses, reduced industrial output owing to shorter working hours, sharp declines in revenues driven by decreased demand for non-essential goods and services, and compelled many SMEs to scale back business expenditures in order to stay afloat.

Moreover, sectors worst affected by the COVID-19 pandemic in the country included the services sector (for instance, private accounting and legal firms), tourism, hospitality and retail. Although these are among the fastest-growing SME sectors in South Africa, the majority of these businesses were unable to operate during the national lockdown, and their activities continued to be restricted even as the lockdown eased.

Not surprisingly, business disruptions attached thereto signalled a significant decline in revenues and profitability for the SMEs. The pandemic further eroded business confidence among South African SMEs. In a brief survey conducted by McKinsey & Company in 2020, over 55,000 SMEs were projected not to survive the pandemic owing to low resilience. Just over a third of the businesses surveyed expressed pessimism about the economy and its outlook, while more than 30% anticipated a revenue decline of between 5 and 50% over the next 6 to 12 months, leading to negative profits exceeding 5%. Furthermore, growing global concerns suggest that the long-term effects of the COVID-19 pandemic may exacerbate inequality among SMEs in at least two ways. Firstly, studies found that female SME owners faced a 35% higher likelihood of income losses compared to their male counterparts, largely owing to the overrepresentation of women in industries affected disproportionately by the pandemic (Graeber, Kritikos & Seebauer 2021; Rahayu & Ellyanawati 2023). Secondly, the consequences of the pandemic may be more severe for minority populations in both developed and developing countries (Li et al. 2021). As a result, Munongo and Pooe (2022) argued that these SMEs have experienced reduced flexibility in managing the opportunity costs associated with business uncertainty, thereby making their survival during the COVID-19 pandemic more challenging.

Government's response to coronavirus disease 2019 pandemic

Governments worldwide implemented a range of support initiatives in response to the COVID-19 pandemic. In the United States of America, the Paycheck Protection Program was the largest initiative supporting small businesses, allocating US$650 billion during the early phase of the pandemic (Bhutta et al. 2020). Administered by the Small Business Administration, this programme facilitated loans through banks, credit unions and other financial institutions to help small businesses remain operational and retain employees on their payrolls (Fairlie et al. 2023). Likewise, the UK government implemented the Coronavirus Job Retention Scheme, popularly called 'the Furlough' scheme for waged workers. This scheme covered 80% of employees' salaries, up to a maximum of GB£2,500 per month. More than 8.7 million jobs were furloughed at an estimated total cost of about GB£60 billion (Yue & Cowling 2021). After initially ignoring the 4.6 million

self-employed, the UK government announced the Self-Employment Income Support Scheme, which awarded grants of 70% of average monthly trading profits calculated from tax returns for 2018 and 2019. This scheme applied only to self-employed individuals who earned less than GB£50,000 in profit for the relevant period. In Germany, the government-backed measures aimed at protecting businesses and start-ups affected by the COVID-19 crisis included tax relief, state-supported short-time work compensation schemes, enhanced provisions at guarantee banks, loans and special programmes offered by Kreditanstalt für Wiederaufbau (PwC 2020), as well as emergency aid providing one-time lump sum payments to self-employed individuals experiencing significant revenue losses.

In response to the COVID-19 pandemic, tralac.org (2020) reported that the South African government introduced a ZAR500 billion social and economic support package, equivalent to approximately 10% of the country's gross domestic product (GDP). This initiative focused on three key areas:

1. Reallocating resources to strengthen the health care response to the coronavirus
2. Offering direct support to households and individuals to alleviate hunger and social distress
3. Assisting struggling businesses while safeguarding jobs by supporting the wages of workers.

Furthermore, CNBC Africa (2020) reported that the South African government, through the Department of Small Business Development, implemented three intervention measures to support affected small, micro and medium enterprises (SMMEs). These initiatives included:

1. Business Growth and Resilience Facility
2. Small, Micro and Medium Enterprises Relief Finance Scheme
3. Small Enterprise Finance Agency (SEFA) Debt Restructuring Facility.

The Business Growth and Resilience Facility was initially designed for SMMEs engaged in the local manufacturing or supply of hygiene and medical products needed to help control and manage the spread of COVID-19. This facility provided financial support in the form of working capital, stock, bridging finance, order finance and equipment finance, with funding amounts tailored to each business's specific needs. The SMME Relief Finance Facility provided soft-loan funding to existing businesses struggling owing to the effects of the COVID-19 pandemic (Thukral 2021). The relief was originally scheduled for a 6-month period starting from 01 April 2020. However, CNBC Africa (2020) found that, in cases where SMMEs needed support beyond the initial six months, the terms were extended to meet their requirements. In addition, specialised financing facilities were established for the informal sector, including spaza shops

and self-employed individuals. The report specified further that a crucial requirement for eligibility for the Business Growth and Resilience Facility and the SMME Relief Finance Scheme was that the enterprises should be 100% South African-owned, employ at least 70% local staff, and be registered and compliant with the South African Revenue Service. If an SMME was found to be non-compliant, they were supported in meeting compliance requirements before their applications could be reviewed. In addition, the SEFA Debt Restructuring Facility targeted SEFA-funded SMMEs affected negatively by the pandemic. Eligible SMMEs were granted a payment moratorium or holiday of up to six months to reduce their loan obligations (Kavuro 2021). However, these SMMEs had to demonstrate a direct link between their business challenges and the COVID-19 pandemic (CNBC Africa 2020).

However, Belitski et al. (2022) warn that, although national governments have implemented fiscal and administrative measures to mitigate the impact of COVID-19, such as addressing declines in employment and demand, it appears unlikely that these actions will be sufficient to restore pre-pandemic SME operations fully or to build their resilience. They contend that addressing COVID-19 effectively demands both top-down and bottom-up strategies. For instance, there is currently a pressing need for collaborative and complementary initiatives between the government and private sector, focusing their support on thriving entrepreneurs rather than on struggling industries and failing companies (Amah & Ogah 2023; Sawang 2023).

Supply chain resilience of small and medium enterprises

Despite growing focus on SCR amid heightened vulnerability of SMEs to disruptions in the global supply chain, there is still no universally agreed-upon set of determinants. The United Nations International Strategy for Disaster Reduction (2009) cited in Ginige, Amaratunga and Haigh (2009) defines resilience as:

> [...] the capacity of a system, community or society exposed to hazards to withstand, absorb, adapt to and recover from the impacts of a hazard promptly and effectively, which includes maintaining and restoring its core structures and functions. (p. 2)

Moreover, Bernstein et al. (2008) in the Intergovernmental Panel on Climate define resilience as:

> [...] the ability of a social or ecological system to absorb disturbances while maintaining its fundamental structure and functioning, along with the capacity for self-organisation and the ability to adapt to stress and change. (p. 96)

While the latter definition focuses on the capacity of a system to absorb disturbances, the former definition does not only recognise the occurrence of disruptions but also emphasises the system's ability to recover from them (Ginige, Amaratunga & Haigh 2009).

The concept of organisational resilience is not new; an organisation's capacity to face the unexpected effectively has always been a key factor in its success. However, with the increasing number, variety and intensity of threats that can disrupt a supply chain, resilience has become even more crucial in supply chain management (SCM) (Sheffi 2020). Ponis and Koronis (2021, p. 925) in Munongo and Pooe (2022) describe SCR as the capacity to plan and design the supply chain network strategically to anticipate unforeseen disruptive (negative) events, respond adaptively to these disruptions while maintaining operational control and potentially achieve a competitive advantage. Owing to the COVID-19 pandemic, which has made SMEs increasingly susceptible to failure, business enterprises, especially SMEs, have become more attentive to the need to build SCR. As a result, Sheffi (2020) emphasises that SCR now goes beyond simply managing risk. It entails that, by managing risk effectively, you are not only able to handle disruptions but also, potentially, to gain a competitive advantage from them.

Resilience also involves securing multiple suppliers from various regions. In light of current global geopolitical and socioeconomic uncertainties, relying on a single source for manufacturing or raw materials is highly risky. Therefore, supply chain design is essential to establish redundancy at every stage of the chain. By running simple 'what-if' scenarios, businesses can identify the critical suppliers, subcontractors, equipment types or regions most vulnerable to disruptions or failures (Forbes 2023).

Importance of supply chain resilience

Supply chain resilience is essential for helping SMEs to achieve and maintain their desired financial performance, reputation and reliability. Amid the COVID-19 pandemic and the extensive supply chain disruptions that ensued, supply chains must be more resilient and adaptable than ever to navigate change and disruption effectively. It is worth remembering that SMEs are not only customers of each other but also of larger companies. They play a crucial role in supplying essential goods and services to businesses and households, thereby contributing to the stability of national economies and driving global development. Resilient SMEs are businesses that do not only stay operational but, more importantly, thrive in the aftermath of disasters such as the COVID-19 pandemic. Given their vital role in job creation and economic growth, safeguarding and strengthening the resilience of the supply chains of SMEs during this period of economic instability is essential, as the growth of national economies and the global

economy depends heavily on them (McKinsey & Company 2022). The Organisation for Economic Co-operation and Development (OECD) (2020) argues that resilient supply chains enable organisations to be more proactive and swiftly adjust their operations, ensuring transparency and business continuity during a crisis. Hence, SCR is a source of business competitive advantage, as it is premised on agile business operations and the avoidance of disruptions, which, together, integrate supplier financial and operational exposures with product risk evaluations for informed decision-making.

In essence, SCR enables businesses to reduce risks by providing visibility into all operations within the supply chain network, allowing them to optimise and adjust their processes and logistics in real time. Furthermore, SCR often leads to increased enterprise investment in innovation and growth strategies. According to Schatteman, Woodhouse and Terino (2020) from Bain & Company, businesses that invest in SCR experience product development cycles that are up to 60% shorter and can increase output capacity by as much as 25%. Thus, SCR contributes to increased business productivity. The coronavirus disease 2019 pandemic disrupted nearly every aspect of the supply chain, highlighting the vital importance of resilience.

Features of resilient supply chain

Supply chains are facing unprecedented challenges today that require innovative, creative solutions and agile mindsets to be addressed properly. Presently, numerous characteristics of a 'typical resilient supply chain' are emerging owing to the increased research focus on the discipline because of the COVID-19 pandemic. Despite such variances, four prominent determinants of SCR, as identified by Christopher and Peck (2004), emerge across studies: risk-management culture, collaboration, agility and re-engineering.

Agility

As cited in Patel and Sambasivan (2022), Gligor, Holcomb and Feizabadi (2016, p. 24) define supply chain agility as the capability to adapt supply chain strategies and operations rapidly. From another perspective, agility denotes the supply chain's ability to respond to changes or disruptions swiftly and effectively (Singh & Modgil 2025). Thus, agility plays a crucial role in the reactive aspect of SCR and is strongly associated with emergency scenarios. Christopher and Peck (2004) identified visibility and velocity as two key measurable aspects of agility. Visibility refers to the ability to access or view relevant data or information in logistics and the supply chain, regardless of its location (Nothacker 2021). Supply chain visibility

(SCV) refers to the degree to which participants in a supply chain can access or exchange information they deem essential for their operations and mutually beneficial (Emon & Khan 2024). It also encompasses a transparent understanding of inventory levels, demand and supply dynamics, as well as production and procurement schedules across both upstream and downstream activities (Shahadat et al. 2024; Sunmola & Apeji 2024). Biel (2021) suggests that SCV is enabled by SCM technologies, such as the Internet of Things (IoT), blockchain and cloud-based applications, which provide ubiquitous insights into logistics and other supply chain processes. Furthermore, these technologies enable companies to navigate inventory shortages, prevent bottlenecks, comply with regulations and track products through to delivery. Supply chain visibility can refer to visibility in a company's internal operations and across its partner network. The study establishes that, while internal visibility is generally more manageable since the company controls data access, it still presents challenges. Technologies such as procurement, inventory and order management software, often integrated in a company's enterprise resource planning (ERP) system, play a crucial role in achieving comprehensive SCV. As a result, for SCV to be successful, data should be readily available, timely, accurate and organised in a manner that communicates important information clearly (Singh & Modgil 2025).

On the other hand, supply chain velocity refers to the rate at which corrective measures are implemented when a disruption is identified in the supply chain (Juan, Li & Hung 2022, p. 2). It focuses on the pace of flexible adaptation and therefore controls the promptness of the supply chain recovery after a risk event. Similarly, Ekpudu and Udofia (2023) posit that supply chain velocity can be described as the speed of movement over time, meaning that to boost velocity, the time must be shortened – specifically, the total duration required to move products and materials from one end of the supply chain to the other. Extant studies have acknowledged key determinants of supply chain velocity, including adaptability, innovation, supply chain empowerment and speed.

Re-engineering

In addition, a supply chain must undergo a process known as re-engineering, which entails the readjustment, redesign and reshuffling to incorporate resilience into its structure (Juan, Li & Hung 2022). This is essential for any organisation, as it helps to understand the supply chain, clarifies supply-based strategies and outlines the necessary design principles for building SCR. This is achieved after reviewing available strategies and options and analysing the trade-off between redundancy and efficiency. An enterprise can yield supply chain re-engineering using two widely accepted approaches: flexibility and redundancy (BDO 2020). Flexibility involves

having feasible alternatives in any scenario, such as supply-based flexibility, adaptable production, transportation and sufficient labour, all of which strengthen the business collectively.

Collaboration

Collaboration promotes interconnectivity among the different channels, allowing for the exploration and mutual benefit of the supply chain. Studies suggest that collaboration helps to reduce the chances of disturbances in distribution channels, ultimately leading to competitive market advantages (Movahed et al. 2023; Shahadat et al. 2024). Collaboration is achieved horizontally and vertically through trust and information sharing among all the parties across the supply chain. Digitally Driven (2021) highlights that vertical collaboration involves coordinating with customers, connecting internal functions and working together with suppliers. On the other hand, horizontal collaboration involves integration with competitors and non-competitors. Fostering a good rapport with key suppliers is important for managing supply chain risks effectively.

Supply chain risk management culture

According to Schein (1999), organisational culture is characterised as a set of fundamental assumptions that a group creates, identifies or refines while addressing challenges related to external adaptation and internal integration. Supply chain risk management refers to the process by which a business enterprise undertakes strategic steps to identify, assess and manage risks across all supply chain members. Supply chain risk management culture, a pattern of shared basic assumptions on the risks involved across the supply chain, has two features: leadership and innovation (Sun et al. 2023).

Leadership and innovation are crucial in building a resilient organisation. Juan, Li and Hung (2022) believe that leaders must be engaged actively in all aspects of the firm's supply chain to ensure seamless operations. Furthermore, they contend that a strong risk management culture in SCM should be strategic, systematic and crisis-ready, fostering a supportive environment for the organisation and its stakeholders. Consequently, this culture helps to mitigate vulnerabilities through reactive and proactive approaches (Kumar & Anbanandam 2020). Reactively, it aids in monitoring fluctuations in the supply chain, customer demands, competitor activities and technological advancements. Proactively, it focuses on identifying and minimising potential risks before they arise. Innovation thrives on new ideas, and its level is linked closely to the learning culture and decision-making processes of an organisation. Ultimately, innovation influences organisational survival, long-term growth and overall resilience (Digitally Driven 2021; Sun et al. 2023).

Role of digital capabilities in supply chain resilience during coronavirus disease 2019 pandemic

The Fourth Industrial Revolution is driving transformative and disruptive changes in innovation, operations and SCM. Hence, Nsakanda (2021) states that Africa must engage actively with this revolution rather than remain on the sidelines as the rest of the world progresses. In South Africa, Biyela and Utete (2024) report that the COVID-19 pandemic has led to a significant decline in SME economic activity, with the economy entering a recession. Furthermore, while all sectors have been affected, SMEs have been especially vulnerable owing to their constrained resources and limited ability to withstand financial setbacks (Madondo 2021). The low revenue caused some businesses to shut down completely, even though they still had to cover expenses such as salaries and rent. Early-stage and start-up companies, especially those operating for fewer than three years, experienced a high rate of closure. This was particularly evident among businesses earning less than ZAR120,000 per year, as their expenses exceeded their income (Biyela & Utete 2024). However, many of those who endured have adapted successfully by transforming their business operations, modifying their products or services and adjusting their sales strategies. Meanwhile, some bold and entrepreneurial individuals seized the opportunity to launch new ventures during the crisis (Mhlungu 2021).

The coronavirus disease 2019 pandemic-induced supply chain disruptions underscore the urgent need for effective, innovative interventions to ensure SMEs' SCR during and after the pandemic, with digital technologies as the most effective resilience tool. Currently, all signs point to a widespread need among businesses for a foundational reinvention to achieve a critical level of SCR. This reinvention is taking place through digital capabilities that assist SMEs in adopting new supply chain models and in responding to uncertainty in the face of the COVID-19 pandemic. Organisational capabilities are characteristics that allow a business to foresee and manage disruptions effectively. These capabilities can be either innate or acquired and are present across various functions, including human resources, operations, finance, transportation and logistics. Digital capabilities are anticipated to play an increasingly vital role in entrepreneurship and small business research and practice both during and after the COVID-19 crisis (Lungu, Georgescu & Juravle 2024). They are transforming supply chain models by fostering essential innovation and enhancing resilience.

The introduction of 4IR technologies in supply chains, commonly known as Supply Chain 4.0, presents an opportunity to minimise inefficiencies, lower costs and increase flexibility – key factors in strengthening SCR (BDO 2023). Munongo and Pooe (2022) find that by utilising 4IR technologies,

SMEs can gain real-time visibility in every aspect of the supply chain, allowing them to monitor operations proactively, identifying potential risks swiftly before they arise and promptly address any disruptions. The integration of 4IR technologies into the supply chains of SMEs offers a promising avenue for gaining a competitive edge, as it optimises interactions across the supply chain to deliver collective business benefits (BDO 2020). The rise of 4IR technologies has lowered the economic costs associated with data significantly, such as search, storage, computation and transmission, while also facilitating new economic activities, particularly during the COVID-19 pandemic, which reshaped lifestyles (Vijaykumar et al. 2024). Since the onset of the pandemic, Acs et al. (2021) suggest that both small and large businesses have leveraged digital platform-based ecosystems, driving 'creative destruction', value creation, value appropriation and SCR. More efficient and productive firms are likely to expand, leading to the emergence of new businesses and industries. The evolving 'Never-Meet-in-Person Era' is expected to transform sectors such as transport, hospitality, arts and entertainment and personal services (Belitski et al. 2022).

The coronavirus disease 2019 pandemic has highlighted the importance of enhancing SCR by integrating 4IR technologies into SME operations. McKinsey & Company (2020) indicate that SMEs can harness 4IR technologies to expand their customer base and offer a unique value proposition. Furthermore, they suggest that digital advancements enable SMEs to expand their market reach and operational efficiency while reducing costs, thereby mitigating the competitive disadvantage posed by larger firms. Therefore, by concentrating on critical areas in their value chain, products or operations, SMEs can adopt technological tools strategically to strengthen their competitiveness. These insights emphasise the essential role of information technology in helping SMEs to navigate challenges caused by the disruptions of COVID-19 (Munongo & Pooe 2022). Consequently, the adoption of 4IR technology marks an imminent phase in SCM in which suppliers and customers interact innovatively, blurring the divide between the digital and physical realms and removing conventional organisational limitations. By leveraging 4IR technologies, businesses worldwide can transition from conventional linear supply chains to dynamic, intelligent, interconnected, customisable, scalable and agile supply networks (Munongo & Pooe 2022; Olaitan & Mapanga 2024). This shift enables the seamless flow of products, services, information and big data analytics to support decision-making. According to Shlyakhetko, Syerov and Gregus (2023), businesses can therefore utilise the cloud-based Global Positioning System and Bluetooth Low Energy asset-tracking technologies to obtain instant updates on cargo location, assess transportation performance and identify delivery route inefficiencies. Furthermore, SMEs

can use smart sensors for automated data collection and data processing throughout the supply chain for cost reduction and improved operational efficiency.

Automation and artificial intelligence technologies

Automation and artificial intelligence (AI) technologies are critical in enhancing the ability of a business to understand fluctuating customer demand, improve visibility, increase responsiveness and strengthen resilience across the supply chain. Small and medium enterprises can utilise blockchain technology (BCT) to create a real-time digital ledger of financial transactions and movements for all stakeholders in their supply chain. Blockchain technology facilitates increased supply chain efficiency by enabling payments and audits, tracking inventory and assets, and handling purchase orders (POs) and shipment notifications. Augmented reality (AR) and virtual reality (VR) are additional 4IR technologies available to SMEs to enhance productivity, visibility, efficiency and traceability in the supply chain.

Further examples of utilising digital innovations to improve supply chains include studies commissioned by Google in the United States of America in 2020 and in Europe in 2021. These studies reveal that the 'digital safety net' has enabled millions of SMEs to reallocate resources, adjust business strategies and adapt continuously during the pandemic (Digitally Driven 2021; Wu, Li & Zheng 2024). The cited studies further suggest that, although the COVID-19 pandemic posed significant risks to small businesses worldwide, their adoption of digital tools served as a 'digital safety net', helping many to survive.

