Inertia or Progress? Digital Technology Adoption Within a Group of South African Manufacturing SMEs

Justin Barnes and Warren Sachs

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Abstract

Manufacturing SMEs make a significant contribution to the South African economy, but face severe competitiveness challenges. One of these challenges relates to the adoption of digital technologies (DTs), which form an integral part of the fourth industrial revolution. Several studies have identified use-cases for DTs, and have described how manufacturers in Europe and Asia have leveraged these technologies to secure a competitive advantage. However, the adoption of DTs by South African manufacturing SMEs remains under-researched. Whether inertia exists or progress is being made is unclear. The literature has identified several factors that inhibit the adoption of DTs in manufacturing firms, but several key factors are less researched: owner/manager mindsets towards DTs; perceptions of digital platform openness; and the ease of exchanging data in a digitalised business model. In this study, we explore the adoption of DTs by a group of South African manufacturing SMEs, along with the underlying reasons for inertia and/or progress. We also explore the strategies used by SMEs when adopting DTs, and how owner/manager mindsets and platform openness influence adoption. The findings indicate that manufacturing SMEs in South Africa adopt DTs, but only to a limited extent and at an immature level. Influencing factors include a focus on short-term operational issues, and a lack of awareness of DTs and their associated costs and benefits.

Keywords: Digital technologies, manufacturing, SME, competitiveness, mindset, platform openness, South Africa

JEL codes: D21, D81, L21, L23, O33

About the Authors

Justin Barnes is presently the Manufacturing Ambassador of the Toyota Wessels Institute for Manufacturing Studies, an Associate Professor at the Gordon Institute of Business Science at the University of Pretoria, and the Chairperson of B&M Analysts. He holds a BA Hons *cum laude* (Geography), MSocSci (Development Studies) *cum laude*, and PhD (Development Studies – Industrial specialisation). Justin has published extensively on a range of industrial development subjects and has extensive benchmarking, firm-level and supply chain management experience, having pioneered firm-level competitiveness assessment and industry clustering methodologies in South Africa. E-mail: justin.barnes@twimsafrica.com.

Warren Sachs is a registered professional mechanical engineer (PR Eng) and holds a BSc (Mechanical Engineering), a Government Certificate of Competence (Factories), and an MBA *with distinction*. His research interests lie at the intersection of technology and business strategy. Professionally, he is the Chief Operating Officer of the Beier Group, where he is actively involved in business strategy development and implementation, and has extensive experience of digital technology adoption and the challenges of advancing organisational

capabilities that derive business value. This working paper is based on Warren's Master's dissertation, submitted in partial fulfilment of his MBA degree.

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1. Introduction

SMEs are "the backbone of every economy" (Eggers 2020:199), driving competitiveness and generating almost half of the jobs in the United States of America in 2019. In South Africa, SMEs are also critical contributors to the economy. The national government's Small Enterprise Development Agency ([SEDA] 2020) determined that SMEs provided 11.8 million jobs in South Africa in the last quarter of 2019 (before the onset of COVID-19). SEDA (2020) also reported that manufacturing SMEs spent R48.4 billion on employment-related costs in the same period, representing 26.6% of total SME employment costs. Manufacturing SMEs are typically started by an entrepreneurial industrialist owner/manager who builds the firm using personal skills and a unique business model to capture market share (Hulbert et al. 2013). As the business grows, the entrepreneur's initial skill and vision may become insufficient to manage the firm's growing complexity. In such cases, broader general management skills and tools are required to ensure sustained competitiveness (Picken 2017).