Consequently, the emphasis in the 'new normal' during and after the pandemic should be on strengthening the resilience of SME supply chains, as the crisis has highlighted the potential for disruptions and exposed existing operational and technological gaps. The pandemic has highlighted the importance of fostering SCR through the integration of digital technologies into SME operations, helping them to survive and cope with the adverse effects of the pandemic while realigning their supply chains. To this end, SMEs must start thinking more strategically about incorporating 4IR technologies into their supply chains; elevating their digital capabilities is now an imperative rather than an option.

Drivers of Fourth Industrial Revolution technology adoption for resilience

Gaining a clearer insight into the factors influencing the adoption of 4IR technology by SMEs is essential, given their significant role in job creation

and economic development worldwide. Data indicate that, while businesses were already in a 'disrupted stream' prior to the COVID-19 pandemic, it is the actual outbreak of COVID-19 that has since leapfrogged SMEs into 4IR adoption and now calls for accelerated adoption. The stringent social distancing measures are altering lifestyles and business arrangements. Evidently, 4IR technology offers an opportunity for more SMEs to enter new markets and industries.

Mamphiswana and Bekele (2020) suggest that 4IR technologies, such as additive manufacturing, offer SMEs diverse options for acquiring customised products or for creating products independently. Furthermore, the study recommends that these technologies can also help to lower market entry barriers, particularly for women-owned SMEs. Therefore, embracing 4IR technologies enhances the efficiency of service delivery for SMEs, thereby affecting productivity positively across sectors. Studies show a positive correlation between organisational automation and enhanced productivity (Ballestar et al. 2020; Friday et al. 2024). Moreover, the adoption of digital technology can enhance market transparency, lower transaction costs, boost incomes and ultimately increase the profitability of SMEs (Calderon et al. 2019).

Fourth Industrial Revolution technology adoption in South Africa

A study titled *Fourth Industrial Revolution in South Africa 2019*, conducted by World Wide Worx and reported by the South African Institute of Professional Accountants (SAIPA 2019), indicated a worryingly low adoption rate of 4IR technologies among South African enterprises. The research revealed that in 2019, only 13% of corporate entities in the country had implemented AI, while just 21% of the remaining businesses intended to adopt it within the next two years. Regarding other 4IR technologies, 50% of enterprises utilised basic automation, 25% incorporated IoT and 19% leveraged cloud computing. According to SAIPA (2019), these statistics differ significantly from those of a 2018 survey conducted by the firm, in which 63% of non-users expressed interest in adopting AI technology. Costs were cited as the major constraint to the adoption of 4IR technology. The research further indicates that local SMEs have moved past the hype around AI and have since realised that AI projects are costly. Again, businesses observe that although the software is affordable and easily accessible through online services, the real challenge lies in the shortage of skilled professionals needed to implement and utilise it effectively. This scarcity, in turn, increases the overall adoption cost. The majority of South African SMEs struggle currently to find, attract and retain the requisite technology talent.

Furthermore, 4IR technology adoption in South Africa is deterred by inadequate investments in 4IR infrastructure, power supply shortages and the fact that all digital technology is operated electronically, as well as poor digital literacy skills among the general population (Kayembe & Nel 2019). However, 90% of South African businesses underscored their belief that they will eventually become reliant on 4IR technologies, expecting that their adoption will lead to a measurable increase in efficiency. The businesses admit that, while cloud computing has become an everyday part of their lives, poor connectivity and perceived complexity issues hinder them from moving their business online. Conversely, robotic process automation (RPA), a technology that automates repetitive data entry tasks using programmable software robots, has become more affordable and widely accessible. According to SAIPA (2019), its adoption rate has reached 37%, and RPA has the potential to automate numerous bookkeeping and data input tasks traditionally handled by accountants.

Therefore, according to SAIPA (2019), 4IR technologies should not be viewed as a threat to SMEs. Instead, SMEs should adopt these advancements in information and transaction processing to gain a tangible competitive edge for their businesses, clients and overall practice. However, it is important to recognise that the feasibility and timing of adopting and implementing 4IR technologies successfully depend largely on each SME's readiness level and unique requirements (Gumbi & Twinomurinzi 2020; Mosupye-Semenya 2024). Given the high costs associated with acquiring, developing and mastering these technologies, careful, strategic decision-making is essential.

Despite the recent buzz surrounding the potential of digital transformation in supply chains, the adoption of 4IR technologies remains limited. This is partly due to the overlapping features and blurred distinctions among various digital tools. Moreover, for any technology to be adopted successfully, organisations must have a clear understanding of its value proposition, innovation benefits, deployment requirements and overall readiness for implementation (Patsavellas, Kaur & Salonitis 2021; Serumaga-Zake & Van der Poll 2021). This ensures that they can identify tangible advantages that lead to a compelling return on investment (SAIPA 2019). As a result, SMEs often deliberate on these key questions before deciding to invest in or adopt 4IR technologies:

- What benefits and extra capabilities might the innovative technology bring to supply chains?
- To what extent and in what ways does it enhance the flow of products, cash and information?
- How can we evaluate the preparedness of an organisation for adopting this technology?
- What would be the most effective strategy and ideal timing for its implementation?

Steps towards accelerated adoption of Fourth Industrial Revolution by small and medium enterprises

No business enterprise can afford to ignore the increasingly important role of 4IR technology amid the COVID-19 pandemic. However, organisations looking to leverage technological innovations must integrate cybersecurity into their strategies and systems from the beginning to reduce the growing cyber threats they encounter. The Fourth Industrial Revolution is transforming the world as we once knew it, and South African businesses, including SMEs, are pursuing growth opportunities driven by a 4IR-powered economy. However, adopting 4IR technology without prioritising cybersecurity could jeopardise growth initiatives. Moreover, Markowitz (2019) emphasises that South Africa's workforce generally lacks advanced skills in relation to the 4IR, with many workers primarily engaged in routine and repetitive tasks – making them the first to be affected by efficiency-driven cost-cutting innovations in businesses.

The study further highlights that enhancing SME productivity will necessitate substantial investments in human capital, including skill development, upskilling and reskilling for both entrepreneurs and employees. Consequently, as automation takes over certain production processes, a highly educated workforce will be essential for tasks such as research, design and machine manufacturing. South African Institute of International Affairs (2019) therefore posits that SMEs will need to recruit experts with specialised knowledge in advanced 4IR fields such as nanomaterials, three-dimensional (3D) printing and robotics. In this context, South Africa's education system must adapt its curriculum to equip graduates with the necessary skills to operate and integrate advanced technologies effectively. Likewise, SAIPA (2019) suggests that higher education institutions must restructure their ICT and engineering programmes to keep pace with rapidly evolving technologies. Again, partnered interventions are required from both the government and private sectors to address current shortcomings in power supply and 4IR infrastructure, enhance access infrastructure, reduce the cost of internet connectivity and raise digital literacy among local SMEs.

Accelerating supply chain resilience

In light of the COVID-19-induced supply chain disruptions, SMEs need to adjust their supply chain strategies by adopting innovative approaches to manage disruptions and evaluate resilience. This includes enhancing visibility through demand sensing and control towers, improving agility, diversifying supply sources and implementing effective contingency plans

(Capgemini 2023). Small and medium enterprises can explore various approaches to enhance SCR and improve overall agility.

Build analytics capabilities

Imagine leveraging machine learning (ML) and other AI technologies to analyse vast amounts of transactional and sensor data generated in the supply chain. Rosencrance (2019), in a TechTarget (2019) report, posits that this could lead to a more autonomous and efficient approach to supply chain analytics, ultimately making supply chains more adaptive and responsive. Furthermore, the study suggests that AI enhances supply chain analytics by improving predictions and facilitating more informed decision-making. Consequently, businesses can identify risks and demand fluctuations better, enabling them to respond proactively. In this sense, Rosencrance (2019) submits that AI is a crucial tool for strengthening SCR in SMEs – an area many leaders recognised before the pandemic but failed to implement effectively. Therefore, a key focus in SCM is integrating predictive and prescriptive analytics, combining AI with optimisation technologies. Specifically, SMEs can harness AI in two critical areas: enhancing predictive analytics to gain deeper insights into behaviours and utilising prescriptive analytics, where optimisation tools process ML inputs to support better decision-making (Audretsch, Belitski & Korosteleva 2021).

Small and medium enterprises can also leverage IoT through embedded sensors to track shipments, provide live location updates and enhance forecasting precision, all of which are valuable for time-critical shipments. Rosencrance (2019) states further that sensor-enabled assets provide real-time visibility throughout the supply chain, including to the end user. Similarly, with the rapid growth of IoT devices, the adoption of these applications by SMEs is expected to increase significantly. Consequently, integrating AI with IoT technology can enhance efficiency while minimising maintenance and downtime. IoT and data analytics contribute to better asset performance by collecting data and transforming it into real-time, actionable insights, supporting effective decision-making (Judijanto, Uhai & Suri 2024; Khuntia, Rueda & Van der Meijden 2019).

Continuous human resources investment

To leverage analytics fully, businesses need to acquire the appropriate infrastructure and skilled personnel. Rosencrance (2019), in a TechTarget report, highlights that professionals with advanced digital and analytics expertise are scarce and often expensive to recruit. Therefore, to address this issue, the report suggests that companies focus on developing a more

technically and analytically proficient supply chain workforce. A key aspect of this effort is providing the team with diverse experiences, including opportunities to work across various supply chain areas, in different regions and with different technology platforms.

Consider contactless delivery options

To enhance SCR, SME owners and managers are now more open to adopting practices and technologies they previously hesitated to consider before COVID-19, with contactless alternatives being a key example (Rosencrance 2019). The disruption caused by the pandemic is further intensified by the fact that many business recipients prefer to avoid direct interaction with delivery personnel and worry about the potential risk of virus transmission through packages (BDO 2020; Mittal et al. 2021). As a result, these concerns are driving businesses to fast-track contactless delivery initiatives as part of their COVID-19 adaptation strategies.

Before the pandemic, companies were reluctant to implement contactless delivery owing to resistance from both customers and managers. However, that opposition has largely disappeared. For example, Amazon took proactive steps by making significant investments in its own delivery infrastructure to maintain quality control from warehouses to customers' doorsteps (Himanshu, Chandel & Bhagwat 2022; Sheffi 2020). These investments included electric-powered delivery vans, drones, sidewalk robots and collaborations with third-party service providers. Pursuing this trend, other companies are now adopting contactless delivery technologies to safeguard their employees, customers and all other participants in the supply chain.

Rethink supplier strategy

New sourcing strategies are essential for strengthening SCR in the post-pandemic era. Before the pandemic, cost-cutting pressures led many businesses to rely on just-in-time supply chains with minimal reserves. However, this approach has shifted. In the short term, companies must prioritise building safety stocks of essential supplies as the vulnerabilities of global supply chains become evident (Raj et al. 2022). This involves establishing strategic reserves and encouraging local resource pooling. Eventually, adopting a multi-supplier strategy, particularly for critical items, is crucial, and a pro-local supplier perspective of this shift is significant (Digitally Driven 2021). The coronavirus disease 2019 pandemic exposed disruptions in the supply of low-margin goods such as hand sanitiser, prompting many SMEs to recognise the importance of resilient supply chains and the need for multiple, locally sourced suppliers (Paul, Moktadir & Ahsan 2023).

Build stronger rapport with supply chain members

Small and medium enterprises should focus on strengthening their relationships with key upstream and downstream supply chain partners (Ponis & Koronis 2021). A company's most reliable and cooperative customer or supplier can be more valuable than the one with the highest transaction volume. For instance, Fready, Vel and Nyadzayo (2022) suggest that mid-sized enterprises can enhance their bargaining power by adopting a risk-and-reward-sharing approach rather than relying solely on sales or procurement volume. Building strong relationships can lead to more adaptable contract terms, helping businesses manage capital limitations and fluctuations in demand.

Form strategic horizontal alliances

In today's interconnected world, collaborating with competitors is a common practice, and the post-COVID-19 economic landscape demands strategic adaptation from SMEs, and forming horizontal alliances has become a vital survival and growth strategy. A strategic horizontal alliance is a partnership between two or more businesses in the same industry or sector that cooperate to achieve common objectives while maintaining their independence (Rajab 2024). Unlike mergers or acquisitions, these alliances enable SMEs to benefit from shared resources without losing their autonomy. Soysal, Belbağ and Erişkan (2022) highlight that such partnerships focus typically on joint marketing efforts, supply chain collaborations, technological advancements and product innovation. Again, in the post-COVID-19 business landscape, strategic horizontal alliances help SMEs to pool resources, share expertise, enhance market access, adapt to new market dynamics and improve resilience in a rapidly evolving business environment (Abd Rahim & Halim 2024; Ramjaun, Rodrigues & Kumar 2024). Therefore, the approach fosters collective growth rather than individual competition. However, studies underscore that cooperation with competitors also poses risks for an SME. While beneficial, SMEs may encounter challenges when forming strategic alliances, including trust and competition concerns, alignment of goals and strategies, governance and decision-making complexities, and legal and regulatory issues (Al-Tabbaa & Zahoor 2024; Ramjaun et al. 2024). To overcome these challenges, SMEs must establish transparent agreements, define shared objectives and ensure mutual trust. Furthermore, SME owners and/or managers should weigh the resultant trade-offs before making a strategic horizontal alliance decision.

Adopting Industry 4.0 tools during the coronavirus disease 2019 pandemic

In South Africa, the COVID-19 pandemic exposed deep structural vulnerabilities in SME supply chains, particularly in the manufacturing and agri-processing sectors, characterised by limited buffers and high dependence on imported inputs. However, a subset of SMEs demonstrated notable SCR by adopting selected Industry 4.0 technologies. Studies indicate that SMEs deploying cloud-based ERP systems, IoT-enabled inventory monitoring and data analytics were better positioned to manage supply volatility and logistics constraints during lockdown periods (Aman & Seuring 2023; Munongo & Pooe 2022). The enterprises enhanced SCV and coordination, enabling faster supplier substitution and more responsive inventory replenishment. While adoption was neither comprehensive nor uniform, digital integration enabled SCR by supporting agility and decision-making under uncertainty. However, persistent constraints, including high implementation costs, skills shortages and infrastructure instability, limited the scalability of 4IR-driven SCR across the broader SME population (Munongo & Pooe 2022).

On the other hand, Kenyan SMEs, particularly in retail, agribusiness and light manufacturing, experienced mixed outcomes in SCR during the pandemic. Many enterprises rapidly adopted basic digital tools such as mobile money platforms, social media-based ordering systems and informal digital coordination with suppliers in response to mobility restrictions (Aman & Seuring 2023). These technologies proved effective in sustaining customer access and short-term cash flow. However, the limited integration of advanced Industry 4.0 applications such as predictive analytics, automated inventory systems or digitally integrated supply chain platforms meant that upstream disruptions remained largely unmanaged (Ali, Sadiddin & Cattaneo 2023). As a result, while demand-side continuity improved, supply-side resilience was constrained. The Kenyan case illustrates that partial digital adoption may enhance short-term survival but is insufficient to deliver systemic SCR.

In Nigeria, the COVID-19 pandemic had a disproportionately severe impact on SMEs operating within fragmented, informal supply chains. Although awareness of digital technologies increased during COVID-19, effective adoption of Industry 4.0 tools remained limited. Many SMEs relied primarily on rudimentary digital solutions for marketing and customer communication, while core supply chain processes continued to operate

manually (Aman & Seuring 2023; Hossain, Akhter & Sultana 2022). Weak digital infrastructure, unreliable power supply, limited access to finance and low absorptive capacity significantly constrained meaningful 4IR implementation. Consequently, Nigerian SMEs were often unable to mitigate supplier disruptions or logistics delays, resulting in prolonged operational interruptions. This case highlights a failure trajectory in which structural and institutional barriers outweighed the potential benefits of digital technologies (Kazancoglu et al. 2023).

Also, Indian SMEs, particularly in manufacturing and health care-related supply chains, showed comparatively strong SCR during the pandemic, supported by more advanced Industry 4.0 adoption. Firms that implemented AI-driven demand forecasting, digital supply chain platforms and automated planning systems demonstrated superior capabilities in sensing disruptions and reconfiguring operations (Mishra & Singh 2023; Tortorella et al. 2023). Government-led digitalisation initiatives and platform-based ecosystems further facilitated SME integration into resilient supply networks. While heterogeneity across sectors and firm sizes persisted, empirical evidence suggests that digitally mature SMEs recovered more rapidly from COVID-19 pandemic-induced shocks and were able to maintain supplier relationships and service continuity better (Tortorella et al. 2023). The case, therefore, illustrates how coordinated policy support and technological capability can amplify the SCR-enhancing effects of 4IR adoption.

In Southeast Asian countries such as Vietnam and Thailand, export-oriented SMEs leveraged Industry 4.0 technologies to mitigate pandemic-related supply chain disruptions. Studies of Vietnamese SMEs establish that firms adopting AI-enabled analytics, digital logistics platforms and real-time supply chain monitoring tools maintained production continuity despite global transport constraints (Dey et al. 2024; Ngo, Pham & Nguyen 2023). Integration into international value chains and exposure to multinational buyer requirements accelerated digital upgrading, enabling SMEs to respond more effectively to demand fluctuations and border closures. However, the SCR outcomes varied across firms, with digitally advanced SMEs outperforming those reliant on traditional practices significantly (Ali, Sadiddin & Cattaneo 2023).

Collectively, the cases show that pandemic-driven SME SCR is not an automatic outcome of Industry 4.0 adoption. Rather, SCR emerges from the interaction between digital technologies, organisational capabilities and institutional contexts (Kazancoglu et al. 2023; Mishra & Singh 2023). Success cases are characterised by strategic, integrated and supported 4IR adoption, while failure cases reveal the consequences of partial digitalisation and structural constraints. This cross-country comparison underscores the

need for context-sensitive, policy-aligned approaches to digital SCR in emerging economies.

Conclusion

In summary, pandemics such as COVID-19 have exposed the weaknesses of conventional supply chains while catalysing the adoption of 4IR technologies among SMEs. By embracing digitalisation and fostering a culture of resilience, SMEs can mitigate supply chain disruptions and thrive in a volatile and uncertain business environment. Amid the COVID-19 pandemic, SMEs are under immense pressure to have adequate technological capabilities in place and to adopt 4IR technologies quickly to capture real-time data and analyse it to execute decisions more quickly. The future supply chain-resilient SMEs will mature their data capabilities in two phases: converting real-time data into immediate analytics; then utilising those analytics to drive concurrent decision-making, ultimately enabling the automated execution of planning, inventory optimisation and other key processes along their supply chains. Furthermore, SMEs will require their human resources to develop the requisite 4IR skills to process and leverage these real-time data flows, generating actionable insights. The path to SCR involves government support in creating an enabling environment for 4IR technology adoption. Small and medium enterprises are investing rapidly in Supply Chain 4.0 technology to facilitate real-time analytics as a stepping stone towards instantaneous implementation. However, as a precaution, SMEs must ensure that they do not become overly focused on the initial phase of real-time analytics, as this could delay crucial investments needed to achieve fully automated execution and build resilient supply chains. Finally, SMEs must be committed to building agility into their supply chain strategy to adapt continually to innovative technologies over time.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Masakale and S Munongo; *methodology* (*desktop-based literature review and conceptual synthesis*), D Masakale and S Munongo; *validation*, D Masakale and S Munongo; *investigation* (*systematic review and interpretation of secondary sources*), D Masakale and S Munongo; *resources*, D Masakale; *writing – original draft preparation*, D Masakale; *writing – review and editing*, S Munongo and D Masakale; *visualisation*, S Munongo; *supervision*, D Masakale; *project administration*, D Masakale.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them inappropriately in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 8

Industry 4.0 and dynamic capabilities

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Introduction

Small and medium enterprises (SMEs) do not operate in a vacuum, as their activities interact with the environment in which they operate. This dynamic environment demands that SMEs use relevant theories and models to respond to the changing nature of the hypercompetitive environment in which they operate. These dynamic and hypercompetitive environments require approaches not locked into historical perspectives and models, but

How to cite: Masakale, D & Pooe, D 2026, 'Industry 4.0 and dynamic capabilities', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 179–200. https://doi.org/10.4102/aosis.2026.BK572.08

rather grounded in contemporary operational models with practical applications to ensure resilience. The models should respond to a constantly changing ecosystem that is both challenging and engaging, especially in the hyper-competitive digital SME market of today. The hypercompetitive environment is where businesses have a temporary advantage over their competition, which can give them a competitive advantage and ensure their survival and resilience (Lindskov 2022).

This chapter examines how absorptive, adaptive and innovative capabilities, as components of the dynamic capabilities theory (DCT), can be leveraged by SMEs to respond to and adapt to the environmental dynamics in which they operate. This will also be done in the context of supply chain management (SCM), specifically digital supply chains (DSC), as the supply chains of SMEs operating in Industry 4.0 need to be responsive and resilient to these changes. Small and medium enterprises tend to be highly vulnerable to disruptions brought by environmental changes, such as the coronavirus disease 2019 (COVID-19) pandemic, as well as Industry 4.0 supply chain disruptions, including intelligent manufacturing, agile supply chains, green economies and sustainability discourses. Others include Fourth Industrial Revolution (4IR) disruptions such as blockchain technologies (BCTs), augmented reality (AR) and virtual reality (VR), among others.

Industry 4.0 context and business environment

In the context of Industry 4.0, resilience is essential, as it enables a competitive advantage by allowing real-time response to changing customer and environmental needs. Real-time reactivity also requires SMEs to invest in Industry 4.0 solutions such as cloud storage and digital distribution systems. The term used for this environment in the context of post-COVID-19, and more relevant to the environment in which SMEs in Industry 4.0 operate, is VUCA. VUCA is an acronym for volatility, uncertainty, complexity and ambiguity (Weerasombat, Pumipatyothin & Napathorn 2022). The environment is made up of the micro-environment that the business influences, the immediate market environment that the business can influence, and the macro-environment over which the business does not have influence (Nieuwenhuizen 2020). D'Aveni (1998) was instrumental in authoritative work on strategies to combat the hypercompetitive environment in the late 1990s and defined hypercompetitive as an environment characterised by an aggressive, dynamic business environment that creates constant disequilibrium and uncertainty. Alnoor et al. (2023) support this view and add that SMEs and their supply chains need to be flexible and responsive to take advantage of the opportunities that the

same environment offers. The hypercompetitive environment requires SMEs to have dynamic capabilities that allow them the flexibility and adaptability to respond to these changes. The ability to be flexible and to adapt gives them a competitive advantage that sustains operational performance and gives a competitive edge.

To be flexible and responsive to the temporary advantage that today's business environment offers, SMEs need to avoid the complacency trap and be ready to respond and adapt to environmental demands – this is what is meant by having a dynamic response. A dynamic response is the ability to reconfigure and realign resources, such as supply chains, to respond and be resilient to these environmental forces (Dubey et al. 2023). To avoid the company trap, SMEs need what is known as dynamic capabilities. The dynamic capabilities theory, derived from the resource-based theory in the field of strategic management, states that SMEs need to be ambidextrous to exploit and explore market opportunities (Ashfaq et al. 2023). Ambidexterity refers to an SME's ability to explore and exploit opportunities simultaneously and is vital to understanding how dynamic capabilities gain a competitive advantage (Yoon, Jeong & Kim 2023). The term ambidexterity is linked to distinct components of the DCT, namely innovative absorptive capacity (AC) and adaptive capacity (ADC).

Understanding dynamic capabilities

As introduced in the previous section, business adaptation and responsiveness to environmental forces in the marketplace are among the most crucial aspects of organisational resilience, survival and success. Adaptation and responsiveness increase the resilience, survival odds and chances of success of SMEs operating in Industry 4.0 (Al-Omoush, De Lucas & Del Val 2023; Bertoncelj, Kavcic & Gosnik 2010). In the current Industry 4.0 dynamic environment, SMEs that take advantage of its intangible capabilities, such as knowledge, capabilities and Industry 4.0 solutions, such as the 4IR, blockchain, metaverse, VR and AR, are enabled to respond to the advantages and challenges of the contemporary hypercompetitive environment. In a more contemporary view of strategic management, the intangible resources that SMEs can access and leverage to gain a competitive advantage are referred to as dynamic capabilities. This chapter aims to link dynamic capabilities as a theory with their influence on enhancing Industry 4.0 supply chain resilience to strengthen SME performance. Studies such as that of Sturm, Hohenstein and Hartmann (2023) have already confirmed this link. Thus, this chapter discusses the DCT and its effect on Industry 4.0 supply chains. This theory will be explained in the next section.

Dynamic capabilities theory

As proposed previously, to survive and prosper, SMEs operating in hypercompetitive environments leverage their intangible assets, known as dynamic capabilities, to gain a competitive advantage and remain resilient. As an extension of the resource-based theory, the DCT explains why businesses operating in the same hypercompetitive environment, with the same resources, achieve different outcomes (Chebbi et al. 2023; Owoseni & Twinomurinzi 2019). The theory proposes that a business that can reconfigure its resources rapidly has a chance of being successful in an unfavourable, volatile, hypercompetitive environment in which it operates (Chowdhury & Quaddus 2017; Owoseni & Twinomurinzi 2019). A dynamic capability is defined as a managerial ability to reconfigure a firm's resources and routines to respond to environmental dynamics. The dynamic capabilities theory also considers the process by which an SME senses and seizes opportunities and engages in strategic renewal.

Dynamic capabilities as a framework proposes how intangible resources are accessible to any SMEs, develop over time and evolve from the resources at hand (Owoseni & Twinomurinzi 2019). Other, more recent definitions include the capacity for SMEs to regenerate their core competencies to sense opportunities and threats, seizing opportunities, transforming or reconfiguring or renewing resources to have the ability for agility and adopt best practices (Mauri-Castello, Alonso-Gonzalez & Peris-Ortiz 2019). In the context of Industry 4.0, dynamic capabilities look at how SMEs can be resilient and competitive through the implementation of their Industry 4.0 solutions through the lens of dynamic capabilities. This is important because it examines how SMEs can take advantage of these newer technologies and opportunities.

History and development of dynamic capabilities theory

The dynamic capabilities theory is one of the most significant theories that has contributed to the discipline of strategic management in the last decade. Teece, Pisano and Shuen (1998) published a body of work that was instrumental in sparking interest in the concept of dynamic capabilities in the field of strategic management. The study ignited empirical studies for decades to come that assessed and questioned how the dynamic capabilities view can be of assistance in influencing business performance. The phenomenon is illustrated further in Figure 8.1, which shows that more than 876 articles were published and analysed using the Bibliometrix analysis tool. The tool shows that the term 'dynamic capabilities' is the



Source: Compiled for this study by David Pooe and Dingi Masakale (2026).

FIGURE 8.1: Most locally cited sources for dynamic capabilities and small and medium enterprises.

most researched concept in strategic management journals compared to any other management studies journals.

As an extension of the resource-based view (RBV), dynamic capabilities have their origins in several schools of thought, which have managed to sensitise researchers to the concept of strategic management. These include, and are not limited to, the evolutionary theory of the firm, transactional cost economics and behavioural theory. These theories aimed to help managers gain an edge in dealing with the dynamic environment that the businesses they managed were experiencing in the early 2000s. These theories were scaffolded on previous strategic management models that addressed the changing, hypercompetitive business environment. Strategic management as a discipline is focused on understanding how competitive advantage influences business performance (Biloshapka & Osiyevskyy 2018). While strategies based on resources may give a temporary competitive advantage, in a dynamic environment, they cannot persist. It will be difficult for a business to be competitive only by using resources in a dynamic environment. Thus, the DCT was born.

Some of the most widely empirically researched previous strategic management models include and are not limited to the firm evolutionary theory, transactional cost economies, behavioural theory RBV and the distinctive competence theory, core and combative capabilities, as well as architectural competence theories (Wang & Ahmed 2007). The firm evolutionary theory explained the relationship between business capabilities and behaviours in an ever-changing business environment and was first

introduced by Nelson and Winters (1982). Then, the transactional cost economics was introduced much later and defined the boundaries within which the business can operate and expand, as well as 'seeking to explain how firms internationalise and the structural arrangements required to improve the odds of success' (Martins, Ferreira & Reis 2010, p. 62). Later, other theories such as the behavioural theory were proposed and looked at the interrelations in a firm and how decisions are made to ensure efficient and effective operations (Todeva 2007). Other earlier models include the RBV and distinctive competence theory discussed in the sections that follow.

Resource-based view

The resource-based view is one strategic management concept that was instrumental to the development of the DCT (Lambourdière, Corbin & Verny 2022). As a strategic management concept, the resource-based theory proposes that an organisation can use its available resources to mitigate the risk of failure that the business environment can cause to a business, and resources can also assist a business to gain a competitive advantage. In the context of Industry 4.0, RBV is still relevant for the deployment of digital solutions, such as in intelligent manufacturing, for example, and can enable SME to gain a competitive advantage (Okorie et al. 2023).

Barney (1991) originally posited a framework that laid the foundation for the RBV, and it defined how resources could be a source of competitive advantage. This framework was accepted widely, adopted and tested empirically in the field of strategic management. To have a competitive advantage, Barney (1991) proposed that resources must be valuable (V), rare (R), inimitable (I) and non-substitutable (N). These collective variables are jointly known as the VRIN framework. On their own, the variables are a temporary advantage, but combined with other competencies, such as strategic capabilities, can enhance the competitive advantage of SMEs (Correia et al. 2023; Johnson, Scholes & Whittington 2009; Wang & Ahmed 2007).

Strategic capabilities

Strategic capabilities are a key to strategic advantage and define what a business does very well and sets it apart in the marketplace. They are typically measured via a strategic value analysis, a complex process that considers several factors. The business can take advantage of its strategic capabilities to gain market share and a competitive advantage and, as such, organisational capabilities act as skills and intangibles that SMEs use

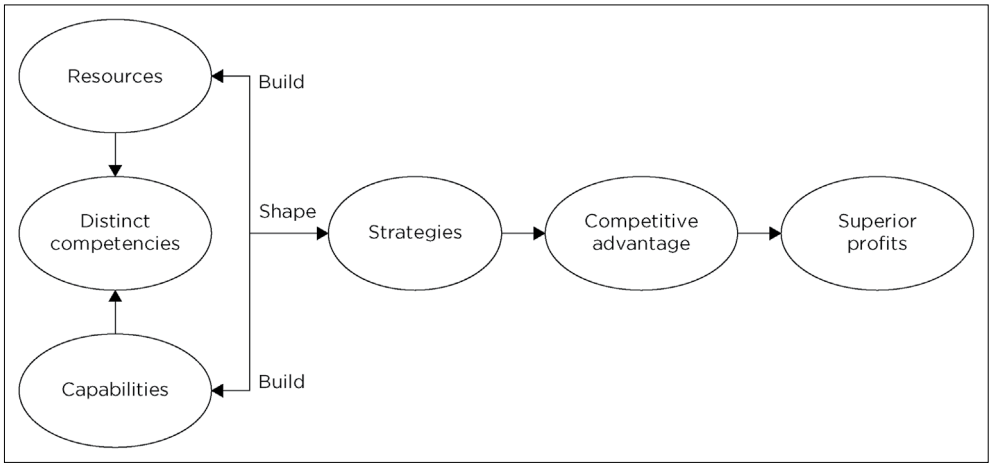
to transform input into outputs (Lubis et al. 2026). A competitive advantage in the context of organisational capabilities occurs when SMEs use them to enhance profitability over their competition over several years. Strategic capabilities give a business a competitive advantage by building on key competencies that an SME possesses, such as supply chains and unique products and services (Zhang et al. 2023). While organisational capabilities explain a firm's capacity to deploy resources to gain a competitive advantage, strategic capabilities are how SMEs deploy intangible resources and core competencies to gain an edge in the market.

Competitive advantage can be gained by managing the resources, capabilities and core competencies of a business (Iqbal et al. 2026). In the context of Industry 4.0, the key to competitive advantage is not the technology itself, but the strategy employed. Technology is an effective tool available to SMEs to mitigate and play in the Industry 4.0 arena and can be used to implement strategic capabilities. Small and medium enterprises generally have few options at their disposal to enhance competitive advantage. These typically include low cost, focus and differentiation. These could also be adopted by SMEs as a hybrid strategy to improve performance. Strategic capabilities aid SMEs in increasing the options available to them to engage the marketplace (Alnoor et al. 2023; Hill & Jones 2013).

Core competencies also relate to the collective learning of an organisation, also known as AC, and how the learning can be applied to solve business problems (Ahankoob, Abbasnejad & Wong 2026). Adaptive capacity is one of the three elements of dynamic capabilities to be discussed later. Core competencies are also linked to another element of a dynamic capability known as adaptive capacity, also to be discussed later. To create value, Dess, McNamara and Eisnar (2014) propose that three criteria need to be met for a core competency to create value, namely:

- The core competency must create superior customer value to stand out.
- Different businesses in the same company must be similar in at least one core competency.
- The core competency must be difficult for the competition to imitate, thus giving an edge in the market.

Figure 8.2 depicts how all the elements discussed in this chapter, such as core competencies, resources and especially capabilities, make up the strategic competencies that help businesses to develop strategies to gain a competitive advantage and stay resilient. These strategic competencies help to build and shape the SME's strategies to engage the new business environment and determine their resilience and success.



Source: Compiled for this study by David Pooe and Dingi Masakale (2026).
FIGURE 8.2: Strategy, resources, capabilities and competencies.

As resources alone cannot give SMEs a competitive advantage, a dynamic approach is needed to be responsive to the challenges of the contemporary business environment. The resource-based view proposes that a competitive advantage includes core competencies, technology and resources. The resource-based theory acknowledges that resources, capabilities and core competencies shape and build strategies that enable competitive advantage. This is not the only option for SMEs, as they tend not to have the resources equal to big business to compete and stay resilient in the Industry 4.0 setting. The dynamic capabilities theory is an option available to SMEs.

Having a dynamic capability is to have the ability to build and protect one's competitive advantage in changing business environments. As SMEs are confronted with a dynamic, fluid ecosystem, strategic capabilities may not be sufficient to stay competitive and resilient. The dynamic capabilities view thus suggests that businesses in the Industry 4.0 supply chain environment should have the ability to build, integrate and restructure capabilities to address the changing business environment in order to stay competitive. This includes sensing and capturing new opportunities and generating new knowledge to enable SMEs to stay ahead of their competitors.

Dynamic capabilities and their relevance to small and medium enterprises

Adjusting capabilities and competencies distinguish the DCT from the resource-based theory (Krzakiewicz & Szymon 2017). A dynamic capability

means the ability for SMEs to exploit their intangible resources efficiently and effectively, while at the same time exploring opportunities, thus making them ambidextrous (Sollosy 2013). If SMEs are ambidextrous, it means that they can reconfigure typologies and systems to enhance superior performance (Chigori, Chinyamurindi & Rungani 2024). This is also relevant to the digital supply chain strategy (DSCS), as discussed earlier in Chapter 5, primarily the dynamic responsibility to adapt. Sense and pivot focus on building enhanced adaptability to perform against unplanned environmental dynamics.

Components of dynamic capabilities theory

The dynamic capabilities theory comprises three distinct components that a business needs to survive and prosper, namely AC, ADC and innovative capacity (Cappellari et al. 2023; Otengei & Changha 2023; Sollosy 2013). As DCTs are not easily transferred, they have a source of long-term advantage. These three components of the DCT are discussed next.

Absorptive capacity

The concept of AC has always been embedded in the debate on dynamic capabilities by earlier academics (Helfat & Peteraf 2009). In the current Industry 4.0 hyperactive environment in which SMEs operate, one cannot ignore the need to discuss an organisation's ability to create and absorb knowledge as part of its dynamic capability, known as its AC. Earlier models, such as that proposed by Teece and Pisano (1994), linked learning as part of a dimension for dynamic capability. Thus, the interest in dynamic capabilities evolved, and the importance of organisational knowledge was also now being emphasised (Park et al. 2023). Absorptive capacity represents one of the three distinct dynamic capability components linked to the dimension of organisational learning and knowledge management (KM) (Sollosy 2013).

The idea that AC is the collective ability to exploit and explore knowledge for commercial purposes was first introduced by Cohen and Levinthal (1989). Absorptive capacity is an organisation's ability to respond to the competitive environment and embodies past learning, which can depreciate if unused over time (Teece, Pisano & Shuen 1998). Businesses generate knowledge, but those who do not survive or sustain their business often are unwilling or unable to use the knowledge to make the business resilient, especially in competitive environments (Kirschning & Mrożewski 2023). The main premise of AC is how SMEs focus on KM and combine external and internal knowledge to tackle external environmental challenges. Knowledge is useful for entrepreneurial activity only if applied

(Kirschning & Mrożewski 2023). The conference paper of Inayatulloh et al. (2022) supports this view further on how an organisation's ability to grow and adapt depends on its willingness to learn and how it manages knowledge.

Absorptive capacity forms part of the original dimension of the model of dynamic capabilities, which focuses on the routine of sensing (Valentim, Lisboa & Franco 2016). Information is the new currency in Industry 4.0, and SMEs cannot afford simply to let this powerful resource lie dormant.

Dimensions of absorptive capacity

Absorptive capacity is linked directly to the concept of business KM. Knowledge management is about making sure that the right information is available to the right people at the right time to make sound judgements. The original model, as proposed by Teece, Pisano and Shuen (1998), stresses that ideas and insights that are generated by the individuals in the firm need to be captured, absorbed and applied by an SME. Knowledge management represents part of a firm's ability to create new knowledge and use it for problem-solving (Teixeira et al. 2023). It involves the coordination, sharing and application of knowledge and ensuring that the knowledge is embedded into the business memory to create value. Knowledge management is also about systems supporting inter-organisational knowledge transfer (Qader et al. 2022). Thus, KM forms a key dimension of AC and is instrumental as SMEs can utilise it for competitive advantage in Industry 4.0 (Rezaei, Babazadeh & Simal-Gandara 2023).

Determinants of absorptive capacity

The determinants of AC include various factors, which are both external and internal. These include prior learning and experience, culture, company networks, relationship management and adequate resources. Other factors involve human capital and its ability to handle change, innovation, learning culture and communication, as well as the attitudes of management and employees to change (Hejazi, Tang & Wang 2023). Of the factors listed, it is clear that absorption and application of knowledge for organisational adaptation go hand in hand and are crucial success factors in the business environment (Cohen & Levinthal 1990; Guan, Tienan & Tang 2023). Thus, AC is influenced by KM in the context of business and SME. What determines the concepts is related to how an SME in the Industry 4.0 context acquires and absorbs knowledge, while the business interacts with the SME ecosystem. What ensues is a discussion on the relevance and operationalisation of AC.

Absorptive capacity operationalised

The absorptive theory, as a construct of the DCT, has previously been theoretically studied, but few authors have proposed ways to measure and operationalise the theory. Noblet, Simon and Parent (2011) proposed four dimensions of operationalising the theory that relate directly to the concept and KM. These include acquisition, assimilation, transformation and exploitation. Absorptive capacity operationalised means how to measure and assess the ability of an organisation to acquire, assimilate, transform and exploit external knowledge. The acquisition is defined as the capacity of a business to organise, understand the maintenance of and acquire external knowledge for operations. This can be seen as a motivator for collaboration in a business (Noblet, Simon & Parent 2011). Assimilation as a dimension of AC refers to the ability of a business to consolidate external knowledge via systems and procedures that allow it to process and understand the information. Transformation refers to the business's ability to refine routines that facilitate and convert the acquired knowledge and can be measured by the number of project ideas that generate new products or services. Finally, exploitation, which is central to part of the definition of AC, refers to the ability to use new knowledge to gain a competitive advantage (Noblet, Simon & Parent 2011, p. 369).

Impact of absorptive capacity on Industry 4.0 adoption

The impact of AC on Industry 4.0 has been adopted and explored empirically. These include applications in smart manufacturing adoption (Arcidiacono et al. 2023), learning factories and sustainability (Yilmaz et al. 2022), as well as resilient supply chains (Chari et al. 2022). The studies suggest that AC impact enables SMEs and businesses to adopt and benefit from Industry 4.0 technologies. Adoptive capacity allows them to access, understand, apply and create new knowledge related to smart manufacturing. The impact that KM has on business performance, enhanced by Industry 4.0, cannot be undermined, and this is confirmed by the study by Ardito et al. (2022).

The ability of SMEs to adapt and respond to the competitive environment is important, especially in the new normal that SMEs operate in. The environments and economies in which SMEs operate, including green economies, influence the performance, resiliency, sustainability and competitive advantage of SMEs. The more flexible the business is to respond to the environment, the higher their chances of success in the marketplace. In addition to AC, dynamic capability theory proposes that organisations need to have ADC to mitigate environmental dynamics.

Adaptive capacity

The concept of adaptive capacity has also been embedded in the debate on dynamic capabilities by earlier academics such as Helfat and Peteraf (2009). Adaptive capacity, an SME's ability to adapt to the Industry 4.0 hypercompetitive environment, is also one of the crucial success factors that a business cannot ignore. Also, as the interest in dynamic capabilities evolves, the importance of ambidexterity, the ability to adapt, and sustainability in data-driven cultures are now being emphasised. Adaptive capacity represents one of the three distinct dynamic capability components of interest available to SMEs to mitigate today's dynamic environment.

Adaptive capacity, as a dynamic component of dynamic capabilities, is crucial and available to SMEs as a tool to increase the chances of them surviving and making it in the new hypercompetitive Industry 4.0 environment. Adaptive capacity refers to the organisational ability to find a balance between exploring opportunities and aligning its internal strategic capabilities to efficiently exploit them (Knoppen, Saris & Moncagatta 2022). It is a system, which refers to the ability to 'adapt and change and respond to the disturbances' in that system (Buma & Schultz 2020, p. 1115).

Dimensions of adaptive capacity

The concept that is related closely to ADC is ambidexterity, the ability of an SME to be able to loosen its structure, to be 'ambidextrous' and to accommodate change. Ambidexterity is related to the ability to be flexible enough to respond to environmental changes. This is crucial for SMEs and their supply chains in the context of Industry 4.0, where ambidexterity is a defining factor in taking advantage of opportunities quickly. These SMEs need to be ambidextrous, exploring opportunities and exploiting existing resources to optimise the generation of higher performance (Lee et al. 2023). Ambidexterity also means resilience to stand the test of time. This can be achieved by alignment, as the effective and efficient use of existing resources. Ambidexterity is the SME's tendency to move temporarily between the extremes of exploitation of resources and exploration of opportunities. This temporary move to take advantage of opportunities can also be defined as vacillation, a more fluid explanation of the concept of ambidexterity and is related to ADC. Small and medium enterprises showing vacillation tend to achieve higher performance over time, and those exhibiting high ADC and ambidexterity also tend to perform well over time (Teece 2018; Volery, Mueller & Von Siemens 2015).

Determinants of adaptive capacity

The concept of ADC is generally determined by multidimensional factors which enhance the ability of SMEs to adapt and be resilient as they operate across various industries. The determinants of ADC are generally a complex interplay of macro-environmental factors, organisational cultures, strategic leadership, organisational learning and resource flexibility. As for these various determinants of ADC, focusing on one is very important for the context of this chapter. Thus, from the perspective of SME supply chains in the context of Industry 4.0, resource flexibility relating to ambidexterity is discussed. As previously explained, exploitation and exploration are two extremes of the continuum of ambidexterity, which an organisation must juggle to adapt and survive (Kassotaki 2022). Ambidexterity is also an approach to SMEs to ensure supply chain resilience in Industry 4.0 (Aslam et al. 2022).

In the context of ambidexterity, a more relevant determinant of the ADC of SMEs is contextual ambidexterity. Contextual ambidexterity is the choice that SMEs have either to explore or exploit in the quest to gain a competitive advantage (Ramdan et al. 2022). It refers to putting in place systems that allow the ability to make judgement decisions and manage risk to stay resilient in response to the dynamic and turbulent Industry 4.0 environmental changes. Birkinshaw and Gibson (2004, p. 48) initially defined contextual ambidexterity as a 'collective orientation of the employees towards the simultaneous pursuit of alignment and adaptability'. Contextual ambidexterity is important to entrepreneurs in the context of ADC, as entrepreneurs need to make a judgement call in the day-to-day running of their business. The concepts of adaptation and decision-making are difficult to separate, especially when a business has to take a stance when faced with dynamic environmental forces.

Metts (2011) also defines the same concept as 'adaptive decision-making' (ADM), a tendency by the organisation to adapt to the environment with high priority, relevant in today's hypercompetitive arena. Metts (2011) argues that at ADM's core is the decision-making process in environments in which there is 'information overload', relevant to Industry 4.0. Information overload challenges any person to make rational decisions; thus, ADM helps to narrow down options to solve a problem (Collins & Shenhav 2022). Adaptive decision-making is prevalent and relevant to SMEs as they need to think on their feet, make quick decisions and help the decision-maker to cover an array of business situations faced daily (Metts 2011). This concept of ADM also forms part of the ADC of a business (Valentim, Lisboa & Franco 2016). The importance of individual capacity to make decisions cannot be

underestimated in how adaptive and aligned an organisation is to environmental dynamics, thus forming part of the determinants of ADC.

Adaptive capacity operationalised

Small and medium enterprises are facing challenges, especially post-COVID, and the need to adapt by sensing, seizing and transforming to respond to these changes cannot be underestimated (Quansah, Hartz & Salipante 2022). When SMEs face challenges to adapt, literature suggests different approaches to operationalise ADC, such as learning and KM, innovation, collaboration, flexibility and concepts that also link to ambidexterity, vacillation and AC (Quansah, Hartz & Salipante 2022).

Operationalising ADC in the context of SMEs means ensuring that the concepts and their determinants are embedded in the processes and systems of the business. Operationalising ADC includes ensuring:

- Small and medium enterprises' supply chains are flexible to ensure that when opportunities arise, they can realign resources to take advantage of them (ambidexterity).
- Small and medium enterprises have systems that capture the learning that the business gains as they engage with the environment (AC).
- Small and medium enterprises have a culture that allows employees to make mistakes to ensure that they can take risks with these new opportunities, and management should encourage that. This also encourages innovation and risk-taking.
- Small and medium enterprises have strategic agility, where the processes and procedures do not hinder SMEs as they respond to market dynamics.
- Small and medium enterprises monitor and control using tools such as key performance indicators to measure the ability to adapt and to use the information to gauge if they can respond when opportunities arise.

In the context of the wider environment and complete adaptation of nations and households, six institutional characteristics were identified that influence ADC, which are fair governance, variety and availability of resources, learning capacity, room for change and leadership learning capacity. These variables were used to develop the Local Adaptive Capacity Framework, which was developed as part of the Africa Climate Change Resilience Alliance programme and initially targeted to understand the effect of ADC in households and communities at large (Jones et al. 2019).

Impact of adaptive capacity on Industry 4.0 adoption

The impact of ADC, as with AC, in the context of Industry 4.0 has been adopted and explored empirically. As with AC as a dynamic capability, it has also been tested in empirical studies, such as smart manufacturing

adoption (Arcidiacono et al. 2023) and learning factories (Yilmaz et al. 2022). Other studies focusing on adaptability as a dynamic capability include Bai, Orzes and Sarkis (2022), which also focused on the sustainability of Industry 4.0 interventions.

The adoption of ADC in Industry 4.0 is multi-dimensional. As a tool to manage learning and ensure a culture, processes and systems to mitigate change, its adoption should aid agility to adapt to change, allow ambidexterity and, most importantly, an innovation mindset in the Industry 4.0 context. It should also aid knowledge absorption and application, as well as resource allocation to adapt quickly to change. This is especially relevant since the disruptions that COVID-19 has had on traditional supply chains. Highly adaptive industries have a higher chance of adapting, being flexible and agile and staying resilient to respond to the challenges they face in the Industry 4.0 arena (Efthymiou & Ponis 2021).

Innovation capacity

The concept of innovative capacity was not included in the originally proposed model of dynamic capabilities, which only focused on learning (AC), seizing and transforming (ADC) when it was introduced around 1997 by Teece, Pisano and Shuen (1998). Innovation capacity as a construct of dynamic capability was later proposed by researchers such as Breznik and Hirsch (2014), Saunila, Pekkola and Ukko (2014) and Sollosy (2013). It was also further proven via empirical research that enterprising SMEs display higher creativity and innovation, a prerequisite for business growth (Wagener, Gorgievski & Rijsdijk 2010). The concept was further empirically tested in varying fields, from health care, sales management and information technology, to name a few (Pedron et al. 2018; Strønen et al. 2017; Yoshikuni, Galvão & Albertin 2022).

Innovation is defined as a 'process of using new concepts for a product, service, business model or process that will create value', which a customer will be willing to pay for (Pedron et al. 2018, p. 499). This is achieved via knowledge about the market and its customer dynamics to gain a competitive advantage. Thus, innovation capacity, in simpler terms, means the ability of a business to develop new ideas, processes and business models to gain a competitive advantage and enhance resilience. The study by Ndesaulwa and Kikula (2016) of SMEs in Tanzania reveals that innovation capability unlocks the ability of SMEs to create innovation with existing strategic resources and capabilities, which require continuous improvement to add value to the customer of the SME. Schumpeter was the first to describe entrepreneurship as 'a process of change where innovation is the most vital function of the entrepreneur' (Wadhwani et al. 2020). Innovation disrupts industries, and Schumpeter identified entrepreneurs as 'creative

destroyers', people who bring change and disturb the status quo in the marketplace (Miller 2015).

Furthermore, Ng and Kee (2018) are of the view that entrepreneurial competencies, which entrepreneurial SMEs have to have to start making profits, enhance organisational capabilities that also cover innovation capacity. It is important to note that an SME's innovativeness depends on innovation-related activities (Yordanova & Blagoev 2015). In general, the literature acknowledges that innovation capabilities are necessary for SMEs to mitigate the tough competition in today's environment.

Dimensions of innovation capacity

Schumpeter believed that innovation is key to creating demand and thus of value for enterprises, contributing to maintaining their competitive advantage in a dynamic entrepreneurial environment (Hajar et al. 2022). Thus, as with the previous components of dynamic capability, innovation capacity is also a multifaceted concept with several dimensions that are available to SMEs to stay resilient. These dimensions of innovation capability include resource availability to take risks to stay innovative, a culture of innovation, KM and collaboration between employees and management. These dimensions are very important for the probability of full development of innovation capacity. As mentioned, the KM aspect was discussed under AC and collaboration between management as a general strategy for competitive advantage. Thus, the focus for this part will be on risk-taking and the culture of innovation.

As SMEs are the engine of capitalism, taking advantage of opportunities at risk, and expecting to profit from risk-taking is part of the process (Murinde, Rizopoulos & Zachariadis 2022; Nieuwenhuizen & Oosthuizen 2017). Schumpeter was also the first to coin the term 'risk-taker' as a trait of entrepreneurs, and this has led many researchers to include risk as one of the characteristics that define an entrepreneur, the person who is responsible for running a business. Risk is defined as 'the effect of uncertainty on objectives' of a business (Nieuwenhuizen 2020). The risk-taking propensity of an entrepreneur is one of the competencies of an entrepreneurial, growth-oriented SME owner (Nieuwenhuizen & Oosthuizen 2017). A business that does not have any aim risks any outcome. An ideal situation for making decisions is one of certainty, but unfortunately, SMEs in Industry 4.0 operate in a VUCA environment and thus have to consider the likelihood of certain outcomes resulting from their decisions. Growth-oriented entrepreneurs make the necessary calculations, business plans and forecasts and execute them despite the uncertainty and risk associated with the opportunity.

Another dimension of innovative capacity is the culture that encourages innovation, and this is also associated with making mistakes. This is important because if SME owners do not allow their employees to make mistakes, they will not experiment, which is the source of innovation. Bateman and Konopaske (2021) suggest that innovative cultures encourage finding external opportunities that bring resilient value. They also suggest that SMEs should overcome internal resistance and reluctance to change. This is done to enable SMEs to apply new technologies to enhance flexibility to take on new opportunities. Finally, they suggest that SMEs should experiment continuously to encourage innovation. Other dimensions of SMEs that embrace innovation include intrapreneurship, risk-taking, conflict tolerance, open systems, focus on outcomes and not only the route to get there, and accepting ambiguity (Naranjo-Valencia & Calderon-Hernández 2018).

☐ Determinants of innovation capacity

As the concept of innovative capacity is also determined by multidimensional factors, it is relevant as a determinant that enhances the ability of SMEs to adapt and be resilient in Industry 4.0. The determinants of innovative capacity are also a complex interplay of VUCA environmental factors as well as organisational cultures, organisational learning and resource flexibility, similar to the two dimensions of dynamic capabilities as discussed. In the context of innovation, organisational culture plays a crucial role in fostering innovation. This includes flexible human capital as well as collaboration and agreement with management. A culture that nurtures innovation should be a top priority of an SME that wants to apply innovation capability to stay resilient in the VUCA environment. The culture should have open systems and communication, experimentation and non-conformity. To experiment, the ongoing injection of funds into their research and development (R&D) should be a priority, as well as ensuring the protection of intellectual property.

☐ Innovative capacity operationalised

Small and medium enterprises are facing challenges, especially in the post-COVID-19, VUCA environment and need to be innovative to be resilient in the Industry 4.0 context. They need to have systems to manage organisational learning and resource flexibility to be able to apply the innovation in the window of opportunity at hand, most importantly, supporting culture. To encourage innovation capacity, SMEs should use different approaches to operationalise ADC. These again focus on organisational learning, resource flexibility and culture.

Operationalising innovation capacity in the context of SMEs means ensuring that the concepts and their determinants are embedded in the culture, in the learning, and in how the learning should be applied for innovation to take advantage of opportunities as soon as possible. When operationalising innovative capacity, SMEs should ensure:

- Human capital is managed in a way that ensures they apply themselves to the best of their ability.
- Human capital should be encouraged to know what is expected and be rewarded accordingly.
- Connections are between team members as well as management.
- Focus is on AC management, that people are managed properly involves ADC, meaning the application of the innovations in all aspects of the enterprise.
- There is a culture of trust, cooperation and appreciation and a culture that means business.

Impact of innovative capacity on Industry 4.0 adoption

Innovation capacity has had a great impact on industries that are grounded in Industry 4.0, especially the technology sector, recently. More research is currently trending in the context of technology ecosystems and how they can improve DCSs. This is a rapidly growing area of the adoption of innovation as a tool for competitive advantage. The ecosystems in question focus on how to adopt innovation in the Internet of Things (IoT), for example, in smart manufacturing and how to collaborate with supply chain partners, as well as how the ecosystems affect the development of smart products. These studies suggest that the focus should be on how to connect people and machines with new technologies such as artificial intelligence (AI), AR, blockchain and robotics, to name a few (Jegede 2021).

Innovation can be a great tool for any company that is looking for a transformation in the VUCA environment. Mancini et al. (2021) report that 94% of 400 global manufacturing companies indicated that Industry 4.0 has assisted them in being resilient in crises such as the COVID-19 disruption, and 56% state that it was essential to their pandemic response. The study does support the idea that innovation capacity enables SMEs to adopt and benefit from Industry 4.0 technologies. It allows them to be responsive to the new business environment and its effect on business performance, enhanced by Industry 4.0, which cannot be undermined.

Catalysing dynamic capabilities in an Industry 4.0 context

As discussed, it is clear that dynamic capabilities such as absorptive, adaptive and innovation capabilities can be a catalyst that will ensure that SMEs can cope and be resilient in the new world in which they operate. The dynamic capabilities lens adds value to SMEs, and its implementation to mitigate the Industry 4.0 challenges cannot be undermined.

Knowledge management

Dynamic capabilities enable SMEs to be proactive in the marketplace and, when active, ensure that the learnings are crystallised in the system and procedures. This is to ensure that the new knowledge can be applied to new opportunities and incorporated into systems and structures, referred to as the AC of an SME (Müller, Buliga & Voigt 2021).

Systems and structures

As a catalyst, ADC is a dimension of dynamic capabilities that SMEs need to undergo a digital transformation of their supply chains to survive the VUCA environment that ensures disruptions to how things are done. Small and medium enterprises need to develop ADC for their systems and structures to have the ambidexterity to survive the disruptions that Industry 4.0 guarantees.

Supportive culture

In addition, SMEs need to encourage a culture of innovation that is responsive to the disruptions that Industry 4.0 imposes on them. To foster a culture of innovation, SMEs need to have a supportive culture that encourages trust, cooperation and appreciation and a culture that means business. The role of human capital in unlocking innovation cannot be understated. When the human capital is aligned and encouraged to have a culture of innovation, they can assist SMEs to unlock huge potential in the changing business environment and stand a chance to also compete with big business.

Dynamic capabilities and research landscape of small and medium enterprises

The phenomenon was further expanded in about 2011 and has seen more than 200 publications per year since then. This saw dynamic capabilities

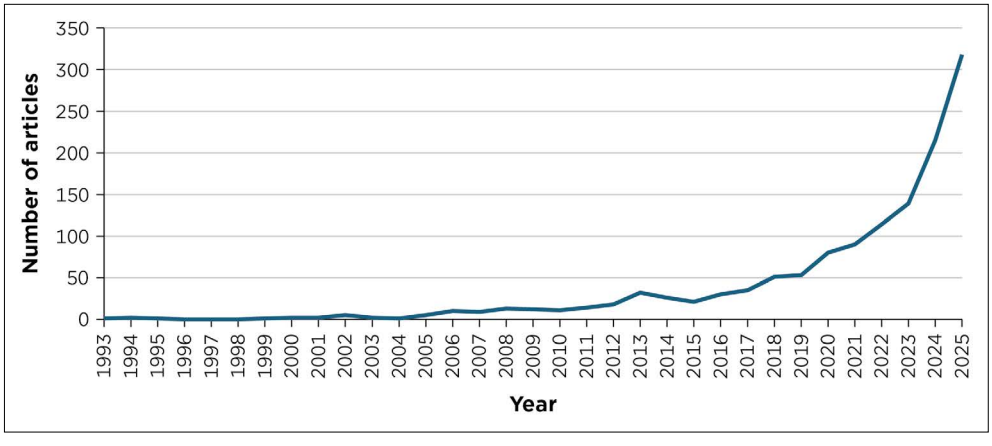
leading as the most researched topic in strategic management (Gremme & Wohlgemuth 2017). Table 8.1 shows some of the key contributors to the theory.

In addition, a bibliometric analysis was conducted to assess the current level of research on dynamic capabilities studies concerning SMEs worldwide. A search of documents dealing with dynamic capabilities studies concerning SMEs was realised in the Web of Science database, a world-leading publisher-independent global citation database. The search identified 191 documents, and the data collected were analysed using a bibliometric tool called Bibliometric. Figure 8.3 is an analysis of documents ranging from 1993 to 2023 and shows a spike in publications from 2017 to 2023, thus indicating an interest in the research on dynamic capabilities and their relevance to SMEs.

TABLE 8.1: Key theoretical contributors shaping the dynamic capabilities theory framework.

Authors' surnames and dates of studies	
Ambrosini and Bowman (2009)	Rindova and Kotha (2001)
Augier and Teece (2009)	Teece (2007)
Cepeda and Vera (2007)	Teece (2014)
Easterby-Smith and Prieto (2008)	Teece, Pisano and Shuen (1998)
Easterby-Smith, Lyles and Peteraf (2009)	Verona and Ravasi (2003)
Eisenhardt and Martin (2000)	Weerawardena et al. (2007)
Helfat and Peteraf (2003)	Wheeler (2002)
Hodgkinson and Healey (2011)	Winter (2003)
King and Tucci (2002)	Zollo and Winter (2002)
Pavlou and El Sawy (2011)	Zott (2003)

Source: Compiled by David Pooe and Dingi Masakale for this study (2026).



Source: Compiled for this study by David Pooe and Dingi Masakale (2026).

FIGURE 8.3: Annual scientific production of articles on dynamic capabilities and small and medium enterprises.

Furthermore, a concurrent analysis using Bibliometrix to analyse articles and papers on the terms in Figure 8.3 shows how relevant the dynamic capabilities are to SMEs in enterprise resource management. This analysis sheds light on the scholarly discourse surrounding the subject matter, uncovering insights into the role and effect of dynamic capabilities within the context of SMEs. By leveraging Bibliometrix, researchers can gain a comprehensive understanding of the current trends, perspectives and research gaps pertaining to dynamic capabilities and SMEs in enterprise resource management. This sophisticated analytical approach enables the synthesis of vast amounts of academic literature, facilitating nuanced interpretations and actionable insights for practitioners and policymakers alike.

Conclusion

SMEs operate in a highly volatile Industry 4.0 environment and, in order for them to be resilient and be competitive in this environment, they need to be open to new approaches to ensure that they can be competitive. The volatile environments, also known as VUCA, demand a dynamic approach in order to be resilient and competitive in these environments, a dynamic capability. This chapter explored the theory of dynamic capabilities, its history, as well as a brief bibliometric analysis of the most cited work on dynamic capabilities in the context of SMEs. This includes its origins in the field of strategic management, specifically the RBV and strategic capabilities. The chapter further discussed the relevance of the DCT to SME. As the components of the dynamic capabilities, the chapter further discussed the AC, ACD and innovation capabilities, their usefulness, their dimensions and determinants. Furthermore, in the context of supply chains, the chapter also discussed the operationalisation and the effect of the components on Industry 4.0 adoption. The chapter then discussed how dynamic capabilities act as a catalyst for change for SMEs in the Industry 4.0 context. Finally, using bibliometric analysis, the chapter analysed dynamic capabilities as a theory in the SME research landscape.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and D Masakale; *methodology* (*desktop-based literature review and conceptual synthesis*), D Pooe and D Masakale; *validation*, D Pooe and D Masakale; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and D Masakale; *resources*, D Pooe; *writing – original draft preparation*, D Masakale; *writing – review and editing*, D Masakale and D Pooe; *visualisation*, D Masakale; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 9

Augmented and virtual reality among small and medium enterprises

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Introduction

Nearly everything we consume, wear and/or utilise moves through a supply chain. However, the supply chain is not a fixed model; it adapts and innovates continuously to address the challenges posed by new market trends. As supply chain disruptions such as the global trade wars, the physical and

How to cite: Munongo, S & Pooe, D 2026, 'Augmented and virtual reality among small and medium enterprises', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 201–222. https://doi.org/10.4102/aosis.2026.BK572.09

financial restrictions resulting from the coronavirus disease 2019 (COVID-19) pandemic and consequent technology-driven shifts in consumer customisation demands accelerate, companies need innovative supply chains that can pivot quickly towards operational and informational efficiency with fewer capital obligations. Owing to the significant expenses involved in transporting goods, organisations are seeking ways constantly to reduce costs while also enhancing service. Emerging technology could provide a potential solution, and Industry 4.0 innovations in the form of augmented reality (AR) and virtual reality (VR) are poised to transform the supply chain innovation landscape. The coronavirus disease 2019 pandemic prompted a global shift to remote work, driving a surge in the AR and VR market. This growth was driven by the rise in online training, shopping, education, as well as sector-specific training and supervision facilitated by AR and VR technologies (Javadinasr et al. 2022; Lipták & Musinszki 2022). Interestingly, Deloitte (2023) indicates that these two realities are of keen interest as companies have developed composite product development processes increasingly, and the growing need for global alliances is beginning to drive the use of technology for smarter supply chain efficiencies. Accordingly, this chapter provides an overview of the AR and VR, looks at their potency in business, the current fields of application, adoption by small and medium enterprises (SMEs) and, finally, the critical success factors for their use.

Overview of augmented reality

Augmented reality refers to technology that enhances the real world by overlaying digital content such as images, sounds or other sensory inputs onto the real world in real-time (Arena et al. 2022; Isaksen 2020). It improves the user's perception of their surroundings by merging virtual components with the physical environment, usually through devices such as smartphones, tablets or AR glasses. Therefore, Cveticanin (2024) highlights that AR enhances the real world without replacing it.

Studies indicate that AR is revolutionising various sectors by merging digital elements with the physical world (Hidayat & Wardat 2024; Mendoza-Ramírez et al. 2023). In retail, AR helps to improve the shopping experience through virtual try-ons and interactive displays. Looking at health care, AR aids surgeries, training and patient care by displaying vital information. In manufacturing, AR provides on-the-spot assembly and maintenance guidance. Likewise, real estate employs AR for virtual tours and design visualisations (Naeem, Rana & Nasir 2023). Tourism and entertainment enhance experiences with interactive city tours and immersive gaming. In the automotive industry, AR is used for navigation and design visualisation, while military applications focus on training and operational support.

Also, De Moraes Rossetto et al. (2023) suggest that education benefits from AR for interactive lessons, virtual field trips and simulations. Finally, marketing uses AR to create engaging ad campaigns and product demos (Javeed, Rasool & Pathania 2024).

On the other hand, Cook et al. (2019), in a Deloitte (2018) report, describe VR as a technology that creates a fully immersive, computer-generated environment where users can interact with a three-dimensional (3D) world. They submit that, using specialised equipment such as headsets, gloves and motion sensors, VR allows users to experience and explore environments that feel real, even though they are simulated.

Additional studies indicate that VR has emerged as a transformative technology with widespread applications across various industries, offering immersive and interactive experiences that can replicate real-world environments or create entirely new, simulated worlds. In entertainment and gaming, Bhambri and Kautish (2024) submit that VR provides users with engaging, lifelike experiences, enabling them to explore virtual spaces and to interact with dynamic content in real time. In education, VR facilitates interactive learning by creating simulations that enhance understanding of complex subjects and provide experiential learning opportunities in fields such as medicine, engineering and history (Feridun & Bayraktar 2024). According to Paiva et al. (2024), the health care industry has benefited from VR by allowing for virtual training and simulations in surgical procedures, patient rehabilitation and mental health treatment, such as exposure therapy for anxiety and post-traumatic stress disorder. In addition, VR has become a valuable tool in manufacturing and engineering, where it is used for design visualisation, prototyping and simulation of processes in a virtual space before physical implementation (Bano et al. 2024). In retail, VR enhances consumer experiences by enabling virtual try-ons, product demonstrations and immersive shopping environments, improving customer engagement and satisfaction. Furthermore, studies reveal that VR is being employed increasingly in sectors such as real estate, tourism and architecture for virtual property tours, destination previews and architectural design walkthroughs (Adi et al. 2025; Riaz & Pervez 2024). Its potential to offer cost-effective training solutions, reduce risks and improve decision-making has made VR an essential tool in numerous sectors. As VR technology advances, its use across various industries is anticipated to grow, creating fresh opportunities for innovation and improved efficiency.

Power of augmented reality and virtual reality technology

According to Statista (2021), AR has been available commercially for several years, with its origins tracing back to the release of the iPhone's first AR application in 2009. Notwithstanding that, how big is the AR market? Is it merely a passing trend, or is it growing towards something important? Augmented reality statistics show that multiple brands, from e-commerce to health care, realise astounding results by adopting AR-enabled solutions. According to a report by Threekit (2020), the AR market was estimated to exceed US$50 billion by 2024. Moreover, global investments in AR technology have been expanding rapidly, with US$18.8 billion invested in AR in 2020 at the start of the COVID-19 pandemic. This represents a 78.5% increase compared to 2019.

In addition, a report on global market insights by Statista (2021) reveals that the AR market was valued at just US$1 billion in 2016; its growth rate from 2013 to 2016 provides a strong reference point for future projections. Furthermore, the report estimated that the AR industry's compound annual growth rate between 2017 and 2024 would be approximately 65%, with expectations to reach US$50 billion by 2024. However, Statista (2021) states that these estimates may have undervalued the AR market – by 2017, its worth had already increased to US$3.5 billion, and with revised forecasts, projects that its value will soar to US$198 billion by 2025. Significantly, the launch of the Metaverse and the growing accessibility of AR-related applications indicate that the current revenue forecasts for 2025 could still be overly cautious. Interestingly, Cook et al. (2019) find that nine in 10 medium-sized brands are using AR to power their business ventures. The research states that 88% of mid-sized businesses leverage AR capabilities for multiple purposes, including accelerated training, goal-oriented supply chain and marketing strategies, effective product development, fostering collaboration and enhanced internal communication. Moreover, a study by Deloitte Digital and Snap Inc. (2021) reported that by the year 2025, 75% of the global population will become active AR users. These usage statistics show that AR is thriving across industries, and more brands will invest to gain AR benefits.

From a business standpoint, Deloitte (2017) contends that VR is utilised for product and process development, remote collaboration and immersive learning experiences. The study further submits that, from 2013, there has been a significant surge in both the capabilities and adoption of VR devices – once primarily used by hard-core gamers, these devices have evolved into mainstream technology with broad applications for both consumers and businesses. Since the beginning of the outbreak of the COVID-19 pandemic-induced supply chain disruptions, organisations across the

globe have made significant investments in both VR hardware and software development in a bid to innovate traditional supply chains. It is only a matter of time before additional obstacles are overcome, allowing the full potential of enterprise capabilities to be realised fully (Deloitte 2018).

Fields of augmented reality and virtual reality technology application

There are various fields that can benefit from the use of AR and VR technology, and these include supply chain, manufacturing, retail, entertainment and gaming, immersive education, health care and real estate.

Supply chain

Augmented reality and VR are now integral to the supply chain, transforming how factory workers, engineers and service technicians operate. Distributors also leverage these technologies, particularly in inventory management, as they enhance tracking, monitoring and understanding of consumer demand (Isaksen 2020; Tsang et al. 2022). While still in the early stages of adoption, AR provides significant advantages in the logistics sector, particularly in supply chain management. Rejeb et al. (2020) report that as companies work with various partners and suppliers to coordinate orders across multiple warehouses, AR can enhance efficiency and accelerate supply chain processes. Owing to advancements in artificial intelligence (AI) and blockchain technology (BCT), AR is expected to revolutionise the software used for managing supply chains (Rane, Choudhary & Rane 2023).

Augmented reality now assists truck drivers, warehouse workers, the management of companies and other supply chain stakeholders to keep track of the product picking process, warehouse planning, transportation, freight loading, completeness checks, dynamic transport support and international trade from when products depart the factory to when they reach the end-consumers. Chen et al. (2020) indicate that by using sensors on packaging, different stakeholders in the supply chain will be able to conduct in-depth analysis of the performance of a company's products. In addition, the study suggests that data scientists involved in the digital supply chain can derive new insights from these products, whether they are in the back of a delivery truck or on the warehouse shelf of a distributor. Therefore, AR technology can foster supply chain innovation through improving the picking process, warehouse planning, performing completeness checks and improving inventory visibility and management.

In essence, VR holds the most promise for transforming supply chains in four key areas: product and process design, employee collaboration, data and process visualisation and experience-driven learning (Fitzgerald et al. 2018, in Deloitte 2018). Through immersive VR applications, Deloitte (2018) indicates that global teams can streamline process and product design by working together in real time, regardless of physical location. Furthermore, the report finds that by leveraging VR to plan a factory line, engineers can collaborate on the design and gain hands-on experience in the new environment. Again, simultaneously observing the interaction between workers and robots in the virtual space provides valuable insights into optimising the factory line. In addition, the use of 3D visualisation to analyse complex data sets in innovative ways will affect supply chain planning, as businesses adopt new tools to handle customer data (Deloitte 2018). The report also submits that immersive virtual environments are proving to be an effective resource for training, allowing decision-making best practices and procedures to be learned through low-risk trial and error.

Manufacturing

In the manufacturing industry, AR and VR are typically employed in domains such as automated workflows, remote collaboration and access to data. In automated workflows, AR enables engineers to complete tasks more efficiently; otherwise, they would typically need extensive training over several years to put together intricate machines such as aircraft. However, by using AR glasses, those same engineers can view instrument executions and receive step-by-step instructions for assembling a specific component.

While remote work has existed for some time, in the manufacturing industry, it has not always been easily achievable. Isaksen (2020), in a report for enavate.com, emphasises that AR introduces new possibilities for digital collaboration and expert support in troubleshooting and maintenance, reducing costs and time by eliminating the need for physical travel. Furthermore, the report observes that the urgency for remote capabilities has increased as organisations have adapted to new health and safety regulations. Again, AR and remote collaboration help employers comply with safety guidelines, protect high-risk employees and manage workforce capacity effectively. Therefore, by enabling seamless interaction between on-site and remote workers, organisations can adopt more flexible and innovative scheduling approaches promptly.

Furthermore, for seamless data accessibility, manufacturing companies can leverage AR-powered solutions to scan QR codes and access live video feeds, pictures and graphics (Patel 2024). This, in turn, enables efficient and cost-effective machine repairs when necessary. Augmented reality

allows organisations to detect issues visually on the shop floor and address them swiftly, enhancing workflow optimisation while conserving valuable time and financial resources.

On the other hand, it is observed that a key value driver for manufacturing companies is the ability of VR to provide interactive visualisation (Deloitte 2017; Pessot, Zangiacomi & Sacco 2023). The studies suggest that SMEs are beginning to adopt this technology in their design teams to improve computer-aided design (CAD) functionality and boost employee engagement. Virtual reality-enhanced designs offer advanced visualisation features that were unavailable previously, enabling product engineers, architects and designers to explore multiple design iterations quickly and assess them in real time. Moreover, automotive and large construction firms are collaborating with design software developers and VR hardware manufacturers to develop these immersive experiences. Since producing virtual archetypes can be time-intensive, VR helps to reduce reliance on physical prototyping and expensive initial testing, ultimately lowering costs for these organisations.

Retail

In the retail sector, AR and VR help businesses to engage effectively with their target consumers by guiding them through the entire buying journey – from identifying a need to searching for a product and ultimately selecting the preferred item (Singh et al. 2024). For instance, through AR, SME retailers can improve their sales revenues by employing 3D models that are much more appealing compared to conventional web configurators. Furthermore, AR applications can provide SMEs with critical data to leverage better business opportunities. Augmented reality-based applications offer retailers comprehensive insights into customer behaviour, preferences and demographics, enabling managers to optimise their sales strategies. In addition, AR enhances brand visibility and facilitates the promotion of new products or services to targeted consumers (Thakkar, Joshi & Kachhela 2023). For instance, Converse and L'Oréal Paris have long employed AR technology for their advertising campaigns.

Entertainment and gaming

Gaming is evolving constantly and advancing in sophistication, with AR-powered applications offering limitless benefits. Simulation games are recognised widely and growing in popularity among users. Augmented reality enhances the realism of virtual environments for gamers, allowing them to refine real-life skills in a secure setting.

Immersive education

A typical example of the use of AR in immersive educational initiatives is the Google Classroom platform. The extensive use of 360-degree videos, virtual walkthroughs and 3D graphics is an example of the excellent benefits of AR technologies. In addition, advanced AR applications assist students and workers in high-risk environments, such as the military, to improve their skills and to eliminate mistakes that could possibly cost them their lives.

Health care

Augmented reality application in the health care field allows the monitoring of patients' vital signs for more precise diagnosis and eventually ensures effective treatment. The augmented reality-powered technologies send alerts about irregularities or signs to clinicians, enabling them to evaluate the condition quickly and to provide prompt support. Examples of such technologies include The EyeDecide and AccuVein applications, which diagnose vision and vein problems, respectively (Vijayanarayanan et al. 2023).

Real estate

Both AR and VR have stirred a ripple of excitement and sparked interest among businesses in recent years in the real estate market. Some of the advantages of AR and VR technologies in real estate include mobility and interactivity. Augmented reality removes the need for a potential client to travel to the actual location to envision their needs, as accessing AR and VR requires nothing more than a suitable device. The technologies enable users to experience 3D walkthroughs of the listed properties (Kamil et al. 2021). They assist businesses in showing workspaces or homes to potential buyers before they are even constructed or designed. Augmented and virtual reality also offer a high degree of interaction, when an estate agent wants to show their customers what their new apartments will look like.

Small and medium enterprises' augmented reality and virtual reality technology adoption

While still in the early stage of adoption and subject to resource limitations, augmented and virtual technologies hold the promise of numerous benefits and opportunities for SMEs. Adoption of AR and VR technologies assists in the social media marketing strategies of SMEs, avoids design errors and

revolutionises how organisations develop prototypes, manage operations and train staff.

Social media marketing

According to the Immersive Learning News (2022), both AR and VR focus on creating an engaging digital experience for users. These technologies offer tangible benefits to businesses aiming to accelerate growth and improve key metrics such as conversion rates, retention and profit margins. A simple way for SMEs to implement AR and VR is through marketing strategies – platforms such as Facebook already support AR advertisements. According to Immersive Learning News (2022), these captivating technologies can also enhance brand recognition, help SMEs to stand out from competitors and enable customer engagement even during times of social distancing. For instance, Cveticanin (2024) identifies that Google's 'view in 3D' mobile search feature allows e-commerce platforms to showcase products through AR, making it possible for consumers to view items virtually as though they were physically present, provided the SME product is well ranked in search results. Moreover, AR and VR can help businesses to attract tech-savvy candidates and appeal to millennials who may feel more comfortable in digital environments (Dutta, Srivastava & Singh 2023).

Avoiding design errors

Developing new equipment is quite complex, and any flaws that arise during this phase can be costly, as it may take a significant period of time to resolve them. The adoption of AR and VR by SMEs helps to save financial, human and time resources by employing simulated archetypes of the intended model (Subramanian et al. 2025). For example, experts can view designs as 3D projections on tablets, and virtual design tests can be conducted to identify flaws that may not be apparent during the initial design phase.

Speeding up product development and installation

Virtual reality is an excellent tool for SMEs to improve product development. Businesses can use VR to create new products or to test store layouts, gathering customer feedback before refining and implementing the final design in the physical world. Like AR, VR offers companies a unique opportunity to collect real-time feedback from users consistently (Deloitte Digital and Snap Inc. 2021). Furthermore, Fang et al. (2023) note that SMEs often struggle with the lengthy process of interpreting machinery installation instructions.

Consequently, they are constantly looking for ways to accelerate the installation of technological systems without compromising on quality. Augmented reality comes through as a solution, allowing businesses to reduce both effort and time spent on installations. Therefore, it replaces paper manuals fully, as each component comes with a detailed certificate outlining its use.

Efficient staff training

Even highly skilled employees still need ongoing training and development, but this often consumes valuable time that could be spent on other tasks. Augmented and virtual reality offer more efficient learning opportunities during work, reducing the need for human involvement (AlGerafi et al. 2023). A notification system is more effective than having a personal mentor to address this issue. Furthermore, AR can help to reduce organisational expenses related to employee recruitment, onboarding and training. Although initial investment in specialised equipment may be required, Immersive Learning News (2022) suggests that AR and VR headsets or mobile apps are reusable and can help to offset the costs of in-person lessons or training sessions.

Critical success factors for adoption of augmented reality and virtual reality applications by small and medium enterprises

The rapid advancements in AR and VR have opened new avenues for SMEs to enhance their competitive edge. Undeniably, AR and VR technologies have gained significant traction across various industries, offering immersive experiences and innovative solutions. However, SMEs face unique challenges when integrating these applications into their operations. This section explores the critical success factors necessary for the successful adoption and implementation of AR and VR applications by SMEs. These are some of the various key determinants to be discussed: technological infrastructure, financial investment, user experience, training and skills development, regulatory compliance, market readiness and strategic partnerships.

Technology infrastructure

The adoption of AR and VR by SMEs is influenced significantly by the availability and robustness of technology infrastructure, which serves as a foundational enabler of these immersive technologies. Augmented and virtual reality require substantial computing power, high-speed internet

connectivity, compatible hardware and software, and seamless integration into existing business processes (Javeed, Rasool & Pathania 2024). Small and medium enterprises must invest in high-speed networks, software compatibility, cloud computing and cybersecurity measures to shape the feasibility and effectiveness of immersive technology integration collectively (Naik & Bhardwaj 2024). In addition, it is essential to invest in high-performance hardware, such as AR headsets and VR devices, and to ensure compatibility with existing software and networks. Given the financial and technical constraints of SMEs, Mosbah (2024) highlights that strategic partnerships with technology providers, cloud service firms and telecom companies can bridge infrastructure gaps and enhance the accessibility of AR and VR solutions. Policymakers and industry stakeholders can promote AR and VR adoption by facilitating affordable digital infrastructure, grants and technical support to drive SME innovation through AR and VR adoption.

Financial investment

The adoption of AR and VR technologies by SMEs represents a transformative step towards enhanced business capabilities. However, financial investment is a critical determinant in integrating these advanced technologies, as the high costs associated with their development and deployment often pose a significant barrier to SMEs. The initial financial commitment required for AR and VR adoption includes not only the purchase of hardware and software, but also the potential costs of training, infrastructure and maintenance (Rahman & Ayob 2024). This financial hurdle is particularly pronounced for SMEs, which operate typically with limited capital and face higher financial risks than larger enterprises. Nevertheless, Rialti and Zollo (2023) note that several strategic approaches can enable SMEs to mitigate the financial burden of AR and VR adoption while ensuring that they maximise the return on investment. In turn, SMEs can use these strategies for effective financial management: phased implementation, seeking financial grants or subsidies and leveraging targeted-use cases. A phased approach to AR and VR implementation allows SMEs to spread their financial investment over time, reducing the pressure of a large, upfront expenditure. By introducing AR and VR solutions gradually into key business processes such as marketing, product design or customer service, SMEs can limit their initial outlay and assess the effectiveness of the technology before committing further resources (Alshahrani 2023).

This step-by-step adoption also enables businesses to gather data on performance, adjust their strategy as needed, and ensure that the investment aligns with organisational goals. In addition, phased implementation provides the flexibility to adapt to evolving technological

advancements, ensuring that SMEs remain competitive without overextending their financial resources. Many governments, industry organisations and research institutions also offer financial grants, subsidies or tax incentives to encourage the adoption of emerging technologies such as AR and VR, especially for SMEs (Spina 2024). These financial support mechanisms can reduce the cost burden of AR and VR adoption significantly by providing direct funding or subsidised access to hardware, software and training resources. Small and medium enterprises should explore available funding opportunities actively to help offset initial investment costs. Furthermore, such financial support can also signal the commitment of the business to innovation, potentially opening doors to additional sources of funding, partnerships and business development opportunities. Moreover, to ensure that financial investment in AR and VR yields a high return, SMEs must select and focus carefully on specific use cases that offer the greatest potential for cost reduction, increased productivity or enhanced customer experiences (Aithal 2023). For example, SMEs in manufacturing could implement AR for remote maintenance, while those in retail might leverage VR for virtual product trials or immersive shopping experiences. By targeting high-impact applications, SMEs can demonstrate the value of AR and VR adoption to stakeholders quickly, accelerating the recovery of initial costs and ensuring that the technology delivers tangible benefits. Therefore, while the financial challenges associated with AR and VR technology adoption for SMEs are considerable, these challenges are not insurmountable. Small and medium enterprises can manage the costs of AR and VR adoption successfully, and by doing so, they position themselves to leverage the transformative potential of these technologies, driving innovation, improving efficiency and gaining a competitive edge in their respective markets. Ultimately, the ability to invest strategically in AR and VR technologies is a key success factor that can determine the long-term viability and growth of SMEs in an increasingly digital and technology-driven business landscape.

User experience

User experience also plays a crucial role in fostering long-term engagement with AR and VR applications. The more positive and effortless the experience, the higher the likelihood of sustained use and acceptance across the organisation or among customers (Ebrahimabad et al. 2024). Engaged users are more likely to leverage the full potential of the technology, providing SMEs with a competitive advantage. By ensuring that the technology is not only functional but enjoyable and easy to use, SMEs can encourage both immediate adoption and long-term loyalty to AR and VR systems. Also, for SMEs integrating AR and VR into their business processes,

this can be a game-changer, but more importantly, is the seamlessness and intuitiveness of the technology, which is paramount to its successful adoption and continued use.

Kim, Rhui and Yun (2020) posit that a user-friendly interface is the foundation of an effective AR and VR experience. If an application or system is difficult to navigate or requires a steep learning curve, even the most advanced technological features will not drive adoption. Small and medium enterprises must prioritise simplicity and accessibility, ensuring that users, regardless of their technological expertise, can interact easily with the system. This approach does not only reduce barriers to entry for non-technical users but also fosters confidence in using the technology regularly. In addition to user-friendliness, functionality is a major determinant in the success of AR and VR applications. Functionality refers to how well the application meets the specific needs of the users in the SME context, such as enhancing training experiences, improving product design or facilitating virtual product trials (Karre, Reddy & Mittal 2024). These applications must be reliable, responsive and capable of delivering the intended outcomes, such as high-quality simulations, accurate tracking and real-time data interaction. Therefore, SMEs should focus on aligning the functionalities of AR and VR with their strategic business goals to provide value to their users. Therefore, conducting usability testing is an essential component of refining the user experience. By assessing how real users interact with the technology, SMEs can uncover pain points, usability issues and areas for improvement. Testing should be comprehensive, engaging end-users in the process from the early stages of development to post-launch feedback. Gathering direct input from the end users provides invaluable insights that can guide iterative improvements and feature updates. Furthermore, integrating feedback loops into the development process encourages continuous engagement and adaptation, ensuring that the technology evolves alongside user needs and preferences.

Training and skills development

Training and skills development are crucial – as SMEs increasingly recognise the value of AR and VR in enhancing business operations, whether for customer engagement, product development or process optimisation, the role of skilled employees becomes paramount. According to Kaplan et al. (2021), AR and VR are complex technologies that require specialised knowledge for development, deployment and maintenance. For SMEs to capitalise on these technologies, investing in targeted training programmes is not merely an option but rather a strategic necessity. The implementation

of AR and VR involves various technical domains, including software development, hardware integration, 3D modelling and user interface design. Small and medium enterprises must ensure that their workforce possesses the requisite technical capabilities to develop, deploy and maintain AR and VR solutions effectively.

Training programmes can focus on specific technical skills, such as software development, hardware integration and maintenance, 3D design and modelling, and UX and user interface design for immersive technologies. Employees need proficiency in coding for AR and VR platforms, understanding programming languages, for example, C++, Python and Unity, as well as requisite frameworks tailored for immersive experiences (Scott et al. 2020). Similarly, it is key that there is an in-depth understanding of the integration of hardware components such as VR headsets, AR glasses, motion tracking devices and sensors, which is critical for ensuring seamless deployment and performance. Furthermore, employees must be trained in creating virtual environments, objects and animations, which are essential for delivering compelling AR and VR experiences. Also, specialised training is required in designing intuitive user interfaces for AR and VR platforms as these interfaces differ significantly from traditional web or mobile designs. Studies indicate that a key challenge for SMEs lies in bridging the knowledge gap, as AR and VR technologies often require expertise beyond their internal capabilities (Aquino et al. 2023; Jalo et al. 2022).

Collaborations with educational institutions and industry experts can address this gap. Most importantly for SMEs, the challenge is not only in training employees but also in ensuring that knowledge is transferred and retained effectively. Training should be structured to support both theoretical understanding and hands-on experience. Some strategies include mentorship programmes, simulated environments and pilot projects, cross-functional training and continuous learning and development. Ultimately, the adoption of AR and VR technologies by SMEs hinges on the skills and expertise of their workforce (Xygkogianni 2023). By investing in comprehensive training programmes, collaborating with educational institutions and industry experts and fostering a culture of continuous learning, SMEs can position themselves effectively to harness the full potential of AR and VR. Skilled employees will not only facilitate the smooth implementation of these technologies but will also contribute to their evolution in the enterprise, ensuring long-term success in an increasingly immersive technological landscape.

Regulatory compliance

Regulatory compliance also serves as a critical success factor for the effective and ethical integration of AR and VR technology by SMEs. Ensuring adherence to industry regulations, data privacy laws and cybersecurity standards is not a mere legal obligation, but also a key enabler of long-term success (Mosbah 2024). Small and medium enterprises must be cognisant of the industry regulations and standards in which their intended AR and VR applications operate. Many sectors, such as health care, education, finance and entertainment, are governed by specific regulations that set the standards for the use of immersive technologies. Compliance with such sector-specific regulations is vital for SMEs to avoid legal repercussions and to ensure the responsible use of AR and VR technology (Singh et al. 2024). Hence, SMEs must navigate complex regulatory frameworks to ensure that their applications are safe and effective. Furthermore, SMEs need to take data privacy laws into account as AR and VR technologies can gather significant amounts of user data, ranging from biometric information to behavioural and interaction data. Consequently, SMES must adhere to data privacy laws, such as the *Protection of Personal Information Act* in South Africa and the General Data Protection Regulation in the European Union.

Compliance with such laws ensures that user data are collected, processed and stored in a way that is transparent, secure and respectful of user rights. Small and medium enterprises must therefore establish robust data management frameworks that include consent mechanisms, data anonymisation techniques and stringent access controls to protect sensitive information. Failing to comply with these regulations can lead to hefty fines and reputational damage, undermining the trust that users place in AR and VR applications (Tang 2025). In addition, the immersive nature of AR and VR applications makes them vulnerable to cybersecurity threats, including data breaches, unauthorised access and system manipulation. Given the sensitive nature of the data involved in these technologies, such as user behaviour, physical movements and potentially health-related data, securing these systems is paramount. Small and medium enterprises adopting AR and VR must implement rigorous cybersecurity measures to safeguard user data and ensure the integrity of their applications (Rana & Chicone 2025).

Adhering to cybersecurity best practices involves encryption of data, secure authentication mechanisms and regular security audits. Compliance with internationally recognised cybersecurity standards can enhance the credibility of the AR and VR offerings of SMEs further and demonstrate a

commitment to protecting users. Moreover, for SMEs, regulatory compliance is about meeting current requirements and future-proofing their AR and VR investments. As regulatory landscapes continue to evolve, especially with the rapid development of immersive technologies, SMEs must stay ahead of regulatory changes to remain compliant. By integrating regulatory compliance proactively into their AR and VR development processes, SMEs can avoid costly revisions to their applications and ensure a smoother path towards scaling their solutions (Mattiello & Domann 2024). This forward-thinking approach enables SMEs to expand their user base without the risk of falling foul of emerging regulations, thereby supporting sustainable growth. Therefore, by ensuring adherence to industry regulations, data privacy laws and cybersecurity standards, SMEs avoid legal and financial risks and foster trust with users and stakeholders. This comprehensive approach to compliance supports the ethical and secure deployment of immersive technologies, enabling SMEs to innovate and scale responsibly. In a rapidly evolving technological landscape, integrating compliance frameworks into AR and VR adoption strategies is essential for long-term success, reputation management and fostering user confidence (Rawat & Hagos 2024).

Market readiness

Market readiness encompasses customer awareness, demand and the overall preparedness of the ecosystem for these innovations. Market readiness determines whether AR and VR solutions can achieve sustainable integration and commercial viability (Anjum & Bakar 2024). Firstly, SMEs need to have a comprehensive understanding of market demand and customer expectations. Scholars note that AR and VR technologies are transformative, but their adoption hinges on consumer and industry acceptance (Hwang & Seo 2025; Oyewole et al. 2024). Small and medium enterprises must conduct comprehensive market research to identify industries and customer segments that benefit most from AR and VR applications. For example, retail, health care, manufacturing and education assess consumer familiarity with and willingness to pay for AR- and VR-enhanced experiences, and understand usability expectations, ensuring accessibility and seamless interaction. Secondly, without sufficient demand and clear customer value, AR and VR investments may fail to yield expected returns. Therefore, SMEs must have customer education and awareness campaigns, which can also influence market acceptance (Dallasega et al. 2025).

Thirdly, conduct market research and feasibility analysis, which enables SMEs to leverage qualitative and quantitative research methods to evaluate market feasibility. The methodologies employed may include surveys and

focus groups to assess consumer perceptions, competitive analysis to benchmark against existing AR and VR applications, and cost-benefit analysis to determine financial viability (Pöhler & Teuteberg 2024). It is essential to note that market research should also consider technological trends, regulatory frameworks and industry-specific barriers to AR and VR technology adoption. Fourth is the pilot projects and prototyping. Given the high initial investment required for AR and VR, SMEs should implement pilot projects to test feasibility before full-scale deployment. Pilot programmes allow for real-world validation of AR and VR applications, customer feedback collection to refine offerings and iterative improvements based on actual user interactions (Chandana, Shaik & Chitralingappa 2023). Pilot projects also help SMEs to minimise risk, optimise solutions and build stakeholder confidence before scaling up.

Last is the process of tailoring the AR and VR technology offerings to suit the specific market needs. In this final stage, SMEs must customise their AR and VR solutions to align with the specific demands of their target markets. This customisation includes personalisation – developing industry-specific applications, for example, VR training for manufacturing workers, AR-enhanced online shopping experiences, scalability – ensuring that solutions are adaptable for businesses of different sizes, affordability – addressing cost barriers by offering flexible pricing models and a customer-centric approach, which enhances adoption rates by ensuring that solutions deliver tangible business value (Abrokwah-Larbi 2024).

Strategic partnerships

Strategic partnerships play a critical role in mitigating the numerous challenges faced by SMEs, which include high costs, technical complexity and limited expertise in AR and VR integration (Pessot, Zangiacomi & Sacco 2023). Small and medium enterprises should collaborate with technology providers, investors and industry stakeholders to enhance market readiness. These strategic partnerships can help SMEs to reduce the cost of AR and VR development through shared resources, improve interoperability with existing business systems and increase market reach through joint marketing efforts. Developing and deploying AR and VR solutions requires significant financial investment in hardware, software and skilled labour. Through strategic partnerships with technology providers, SMEs can access cost-effective development frameworks, shared infrastructure and technical expertise (Jalo et al. 2022). Again, collaboration with research institutions and technology incubators supports innovation further by providing SMEs with access to cutting-edge research, prototype testing and regulatory guidance (Mattiello & Domann 2024).

Collaborating with AR and VR development firms or cloud service providers allows SMEs to leverage Software-as-a-Service and Platform-as-a-Service models, reducing upfront costs (Mourtzis et al. 2024). In addition, pooling resources through industry consortia and innovation hubs fosters a cooperative approach to technological advancement, making AR and VR adoption more financially viable. One of the major hurdles that SMEs face when adopting AR and VR applications is also integrating these technologies with existing business processes and information technology (IT) systems. Strategic partnerships with software developers and enterprise technology providers help to ensure that AR and VR solutions are compatible with current customer relationship management, enterprise resource planning (ERP) and supply chain management systems (El Khatib et al. 2023). Such collaborations enhance seamless data exchange, improve workflow automation and increase overall business operation efficiency, thereby reducing the risk of technology fragmentation.

Also, strategic alliances with marketing firms, industry influencers and distribution partners enable SMEs to broaden their market exposure and enhance customer acquisition. Joint marketing efforts, such as co-branded campaigns and AR and VR demonstration events, create greater awareness and facilitate market penetration (Wang et al. 2020). In addition, partnering with established players in the AR and VR ecosystem allows SMEs to leverage existing distribution networks, accelerating the commercialisation and scalability of their AR and VR offerings (Falola et al. 2025). Furthermore, public–private partnerships (PPPs) and government-backed initiatives can serve as essential enablers of the AR and VR adoption of SMEs by addressing financial and technical constraints faced by SMEs. Governments can provide grants, tax incentives and subsidised training programmes that encourage SMEs to explore and implement AR and VR solutions (Amuso, Poletti & Montibello 2021). By participating in PPPs, SMEs can enhance their technological capabilities while minimising financial risks.

Scalability and flexibility

The adoption of AR and VR by SMEs hinges significantly on scalability and flexibility, as these factors determine the long-term viability and adaptability of these immersive technologies in dynamic business environments. Unlike large enterprises with extensive financial and technological resources, SMEs often operate with constrained budgets and evolving operational demands (Bakhtiari et al. 2020). As such, AR and VR solutions must align

with the growth trajectory of SMEs while allowing for incremental expansion and adaptation to changing market conditions.

☐ Scalability

Scalability refers to the ability of AR and VR solutions to expand in capacity, functionality and user base without requiring complete system overhauls (Qiao et al. 2019). For SMEs, scalable AR and VR solutions ensure that initial investments remain viable as business operations grow. This is particularly relevant in industries such as retail, manufacturing and training, where an increasing number of employees, customers or processes may require AR and VR integration. A scalable AR and VR solution possesses these characteristics:

- *Modular design*: Modular AR and VR platforms enable businesses to start with core functionalities and add new features over time (Joshi et al. 2023). For example, an SME in e-commerce may initially adopt AR for virtual product try-ons and later integrate VR for an immersive shopping experience.
- *Cloud-based infrastructure*: Cloud-based AR and VR solutions provide SMEs with on-demand scalability by leveraging cloud computing power to handle increased data processing needs. This reduces the dependency on costly on-premises hardware while ensuring seamless upgrades (Sabah Mustafa et al. 2023).
- *Interoperability with existing systems*: Scalable AR and VR solutions should integrate with existing business software, including customer relationship management and ERP, to facilitate a smooth transition and ensure operational continuity as the company grows (Saranya et al. 2025).

☐ Flexibility

Flexibility refers to the adaptability of AR and VR systems to changing business needs, technological advancements and market trends (Yazdi 2024). Given the rapid evolution of immersive technologies, SMEs must adopt AR and VR solutions that allow for easy updates and modifications without significant financial burdens.

These features are key aspects of a flexible AR and VR technology:

- *Customisation options*: SMEs require AR and VR solutions that can be tailored to specific industry requirements, such as virtual training modules in manufacturing or interactive customer engagement tools in retail (Jalo et al. 2022).

- *Device-agnostic solutions*: Flexible AR and VR platforms should support multiple devices, including headsets, smartphones and tablets to maximise accessibility and minimise hardware constraints.
- *Subscription-based and Pay-per-use models*: Many SMEs benefit from Software-as-a-Service AR and VR models that allow them to scale their usage based on demand without heavy upfront capital investments (Mourtzis et al. 2024).

Ethical and sustainability implications

Augmented and virtual reality technologies present significant ethical and sustainability implications for SMEs, particularly as these tools become embedded in training, design, maintenance and customer engagement processes. From an ethical perspective, SMEs adopting AR and VR must address concerns related to data privacy, surveillance and informed consent, especially where immersive systems collect biometric, behavioural or performance data from employees. Unlike large corporations, SMEs often lack dedicated governance structures, increasing the risk of opaque data use and inadequate protection of worker rights. There is also a risk that immersive monitoring tools could intensify labour control or exacerbate skills-based exclusion if access to training and digital literacy is uneven across the workforce. From a sustainability standpoint, AR and VR can contribute positively by reducing material waste, travel-related emissions and physical prototyping through virtual simulations and remote collaboration. However, these benefits may be offset by the environmental footprint associated with energy-intensive hardware, short device life cycles and electronic waste, which SMEs may struggle to manage responsibly. Consequently, the ethical and sustainable deployment of AR and VR in SMEs requires proportionate governance frameworks, transparent data practices, inclusive skills development and procurement strategies that prioritise energy efficiency and device longevity, ensuring that productivity gains do not come at the expense of social well-being or environmental responsibility.

Conclusion

Augmented and virtual reality technologies have sparked a keen interest among businesses in recent years. Although AR and VR appear identical and share multiple features, these technologies have prominent differences. Virtual reality takes the users into the virtual world while separating them from the physical or real-world scenarios, whereas AR integrates simulated objects into the real world to enrich the user's experience. Currently, there is a growing trend of AR and VR usage in various fields across the globe,

including supply chain, manufacturing, immersive education, retail, health care and real estate. Statistics also project increased AR and VR usage, reach and revenue-generating capacities shortly. As these forms of Industry 4.0 technologies are maturing progressively, SMEs are now adopting and leveraging AR and VR benefits. While still in the early stages of adoption and constrained by resource limitations, augmented and virtual technologies hold the promise of numerous benefits and opportunities for SMEs, such as efficient development of prototypes, management of operations, social media marketing, avoiding design errors and staff recruitment and training. Furthermore, SMEs need to consider several critical success factors for AR and VR applications, such as the needs of the individual organisation, functional deployment, technology infrastructure, cyber-security concerns, operating environment, perceptions and the local and international usage and intellectual property regulatory frameworks and changes thereto over time.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Pooe and S Munongo; *methodology* (*desktop-based literature review and conceptual synthesis*), D Pooe and S Munongo; *validation*, D Pooe and S Munongo; *investigation* (*systematic review and interpretation of secondary sources*), D Pooe and S Munongo; *resources*, D Pooe; *writing – original draft preparation*, S Munongo; *writing – review and editing*, S Munongo and D Pooe; *visualisation*, S Munongo; *supervision*, D Pooe; *project administration*, D Pooe.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

Chapter 10

Industry 4.0 and small and medium enterprise performance

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Introduction

Globally, small and medium enterprises (SMEs) play a pivotal role as catalysts for socioeconomic development, employment creation and poverty reduction, and as engines for innovation. However, they face significant challenges in maintaining competitiveness, improving financial performance

How to cite: Munongo, S & Masakale, D 2026, 'Industry 4.0 and small and medium enterprise performance', in D Pooe (ed.), *Industry 4.0 dislocations in small and medium enterprises: A supply chain management view*, AOSIS Books, Cape Town, pp. 223–248. https://doi.org/10.4102/aosis.2026.BK572.10

and optimising non-financial outcomes. On the other hand, swift technological developments have led to Industry 4.0, which is altering all manner of doing business across the globe rapidly. Essentially, Industry 4.0 is driven by technological advancements, representing a digital transformation propelled by pioneering innovations and novel ways of value creation through the adoption of digital technologies, including artificial intelligence (AI), additive manufacturing (such as three-dimensional [3D] printing), the Internet of Things (IoT), cyber-physical systems (CPS), big data, cloud computing and autonomous robotics, among others. Recent data indicate that the shift towards Industry 4.0 technology adoption can transform the organisational operations of SMEs, improve product and/or service delivery efficiency and enhance overall performance. Ideally, unlike their large counterparts, SMEs should have the advantage of flexibility and should adopt technological innovations readily. This chapter explores the effect of Industry 4.0 on SME performance, evaluating financial and non-financial dimensions. It provides insights into how Industry 4.0 enhances operational efficiency, cost-effectiveness, decision-making, customer engagement and sustainable practices. Furthermore, it highlights potential barriers and strategies for SMEs to leverage Industry 4.0 effectively.

Dimensions of small and medium enterprise performance

Adam and Alarifi (2021) assert that the primary motivation behind innovation practices in enterprises is the aspiration to attain compensation through enhanced organisational performance. Literature defines the term 'organisational performance' in various ways. For instance, Molete et al. (2025) describe performance as the extent to which an organisation attains its objectives successfully, encompassing aspects such as sales, profitability, competitive positioning, market share and other strategic goals. On the other hand, Chittithaworn et al. (2011) describe business performance as the achievement of a set of desired outcomes. Evaluating the performance of an enterprise facilitates the reinforcement of its operational strengths while also enabling the implementation of corrective measures to mitigate identified weaknesses (Ghaatki 2025; Nguyen, Le & Nguyen 2023). The diverse organisational performance definitions translate to numerous measures of SME performance. For instance, some studies employ several measures such as financial, personnel performance, customer satisfaction, improved process and strategy management, sales turnover, number of employees and business cash flow resilience. In this chapter, we focus on two dimensions: the financial and non-financial performance metrics.

Financial performance

Financial performance entails a comprehensive evaluation of a company's financial statements to assess its efficiency and effectiveness, considering assets, liabilities, expenses, revenue, profitability and equity (Fatihudin 2018). Various indicators assess an organisation's financial performance, including profitability, efficiency, gearing and cash flow metrics.

Profitability

In profitability analysis, business proprietors, managers, creditors and investors assess profitability ratios. This assists in determining a firm's performance against its profit-earning ability. The common profitability measures are gross and net profit margins.

Gross profit margin

This is a ratio which determines a firm's profitability after determining the cost of sales. The cost of sales represents the direct expenses associated with production and excludes operating costs, interest and taxation. Consequently, the gross profit margin serves as an indicator of profitability, focusing specifically on a line item or product, without incorporating overhead expenses. Its formula is:

$$\text{Gross profit margin} = \frac{\text{Gross profit}}{\text{Sales}} \times 100$$

EQUATION 10.1: Common method to calculate gross profit margin.

Or

$$\frac{\text{Revenue} - \text{Cost of sales}}{\text{Revenue}} \times 100$$

EQUATION 10.2: Another method to calculate gross profit margin.

Net profit margin

The net profit margin is a profitability ratio that indicates the proportion of revenue and other income remaining after accounting for both operating and non-operating income and costs, that is, the cost of goods sold, operating expenses, interest and taxes. Its formula is:

$$\text{Net profit margin} = \frac{\text{Net profit}}{\text{Revenue}} \times 100$$

EQUATION 10.3: Net profit margin.

Cash flow statement

A cash flow statement shows the effect of activities from the balance sheet and income statement on organisational cash flow, organising these activities into operating, investing and financing categories. It evaluates the effectiveness of a company in sustaining positive cash flow since profitability does not translate readily to the availability of funds for the day-to-day operations of an enterprise, since some funds are accounted for under debts that are yet to be paid. A cash flow statement is crucial in financial performance analysis, as it helps to determine the sources and uses of funds in the SME. If one division of the business is facing significant outflows, the company must generate cash inflows from financing activities or the disposal of assets to remain viable.

Liquidity

Liquidity is a firm's ability to pay its obligations timeously as they fall due (Akenga 2017). The primary cause of business failure is inadequate cash management, rather than a lack of profitability; therefore, it is crucial to manage liquidity effectively. A small and medium enterprise may be profitable yet face cash flow issues simultaneously, rendering it illiquid. The current, quick or acid test, inventory holding period, debtors or receivables collection period and the creditors or payables period are the liquidity measures used frequently.

Current ratio

The current ratio helps in assessing the ability of an SME to meet its short-term debts, specifically those due within one year, using its current assets and liabilities. It is calculated in this way:

$$\text{Current ratio} = \frac{\text{Current asset}}{\text{Current liabilities}}$$

EQUATION 10.4: Current ratio.

The Association of Chartered Certified Accountants (ACCA 2025) indicates that conventional textbooks typically state that this ratio should be greater than 1:1. However, to ensure that a company can meet its liabilities with confidence, a ratio exceeding 2:1 is generally advised. Nevertheless, acceptable current ratios vary across industry sectors, and numerous firms operate efficiently with ratios below this threshold. A higher current ratio is not necessarily advantageous in all circumstances; an excessively high ratio may suggest that a company holds an excessive level of liquidity

(ACCA 2025). Since cash is often described as an 'idle asset' as it does not generate returns, maintaining substantial cash reserves indicates organisational inefficiency. Moreover, a high current ratio may indicate that the company is not leveraging low-cost short-term financing optimally. Furthermore, a year-on-year decline in the current ratio, or a result that falls below the industry average, may suggest the SME is facing liquidity challenges. In this case, it would be advisable for the SME to take corrective measures to enhance its current ratio, such as settling creditor obligations promptly or improving the management of receivables to reduce the incidence of bad debts.

Quick ratio

The quick ratio, often called the acid-test ratio, is a form of liquidity ratio that assesses an organisation's capacity to meet its short-term liabilities. It is calculated using only highly liquid current assets, including cash, marketable securities and accounts receivable, in the numerator. The presumption is that specific current assets, such as inventory, are not converted easily into cash when an urgent need arises. Ideally, the quick ratio must be more than 1; however, this differs across industries. A year-on-year decline in the quick ratio or an outcome below a set benchmark may indicate liquidity problems, and corrective actions applied to the quick ratio should be enacted here as well to improve the liquidity of an SME. The quick ratio is determined in this way:

$$\text{Quick ratio} = \frac{\text{Current assets} - \text{Inventory}}{\text{Current liabilities}}$$

EQUATION 10.5: Quick ratio.

Inventory holding period

This metric reflects the average duration that stock is held by an organisation. An increase in the inventory holding period may suggest that an SME encounters challenges in disposing of its stock and may also signal a higher proportion of obsolete inventory (Lefebvre 2025). To remedy the situation, the SME should improve its inventory turnover rate, for instance, by selling unpopular goods at their cost price. On the other hand, a reduction in the inventory holding time may be advantageous, as it indicates that an SME has improved its inventory turnover and does not have excessive capital tied up in stock. However, any such decrease should be examined further, as it may also suggest that the SME is experiencing liquidity management challenges and lacks

sufficient cash reserves to maintain the optimal inventory level. The inventory holding period formula is:

$$\text{Inventory holding} = \frac{\text{Inventory}}{\text{Cost of sales}} \times 365 \text{ days}$$

EQUATION 10.6: Inventory holding.

Receivables or debtors' collection period

The receivables or debtors' collection period represents the average duration required for a company's debtors to settle their outstanding balances. A prolonged receivables collection period suggests that the SME is encountering difficulties in managing its debtors. Potential strategies to mitigate outstanding receivables include conducting comprehensive credit assessments of both existing and prospective customers, issuing invoices promptly and ensuring swift follow-ups on overdue payments. Conversely, a reduction in the debtors' collection period may suggest improved receivables management. However, if the collection period falls below the industry average, the SME may become less competitive, potentially leading to a negative impact on its profitability. The receivables or debtors' collection period is determined like this:

$$\text{Receivables collection period} = \frac{\text{Receivables}}{\text{Sales}} \times 365 \text{ days}$$

EQUATION 10.7: Receivables collection period.

Payables or creditors' payment period

The accounts payable or creditors' payment period is the average duration a company requires to settle its credit purchases. An extension of this period for an SME may suggest financial difficulties in meeting obligations as they become due. Conversely, it may also indicate that the enterprise is utilising an extended credit period offered by suppliers effectively. Conversely, a reduction in the payables period could signify an improvement in the capacity of the SME to make timely payments for its purchases. However, it is generally advisable for an SME to avoid settling its obligations prematurely, as supplier credit serves as a valuable source of financing. The accounts payable or creditors' payment period is determined as:

$$\text{Payables period} = \frac{\text{Payables}}{\text{Purchases}} \times 365 \text{ days}$$

EQUATION 10.8: Payables period.

Efficiency ratios

Efficiency ratios measure how well an enterprise utilises its resources as it carries out its operations.

Return on equity

Return on equity is a financial metric that assesses a company's capacity to generate profit from the equity capital contributed by its owners or shareholders. It therefore represents the yield generated on equity capital invested in an SME.

It is calculated in this way:

$$\text{Return on equity} = \frac{\text{Net income}}{\text{Average equity}} \times 100$$

EQUATION 10.9: Return on equity.

Where:

$$\text{Average equity} = \frac{\text{Opening equity} + \text{Closing equity}}{2}$$

EQUATION 10.10: Average equity.

Return on assets

The Return on assets ratio assesses a company's capability to employ its assets effectively in order to generate profitability. It is calculated like this:

$$\text{Return on assets} = \frac{\text{Net income}}{\text{Average assets}} \times 100$$

EQUATION 10.11: Return on assets.

Where:

$$\text{Average assets} = \frac{\text{Opening assets} + \text{Closing assets}}{2}$$

EQUATION 10.12: Average assets.

Gearing

Gearing refers to the financial leverage or indebtedness of an entity, indicating the proportion of a firm's operations financed through the owner's equity relative to external borrowings from creditors. Therefore,

gearing ratios compare equity to debt while highlighting the importance of SMEs in managing their financial risk. The gearing ratios of an SME are far more significant when compared to companies of similar size in the same industry.

○ *Financial gearing*

Financial gearing shows the proportion of long-term debt relative to equity. It is calculated in this way:

$$\text{Gearing} = \frac{\text{Debt}}{\text{Equity}} \times 100$$

EQUATION 10.13: Common method to calculate financial gearing.

OR

$$\text{Gearing} = \frac{\text{Debt}}{\text{Debt} + \text{Equity}} \times 100$$

EQUATION 10.14: Another method to calculate financial gearing.

A high level of gearing means the SME is heavily dependent on debt to finance its long-term requirements. Consequently, this elevates the risk for the business, as it is obligated to make interest and capital repayments on the debt, unlike equity, where no such payments are required. The ratio could be enhanced by decreasing the amount of long-term debt and securing long-term funding through equity.

□ ***Interest cover***

Interest cover refers to the capacity of an SME to meet its finance or interest costs from its operating profit, which is the earnings before interest and tax. Its formula is:

$$\text{Interest cover} = \frac{\text{Operating profit}}{\text{Interest expense for the period}} \times 100$$

EQUATION 10.15: Interest cover.

A decline in the interest cover ratio suggests that the company is experiencing a heightened risk of being unable to meet its financial obligations as they become due. The ratio could be enhanced by taking measures to boost operating profit, such as improving cost management, or by reducing financial expenses through a reduction in debt levels.

Non-financial performance

While financial performance indicators such as revenue, profit margins, liquidity and return on investment ratios are used commonly to assess SME success, non-financial performance metrics are equally important. Non-financial performance refers to qualitative and quantitative factors that contribute to the long-term sustainability and competitiveness of an enterprise (Al-Mamary et al. 2020; Raucci et al. 2020). These measures provide valuable insights into customer satisfaction, employee engagement, innovation capability, operational efficiency and sustainability (Mogashoa & Kalitanyi 2023). Non-financial performance metrics include factors such as:

- Customer satisfaction and loyalty, which are measured through customer feedback, retention rates and net promoter scores.
- Employee satisfaction and engagement, as assessed from employee surveys, staff turnover rates and workplace culture indicators.
- Innovation and product development, which are examined through research and development (R&D) investment, the introduction of new products and the adoption of emerging technologies.
- Operational efficiency, as evaluated based on supply chain effectiveness, process optimisation and the use of digital tools.
- Sustainability and corporate social responsibility, which is determined by environmental impact, social responsibility initiatives and ethical business practices.

Theoretical frameworks for small and medium enterprise non-financial performance measurement

Measuring non-financial performance in SMEs is essential for assessing long-term sustainability and strategic growth. Traditional financial metrics alone fail to capture critical aspects such as customer satisfaction, internal efficiency and innovation. Consequently, theoretical frameworks such as the balanced scorecard (BSC), stakeholder theory and the resource-based view (RBV) provide a structured approach to evaluating SME performance beyond financial indicators. Together, these theories offer a comprehensive lens for understanding and enhancing SME non-financial performance in an increasingly competitive business environment.

Balanced scorecard

The balanced scorecard, introduced by Kaplan and Norton (1992), is a management tool aimed at integrating multiple performance indicators to

assess an organisation's performance by encompassing non-financial aspects in addition to traditional financial evaluations. The balanced scorecard integrates financial and non-financial perspectives, ensuring a balanced business strategy evaluation (Al-Hosaini et al. 2023). It measures other aspects of the organisation's health along with its advancement. The balanced scorecard framework is an intersection of strategic management and performance measurement theory, which argues that financial indicators do not explain the whole narrative of an organisation's success over time (Kaplan & Norton 1996). The framework is structured around four interconnected perspectives: finances, customers, internal processes and learning and growth (Kaplan & Norton 2001). By integrating these dimensions, the BSC facilitates a balanced approach to measuring financial and non-financial performance, ensuring that strategic objectives align with long-term business sustainability. Over time, the BSC has been integrated into the operational framework of a wide range of businesses including SMEs to understand their performance better (Jolović & Jolović 2020).

Balanced scorecard as a non-financial performance measurement tool for small and medium enterprises

Since SMEs usually operate with limited financial resources, non-financial performance indicators play a crucial role in tracking progress and promoting long-term competitiveness (Widarti, Desfitrina & Zulfadhli 2020). Unlike large corporations, SMEs work in highly dynamic environments that require adaptability and agility (Omowole et al. 2024). The balanced scorecard framework provides a structured approach that supports SMEs in four dimensions. Firstly, it enhances strategic decision-making, integrating non-financial metrics such as employee involvement, customer satisfaction and operational efficiency, about which SMEs can make informed strategic decisions (Quesado et al. 2022). Secondly, the BSC improves organisational performance – learning and growth mindset stimulates innovation and human capital, which are most important for long-term success in SMEs (Osman, Khazaei & Kanesan 2025). Thirdly, the model improves competitive advantage because customer-oriented measures in the BSC assist SMEs in differentiating themselves by improving service quality and customer relationships (Iannone & Anceschi 2025). Finally, the model is sustainable: it provokes long-term thinking of performance measurement and encourages SMEs to prioritise value creation over short-term gains regarding their investments (Jolović & Jolović 2020).

Challenges and criticisms in small and medium enterprise adoption of balanced scorecard

The balanced scorecard is an internationally adopted system of strategic performance measurement beyond standard financial measurements via

the integration of non-financial elements such as customer perspectives, internal business procedures and organisational-level learning and growth. Although large corporations have been able to institute BSC successfully, the adoption thereof by SMEs has encountered numerous challenges. For example, SMEs tend to be hindered by financial and human resource constraints that are challenging to the setting up and maintenance of a complete BSC system. Studies suggest that the cost of engaging external consultants or educating staff on how to apply the BSC can be prohibitive (El Hamma 2025; Oyewo, Moses & Erin 2022). There is also a severe lack of strategic planning capability because most SMEs concentrate on short-term operating matters rather than long-term strategic objectives. Again, the structured nature of the BSC demands comprehensive strategic planning, which is often lacking in SMEs (Oliveira, Leal & Pinho 2021). In addition, SMEs are confronted with complexity and data collection, while analysis problems in identifying and tracking relevant non-financial performance measures systematically are particularly challenging for SMEs (Żółtowski 2022).

Furthermore, the practical implementation of the BSC relies on technological facilities to achieve data management, which the majority of SMEs lack. Hence, the manual processes for monitoring non-financial performance indicators are typically time-consuming and prone to human errors. Similarly, as opposed to large corporations with formal management hierarchies, SMEs might not have the ability to communicate and implement the BSC system properly (Casas et al. 2020). As the employees of SMEs often play multiple roles, making individual goals congruent with the BSC might be challenging. Alarming, however, is that the majority of SMEs are averse to organisational change – managers and staff in the organisations might be hesitant to implement new performance measurement systems owing to unfamiliarity or fear of extra workload (Park & Jung 2024). Furthermore, research suggests that the four-perspective model of the BSC could be too complex for most SMEs, especially those in emerging countries, since the BSC framework was created for large institutions with abundant resources (Gomes et al. 2021; Suárez-Gargallo & Zaragoza-Sáez 2023). Moreover, even though the BSC is full of promise of enhancing the strategic performance measurement of SMEs, it is hindered constantly by the lack of resources, complexity and implementation issues. To gain maximum performance, SMEs have to simplify, adapt and apply the BSC more frequently in their operational systems, considering their strategic objectives.

Stakeholder theory

The stakeholder theory of Freeman (1984) assumes that organisations do not exist independently of each other within this large network, but rather that

they are surrounded by a web of complex relationships. The theory focuses on fulfilling the expectations of many different stakeholders, such as employees, customers and suppliers (Nicolescu & Nicolescu 2022). Contrary to shareholder primacy for the benefit of owners' profit, stakeholder theory promotes the reconciliation of vying stakeholders such as customers, employees, suppliers, government authorities and community societies (Freeman 2010). The three focal areas of the theory are open government, ethical business and long-term value creation rather than profits. For SMEs, whose limited resources and pocket-sized local spheres limit them, good stakeholder relations are important for ongoing business and a high non-financial performance status. Small and medium enterprises' non-financial performance involves more than profitability qualitative and strategic performance, such as firm reputation, corporate social responsibility, employee welfare and environmental sustainability. The three broad dimensions of stakeholder theory and how they contribute to the value of SME non-financial performance are outlined in the next sections.

Transparent governance

Good governance in SMEs goes beyond complying with the rules; it also includes ethical leadership, accountability and fairness. This stakeholder-oriented governance enhances trust and legitimacy, which are critical for business sustainability. By practising transparency in financial reporting, ethical decision-making and participatory management practices, an SME develops closer relationships with stakeholders (Kintu et al. 2025). Notably, an early practice of open communications with suppliers and customers can help SMEs to cushion the associated risks of supplier disruptions as well as customer dissatisfaction.

Ethical business practices

Aligning with stakeholder expectations through ethical business practices strengthens stakeholder confidence and organisational resilience. Ethical conduct in SMEs includes fair employee remuneration, environmentally responsible production methods, transparent marketing strategies and adherence to labour laws (Turyakira 2018). Studies suggest that prioritising ethical considerations can increase employee commitment, enhance customer loyalty and create a more substantial brand reputation (Kulova & Nikolova-Alexieva 2023). Therefore, SMEs with well-established ethical foundations often outperform their competitors regarding stakeholder trust and market positioning (Abdissa 2023).

Long-term value creation beyond financial gains

The stakeholder view focuses on long-term development ahead of short-run profit maximisation. Corporate social responsibility investment, the

well-being of workers and eco-friendly performance by SMEs lead to business longevity and stakeholder satisfaction in the long run (Basu & Basu 2025). Philanthropic actions by a company may pay dividends of implied approval at a local stakeholder level, improving market share positioning and warding off ill-reputation threats (Harrison, Freeman & Abreu 2015). In addition, well-performing SMEs in non-financial performance terms can easily draw impact investors who will balance financial returns with environmental and social returns (Freudenreich, Lüdeke-Freund & Schaltegger 2020).

Therefore, the stakeholder theory provides a holistic framework for SMEs to increase non-financial performance by instilling openness in governance, ensuring ethical practices and expanding sustainable value creation (Alatawi et al. 2023). As opposed to bottom-line approaches, stakeholder-oriented SMEs construct resilience on the foundations of trust rule of law, and corporate social responsibility. By integrating stakeholders into their strategic decision-making framework, SMEs become more competitive in the speed-based sustainability-focused global marketplace of today.

Resource-based view theory

The resource-based view theory is a strategic management framework that underscores the significance of an organisation's internal resources as the primary source of sustainable competitive advantage (Barney 2001). The resource-based view perspective is suitable specifically for SMEs, as they often work in very competitive contexts with inadequate financial resources. Compared to larger companies that will enjoy economies-of-scale benefits, SMEs need to leverage unique and hard-to-replicate assets to create differentiation and attain long-term success (Rodrigues et al. 2021). Therefore, the RBV classifies strategic resources into four general categories that play a major role in non-financial performance: human capital and organisational knowledge, brand equity and customer relationships, technological capabilities and digital innovation, and organisational culture and CSR. Human capital, which comprises skills, experience and employee commitment, is a significant determinant of SME growth.

Small and medium enterprises that invest in leadership training, development and corporate culture can achieve benefits such as employee satisfaction and retention and cost savings in turnover and business continuity. Enhanced innovation and problem-solving abilities pave the way for agility and creativity in addressing market problems, and improved service quality adds value to customer experience through having an efficient and motivated workforce (Mata, Moleiro Martins & Inácio 2024). Furthermore, brand reputation in SMEs relies heavily on trust, quality of

product and service and customer relations. Therefore, good customer relations are tantamount to high retention and loyalty, contributing significantly to long-term business viability (Le 2023). In addition, word-of-mouth communication is an inexpensive means of gaining new customers, while an established brand offers greater resilience to market adversity and serves as a shock absorber during poor economic conditions. Improved stakeholder relations are also a significant outcome, as aligning business objectives with societal and environmental goals improves partnerships and fosters long-term support (Leena et al. 2023).

In applying RBV to enhance non-financial performance, SMEs are therefore required to identify and develop core competencies – those capabilities that are valuable, rare, inimitable and non-substitutable. These may include specialist knowledge in a niche industry, superior customer relationships and local market knowledge, and adaptable and responsive business models attuned to evolving market trends. The practical application of the RBV model to improve SME non-financial performance necessitates a strategic focus on strengthening core competencies, improving employee engagement, leveraging digital innovation and establishing strategic partnerships. Small and medium enterprises must identify and develop core competencies that align with the VRIN framework – valuable, rare, inimitable and non-substitutable, such as specialised industry expertise, strong customer relationships and in-depth knowledge of local markets. Furthermore, SMEs ought to adopt agile and adaptive business models that respond quickly to changing market trends. Innovation and operational efficiency require a skilful and motivated workforce. Therefore, to keep its human capital alive, SMEs must invest in training and upgrade skill sets continuously. In environments where everyone is made to feel valued with proper career advancement prospects, their knowledge is being shared in addition to leadership development taking place.

Digital innovation now enables SMEs to design paths to competitive advantage by enhancing performance through implementing cloud-based solutions that promote scalability and cost-saving efficiency, applying AI-enabled customer service technologies 'chatbots', which improve customer experiences, and employing social media marketing to build brand awareness and customer engagement (Alabi et al. 2025). Instead of merely relying on internal capabilities, SMEs can alleviate resource constraints through various means, including strategic alliances and networks. Collaborations with academic institutions and research centres foster knowledge transfer, while interactions with industry associations provide avenues for collaborative innovation. Moreover, engaging with large companies offers an opportunity for supply chain integration and business scaling.

However, upon its implementation, the potential advantages of the RBV framework are not without challenges for SMEs. The most predominant hindrance is cash flow, limiting investments in critical areas such as training human resources, adopting obvious technologies or brand-building initiatives (Mogashoa & Kalitanyi 2023). In turn, knowledge gaps can block the effective management of most of the resources. Small and medium enterprise owners and managers lack thorough knowledge about RBV, including its principles and how it would apply strategically. Together with this, the fast-evolving characteristics of industry landscapes become more relevant in technological advancements that require constant adaptation, which may be burdensome for the resource-scarce SMEs. Accordingly, efforts to mitigate difficulties will require that an SME acts proactively by emphasising targeted allocation of resources, enhancing capacity to level with business practices, sustaining the advantage over competition and conserving long-term renovation of non-financial performance.

Non-financial performance metrics

Non-financial performance indicators play a crucial role in assessing the overall health and sustainability of SMEs beyond financial metrics. These non-financial indicators provide SMEs with a broader perspective on their long-term sustainability and competitive advantage, helping them to make informed strategic decisions beyond short-term financial gains. The non-financial metrics help to measure operational efficiency, customer satisfaction, employee engagement, innovation and corporate social responsibility.

Customer satisfaction and retention

Customer retention and satisfaction are prime indicators of an organisation's long-term sustainability and success. Customer loyalty, the customer-commitment aspect linked to repeat business, is another key. On the other hand, repurchase behaviour observed by customers dictates levels of satisfaction and trust towards the company (Israel, Mahuwi & Mwenda 2023). The net promoter score is another most-used loyalty measurement that assesses customer advocacy based on the likelihood of customers referring a company to others (Baehre et al. 2022). In addition, online customer ratings and reviews become sources of valuable insight into which areas require improvement and what levels of overall satisfaction are achieved. How a business handles complaints is also important since the swift and effective resolution of customer complaints increases retention substantially and builds customer loyalty.

Employee engagement and satisfaction

Employee engagement and satisfaction are critical for organisational success. They are the direct determinants of productivity, retention and overall morale in the workplace (Al-Dalahmeh, Khalaf & Obeidat 2018). One of the critical indicators for this situation is employee turnover and retention rates – an indicator of how well a company maintains a stable, committed workforce. Satisfaction in the workplace surveys will bring insight about employees regarding their working environment, the leaders and opportunities for development in a career (Shettigar & Shiva Shankar 2021). In addition, the participation of employees in training and development programmes could be just as valuable a measure since it strongly indicates professional development by the organisation. Finally, productivity levels and performance appraisal outcomes offer quantifiable evidence of employee motivation and effectiveness aligned in some way with business objectives.

Operational efficiency

For any organisation to thrive, operational efficiency must be central to its cost structure, service delivery and competitive positioning. Lead times and turnaround times serve as measures of the capacity of an organisation to respond effectively to customer demand. Adequate inventory management ensures optimal stock levels, thereby minimising waste and enhancing cash flow (Olaniyi & Pugal 2024). The maturity of an organisation, in terms of process automation and digitalisation, reflects its commitment to adopting technology for efficiency purposes. Similarly, quality control metrics and defect rates are crucial indicators that ensure products and services meet anticipated standards and fulfil customer expectations.

Innovation and research and development activity

Innovation and R&D activities transform the face of an organisation in terms of profiting from its growth or gaining competitive advantage. An indicator of organisational innovation is seen in the number of new products and services introduced. This shows that innovation does indeed cover options for market-driven delivery for most SMEs. Investments towards R&D reflect the commitment of SMEs to continuous improvement and technological advancement (Buwule & Kuo 2025). For instance, patent applications and developments in intellectual property provide evidence of the contributions towards innovation by the SME. Moreover,

the effective implementation of innovative business models infers that the company changes according to shifting market dynamics and consumer needs.

Brand reputation and market position

A strong brand image and position in the market is a prerequisite for sustaining a business in the long run and for differentiating it competitively. Brand awareness and public perception surveys help to assess the degree to which consumers recognise and regard the organisation. Mentions and coverage in the media further highlight the visibility and influence of the company in a particular industry. In addition, the awards won by the industry are merit signs of excellence and credibility. There are also points of consumer interaction and sentiment, as well as the complete digital presence in real time in the metrics related to social media engagement.

Corporate social responsibility and sustainability

Corporate social responsibility and sustainability initiatives show an organisation's commitment to ethical business practices along with the resulting societal impact. Environmental impact measures assess the efforts taken by the organisation in reducing its carbon footprint and adopting sustainable practices. The initiatives in community engagement and social impact underscore the role of an organisation in promoting social development. Ethical sourcing and fair trade would ensure that the company at least adheres to responsible supply chain standards. Internal engagement with corporate social responsibility initiatives and corporate citizenship in a much broader dimension is also reflected by levels of employee volunteer participation.

Business growth and market expansion

Business growth and market expansion, as considered, can be regarded as one of the most significant indicators of an organisation as successful and sustainable in the long term. The customer acquisition rate needs to be analysed so that the company can attract new clients and grow its client base. Growth in market share reflects an organisation's competitive strength and situates it in the industry. New business partnerships or collaborations are strategic initiatives made to create new marketing reaches and operational synergies. Further market expansion can be indicative of new geographical markets in which the organisation would want to multiply its revenue streams and seize emerging opportunities.

Governance and compliance

Governance refers to the broad range of systems and processes that have the responsibility of ensuring that an enterprise abides by ethical practices, mitigation of risks and compliance with requests made by its regulatory requirements (Zekos 2021). Vitality in compliance with industry regulations and standards protects the organisation against legal and reputational risks. Subsequently, transparency and ethical practices of the business build trust with stakeholders and investors. The effectiveness of any SME risk management framework ensures that potential threats are dealt with proactively in approach for an effective resolution. Corporate governance practices with an oversight role of the board build resilience and long-term sustainability for the organisation.

Challenges in measuring non-financial performance in small and medium enterprises

Despite its importance, the measurement of non-financial performance in SMEs is met with several challenges. The main hindrance is the absence of standard non-financial indicators, as they can vary widely across industries and individual businesses, thus making comparative analysis complex and, in some cases, impossible (Mahohoma 2024). In addition, Molete et al. (2025) suggest that, typically, SMEs would be resource constrained, both financially and in human expertise, to develop the necessary levels of systematic tracking and evaluation of qualitative performance indicators. Another major problem would arise from measurement subjectivity, since factors such as employee satisfaction and customer experience would be difficult to specify (Alves & Lourenço 2022). Moreover, most SMEs would prefer short-term financial gains to long-term strategic nonfinancial objectives; therefore, they probably would not place sufficient importance on tracking and improving these important performance dimensions. The challenges call for improved structured frameworks to assess and integrate non-financial performance effectively in SME management practices.

Enhancing small and medium enterprise performance through Industry 4.0

Industry 4.0 represents a paradigm shift in manufacturing, service delivery and business processes. Unlike previous industrial revolutions, which focused primarily on mechanisation, electrification and automation, Industry 4.0 emphasises interconnected digital systems that enhance real-time decision-making. For SMEs, Industry 4.0 adoption is not merely a

matter of competitive advantage but a necessity for financial survival in an increasingly digitalised economy.

Industry 4.0 and small and medium enterprise financial performance

The adoption of Industry 4.0 technologies exerts direct and indirect effects on SME financial performance. Through the integration of CPS, AI, IoT, big data analytics and blockchain, Industry 4.0 enhances operational efficiency, adaptability and financial resilience. The Fourth Industrial Revolution (4IR) facilitates revenue expansion and market diversification by enabling SMEs to scale operations effectively and establish multiple income streams (Eslami et al. 2024). For instance, digital platforms and e-commerce allow SMEs to overcome geographical barriers, access wider customer segments and leverage data-driven insights to refine consumer engagement strategies. Furthermore, automated supply chains and real-time analytics contribute to sustainable revenue growth by enhancing production efficiency and customer satisfaction (Chauhan et al. 2022).

In addition, Industry 4.0 technologies promote cost reduction and operational efficiency – factors that are critical to the financial performance of SMEs (Moeuf et al. 2018). Automation and AI-driven analytics subsequently lower production costs by minimising material wastage, optimising inventory management and enhancing energy efficiency. Similarly, Allioui and Mourdi (2023) suggest that IoT-enabled predictive maintenance further reduces equipment downtime and maintenance costs, thereby fostering profitability and long-term financial sustainability. Beyond cost efficiencies, Industry 4.0 supports enhanced financial risk mitigation. Advanced data analytics and real-time monitoring equip SMEs with the capability to anticipate market fluctuations, optimise cash flow management and make informed investment decisions (Wolniak 2024). Artificial intelligence-powered forecasting models generate strategic insights that enable SMEs to navigate economic uncertainties effectively. Moreover, cybersecurity measures such as blockchain technology (BCT) and encrypted transactions strengthen financial security by reducing fraud risks and protecting sensitive business data (Efijemue et al. 2023). A fundamental determinant of SME financial performance is access to funding and investment. The adoption of Industry 4.0 enhances SME creditworthiness by ensuring real-time financial transparency for lenders and investors. Therefore, digital transformation facilitates alternative financing mechanisms, including peer–to–peer (P2P) lending, crowdfunding and blockchain-based transactions, enabling SMEs to secure capital for innovation and expansion. Consequently, technology-driven SMEs are perceived as more resilient and innovative, making them more attractive to potential investors.

Industry 4.0 and small and medium enterprise non-financial performance

The emergence of Industry 4.0 has transformed the operating environment of SMEs fundamentally, extending far beyond financial performance to augment non-financial performance significantly. Industry 4.0 technologies, including AI, machine learning (ML), IoT and digital twins, connect seamlessly with clients, manage human resources and implement sustainable business strategies for SMEs. These technologies enable SME agility and resilience to deal effectively with the increasingly volatile business environment (Jamai et al. 2021). Operational agility and innovation are enhanced through the introduction of Industry 4.0 technologies in SMEs. The application of modern manufacturing and digital twin modelling allows for a faster product development cycle and customisation of products that need to be competitive in extremely fast-moving markets (Talla & McIlwaine 2024).

Artificial intelligence and ML applications bring refinements into the design of products by enabling a more efficient experimentation of configurations long before launching a product into mass production, with a consequent shortening of time to market and avoidance of costly mistakes. The use of 3D printing in a business supports rapid prototyping, providing SMEs the opportunity to individualise products according to the requirements of different consumers. Open innovation platforms and collaborative digital ecosystems also facilitate co-creation and knowledge exchange between SMEs and their large enterprise partners. Industry 4.0 has, at its core, a very new meaning in the world of customer relationship management – SMEs can rely on AI-powered customer relationship management systems and data analytics to generate personalised customer interactions that lead to satisfaction and, eventually, brand loyalty (Iyelolu et al. 2024). Digital means include the platforms of social media, and mobile applications are valued primarily in creating superior personal engagement and interaction with customers. Artificial intelligence chatbots and virtual assistants perform as automated agents that even operate 24/7 to respond to all types of customer inquiries and concerns (Vashishth et al. 2024). Besides these, natural language processing-enabled sentiment analysis will allow SMEs to refine their marketing strategies through customer feedback to improve customer experience and gain a better position in the market.

In addition, while Industry 4.0 technologies indeed create a compelling argument for change in workforce development and rethinking the traditional organisational culture, SMEs must focus significantly on the continuous upskilling or reskilling of employees to have their workforce competent in the required emerging digital technologies (Pedone, Angotti & Barricelli 2023). Artificial intelligence-based learning

management systems provide cost-effective on-the-job development of essential competencies through customised learning road maps. They also promote remote work through cloud-based collaboration tools, which ultimately add flexibility to the workforce, leading to better overall productivity. Two human-centric AIs have been integrated into developing digital leadership training programmes that breed an adaptive and resilient organisational culture for sustained success in the digital age (Enstroem & Bhawna 2025). Sustainability is another domain in which Industry 4.0 technology interacts with SME performance. Internet of Things-enabled smart grids and energy management systems powered by AI correspond to energy-efficient operation by SMEs, which consequently reduce their carbon footprints and associated operational costs (Harikannan, Vinodh & Antony 2025).

Digital twin technology enables environmental monitoring in real time and grants compliance with sustainability directives and corporate and social responsibility commitments. Furthermore, the combination of the principles of a circular economy supported through blockchain plus AI optimises the use of resources while minimising waste generation and thus contributes to long-term ecological and economic sustainability. Industry 4.0 indeed brings a revolution in SME operations that reaches beyond financial performance through considerably improved innovation, customer engagement, workforce development and sustainability initiatives. The digital transformation strategies towards which each SME continues to integrate will require such implementations to create an affordance for the future competitiveness, agility and sustainable development of these firms in the increasingly digitalised global economy.

Challenges in adopting Industry 4.0 for small and medium enterprise financial performance

Nonetheless, despite exceptional benefits, SMEs struggle to adopt Industry 4.0 technologies. The primary hurdle rests upon the enormous upfront cost of digital transformation – that is, purchasing machinery and software, training employees and improving the existing physical infrastructure (Jamwal, Agrawal & Sharma 2023). The absence of financial returns makes many SMEs, who are already strapped for cash, to justify such investments. Moreover, a shift to Industry 4.0 requires a digitally skilled workforce, which many SMEs lack owing to talent gaps and the absence of employee upskilling (Karuppiah et al. 2023). Without the necessary skills, implementing digital technologies becomes a daunting task. Beyond that, digitalisation puts SMEs at greater risk of cybersecurity and data protection threats. Cyber and data threats such as identity theft, ransomware and data breaches pose dire financial and reputational damage to these young companies.

Owing to poor cybersecurity frameworks, numerous SMEs suffer from financial damage. Therefore, they have no choice but to strengthen data protection systems and construct cybersecurity frameworks to avoid damage (Yudhiyati, Putritama & Rahmawati 2021). In the same way, accepting cognitive and behavioural changes in an organisational culture also influences Industry 4.0 technology adoption. Equally important is to strengthen data protection mechanisms and increase investments in cybersecurity infrastructure to address these threats. Aguilar Rodríguez et al. (2021) highlight that organisational culture and even change resistance also affect the implementation of Industry 4.0 technologies. Traditional SMEs are often slow to embrace digital transformation because of a low level of understanding, disbelief in its value and rigid working customs. Digital-first organisational culture requires strong executive sponsorship and a well-defined change management plan to overcome resistance. Hence, adopting Industry 4.0 technologies creates a significant transformation regarding the earnings of SMEs by providing a high possibility of increased income, reduced costs, improved risk management and enhanced financial performance. On the other hand, the effective implementation of these technologies involves dealing with monetary, technical and structural barriers (Jackson & Carruthers 2019). As SMEs increase their level of digital transformation, the investment in technological infrastructure, human resources and cybersecurity is crucial to gain a competitive advantage financially from Industry 4.0.

Case study: South Africa

SAIPA Report on South Africa

According to 'Fourth Industrial Revolution in South Africa 2019' research carried out by World Wide Worx, and reported by SAIPA (2019), the adoption of 4IR technologies by South African enterprises is worryingly low. Only 13% of corporate South Africa reported using AI in 2019. Of the remainder, only 21% of businesses planned to adopt the technology over the next two years. Regarding other Fourth Industrial Revolution (4IR) technologies, 50% of business enterprises currently utilise simple automation, only 25% use IoT and 19% use cloud computing. These statistics are a sharp divergence from a study undertaken by the company in 2018, where 63% of non-users had shown interest in adopting artificial intelligence technology. Costs were cited as the major 4IR technology adoption constraint. The research indicates that local SMEs have moved past the hype around AI and have since realised that AI projects are costly. The businesses note that while the software itself

is inexpensive and widely accessible through online services, it is the skills and expertise necessary for its effective implementation that are in short supply, and this inadequacy contributes to the increase in adoption costs. The majority of South African SMEs currently struggle to find, attract and retain the requisite technology talent. Furthermore, 4IR technology adoption in South Africa is also deterred by inadequate investments in 4IR infrastructure, power supply shortages, as all the digital technology is electronically operated and the poor digital literacy skills among the general population (Kayembe & Nel 2019). However, 90% of South African businesses underscored their belief in eventually becoming reliant on 4IR technologies in the future, expecting that adoption thereof will lead to a measurable increase in efficiency. The businesses admit that while cloud computing has become an everyday part of their lives, poor connectivity and perceived complexity issues hinder them from moving their business online. In contrast, however, Robotic Process Automation, a technology enabling the automation of repetitive data entry tasks through programmable software robots, has become progressively more affordable and accessible, with SAIPA (2019) reporting an adoption rate of 37%. Robotic Process Automation can be utilised to automate numerous bookkeeping and data entry tasks that are currently carried out by accountants.

Source: Kayembe, C and Nel, D (2019). *Fourth Industrial Revolution in South Africa 2019*, World Wide Worx. Reported by the South African Institute of Professional Accountants (SAIPA) (2019). South African organisations are slow to adopt 4IR technologies.

Reflections

This chapter and the rest of the chapters in this book offer a timely and coherent reflection on how the 4IR is reshaping supply chains and, in particular, the strategic positioning of SMEs in these systems. A key insight is the shift from viewing technology adoption as an isolated firm-level decision to understanding it as a supply chain-embedded process. By integrating discussions on digital supply chains, intelligent manufacturing (IM), blockchain and dynamic capabilities, the book demonstrates convincingly that SME competitiveness and resilience depend increasingly on connectivity, collaboration and data-driven decision-making rather than on scale alone. The strong grounding in theory, combined with systematic reviews, bibliometric analyses and contextualised case evidence from emerging economies, makes the work especially valuable for scholars and practitioners seeking to bridge the gap between abstract 4IR concepts and practical SME realities.

A further reflection lies in the balanced treatment in the text of opportunity and constraint. While it highlights the transformative potential of 4IR technologies, it does not adopt a deterministic or overly optimistic stance. Instead, it acknowledges structural challenges faced by SMEs, such as limited resources, skills shortages and institutional constraints, particularly in developing economies. By situating technology adoption in broader socioeconomic, policy and governance contexts, it reinforces the notion that digital transformation is as much an organisational and strategic challenge as it is a technological one. This nuanced perspective strengthens the contribution of the book, positioning it as both analytically rigorous and practically relevant for decision-makers and scholars alike.

Future outlook and research gaps

Looking ahead, the book points to a future in which SMEs that develop digital and dynamic capabilities in their supply chains are more likely to achieve resilience, sustainability and improved performance in volatile environments. As digital ecosystems mature, SMEs are expected to move beyond basic digitisation towards more advanced integration of technologies such as AI, data analytics and CPS. This evolution will most likely redefine traditional supply chain roles, enabling SMEs to act as innovation partners rather than as peripheral actors. The future outlook, therefore, emphasises strategic alignment, collaborative value creation and continuous learning as critical success factors in an increasingly interconnected and technology-driven business environment.

Despite these insights, several research gaps remain that warrant further scholarly attention. There is a clear need for longitudinal and large-scale empirical studies that examine not only technology adoption but also post-adoption outcomes, including productivity, resilience and financial and non-financial performance. In addition, limited research has explored the human and behavioural dimensions of 4IR-enabled supply chains, such as leadership capabilities, workforce readiness and change management in SMEs. Future research should also place stronger emphasis on comparative studies across emerging economies to understand better how institutional frameworks, policy interventions and infrastructural disparities influence SME participation in digital supply chain ecosystems. Addressing these gaps would deepen theoretical understanding and enhance the practical relevance of future research in this rapidly evolving field.

Conclusion

The economic and social contribution of SMEs globally cannot be understated, particularly for developing economies. Technological advancements have

altered the business environment completely through the 4IR. The notion of Industry 4.0 is now crucial for SME operations and has already influenced the global economy significantly. Industry 4.0 is already setting the rules and pace of financial and non-financial organisational performance, dictating how SMEs can remain competitive. Therefore, it can be concluded that the outlook for SMEs appears promising regarding the adoption of Industry 4.0 technologies as these novelties can improve financial, environmental and social performance through scalable operating models. While the advantages of Industry 4.0 for SMEs, including increased productivity and improved personnel utilisation efficiency, are recognised widely, scholars highlight that not all organisations have adapted their operations successfully to this paradigm. Numerous academic and industry reports reveal a concerningly slow pace of Industry 4.0 adoption among SMEs in both developed and developing nations. The reluctance of SMEs towards Industry 4.0 is largely due to resource poverty, general risk-aversion, organisational culture and lack of expertise. Without the adoption of Industry 4.0, research suggests that SMEs across the globe face a growing risk of losing their existing competitive advantage. Therefore, to attain sustainable SME performance, there is a critical need for SMEs, national governments and all relevant stakeholders to collaborate and to work towards the integration of Industry 4.0 in SMEs through an enabling adoption environment.

Declarations

Ethical considerations

This study did not involve human participants, animals or identifiable personal data. As such, ethical approval from an institutional ethics committee was not required.

Consent

This study did not involve human participants. Therefore, informed consent was not required.

Authors' contribution

Conceptualisation, D Masakale and S Munongo; *methodology* (*desktop-based literature review and conceptual synthesis*), D Masakale and S Munongo; *validation*, D Masakale and S Munongo; *investigation* (*systematic review and interpretation of secondary sources*), D Masakale and S Munongo; *resources*, D Masakale; *writing – original draft preparation*, S Munongo; *writing – review and editing*, S Munongo and D Masakale; *visualisation*, S Munongo; *supervision*, D Masakale; *project administration*, D Masakale.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this chapter.

Funding

This chapter received no external funding.

Data availability

Data availability is not applicable to this chapter.

Disclaimer

The views expressed in this chapter are the authors' own and not an official position of the institution, funder or the publisher.

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Chapter 1

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Chapter 2

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Industry 4.0 dislocations in small and medium enterprises: A supply chain management view offers a comprehensive exploration of the Fourth Industrial Revolution (4IR) and its transformative impact on supply chain management, digitalisation, and small and medium enterprise (SME) performance, with a particular focus on the South African context. It traces the evolution of the industrial revolutions and provides a clear account of the defining features of 4IR, including artificial intelligence, big data analytics, cyber-physical systems, the Internet of Things, cloud computing and advanced robotics. These technologies are examined in terms of their disruptive influence on business models and their capacity to reshape competitive landscapes. The book further considers how SMEs can navigate these shifts through digital transformation, capability development and adaptive supply chain strategies, while also engaging with emerging themes such as blockchain technology, intelligent manufacturing and supply chain resilience in the context of global disruptions such as the COVID-19 pandemic.

Overall, this scholarly book addresses topical and highly relevant themes in 4IR and its intersection with supply chain resilience and SME performance. The importance of developing dynamic capabilities grounded in advanced technological trends cannot be overstated, particularly for SMEs that must adapt and redesign conventional business models to sustain competitiveness and survival. The strategic value of 4IR-driven technologies in enhancing operational capacity and performance is clear, yet their effective adoption requires careful consideration of enabling conditions and contextual challenges. The authors provide a holistic appreciation of the complex nature of 4IR and its influence on reshaping SME supply chain capabilities, readiness and resilience. Given that supply chain management is central to organisational success, its ability to adapt to technological and environmental change is essential for improving productivity, competitiveness and long-term sustainability.

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https://doi.org/10.4102/
aosis.2026.BK572

ISBN: 978-1-997449-49-2