Firms are presently under pressure to adopt a range of digital technologies (DTs) to secure their competitiveness (Sturgeon 2021). Traditional digital operations technology (OT) such as enterprise resource planning (ERP) solutions, distributed control systems (DCS) and programmable logic controllers (PLC) operate at a machine and company level with limited data connectivity to external networks (Seetharaman 2019; Sturgeon 2021). Recently, however, there has been a significant increase in the amount of data generated, stored, processed and analysed by organisations with the goal of improved overall business performance (Akhtar et al. 2018; Sturgeon 2021). The advent of smaller, more powerful and significantly less expensive smart sensors and devices, coupled with the growth and rapid expansion of high-speed internet connectivity, has made possible the internet of things (IoT). Digitisation has rapidly developed from product identification and tracking to a system of interconnected devices that transmit sensor data that can be used to monitor, control, optimise and automate processes and services, thereby creating new value for manufacturers and customers (Seetharaman 2019), and associated competitiveness pressure for firms that have not embraced these technologies.

IoT (including industrial IOT, IIOT), cloud computing, big data analytics (BDA) and artificial intelligence (AI) are the four digital economy-based technologies identified by Sturgeon (2021). These technologies enable agility and resource efficiency by streamlining manufacturing processes, predicting machine breakdowns, and assisting diagnosis and design using augmented reality (Navas 2020; Rejikumar et al. 2019). A key benefit of IoT is improved data-driven decision making by management and the possibility of creating a competitive advantage for firms (Rejikumar et al. 2019).

IIoT describes the industrial application of IoT, comprising connected machinery and infrastructure (Sturgeon 2021), which has the potential for devices to emit vast volumes of machine- and process-related data in real time (Olsen and Tomlin 2020), also known as big

data. Big data has been described broadly in terms of three characteristics: volume, velocity, and variety, but has evolved to include veracity and value (Shukla et al. 2019). Big data analytics (BDA) using modern, cloud-based platforms allows for the analysis of petabytes of data, which was previously not possible, thereby enabling businesses of all sizes to make value-adding, informed decisions based on scientific data analytics (Behrendt et al. 2021; McAfee et al. 2012).

IIoT includes the sensors that sense and transmit data, the platform on which the data is stored, processed and analysed, and the artificial intelligence, machine learning and BDA that convert the data into useful information. Digitalisation is the convergence of these various DTs in a manner that enables the transformation of a firm's business model (Gebauer et al. 2020; Kretschmer and Khashabi 2020). Kretschmer and Khashabi (2020) describe how the increase in detailed and unified data available to decision makers can provide new insights, allowing decision makers to eliminate non-value-adding tasks. By consolidating tasks and activities, decision makers can create unique business processes that deliver new value to their customers. Kretschmer and Khashabi (2020) therefore recommend that organisations consider their future competitive advantage and design their strategies and structures based on this future state, rather than viewing digitalisation as a short-term, cost-saving initiative.

Previous research has established that SMEs are often run by owner/managers who lack established business models and depend on their personal expertise and relationships to make decisions (Eggers 2020; Hulbert et al. 2013). Ates and Bititci (2011) identified some of the characteristics of SMEs, including their lack of long-term strategic thinking; a reactive approach to external disruptions; a lack of managerial competence to cope with firm growth; and tacit expertise based on unstructured decision-making. This view is supported by Bessant and Tidd (2011), who argue that SMEs are typically focused inward and are too busy dealing with operational issues to develop long-term strategies for innovation. These characteristics impede the successful adoption of DTs by SMEs.

Use cases exist for DTs within manufacturing to improve asset efficiencies and effectiveness, reduce operational risks and improve customer interactions and experience (Behrendt et al. 2021; Popovič et al. 2018; Tortorella et al. 2019; World Economic Forum 2021). The adoption of DTs and IIoT more specifically has been shown to positively affect the competitiveness of manufacturers (Akhtar et al. 2018; Behrendt et al. 2021; Sturgeon 2021; Tortorella et al. 2019). While the adoption of DTs is well researched in large manufacturers, Goodness et al. (2020) found that only 10% of industrial companies used IIoT in their factories in 2020. They identified that manufacturers were frequently stuck in 'pilot purgatory' and unable to realise the competitive improvement potential of DTs such as IIoT.

Under the broader banner of 'Industry 4.0', DTs have been studied extensively from a technical perspective, with the research focusing primarily on the technology stack – from the device to application layer (Klingenberg et al. 2019; Zdravković et al. 2018). DTs have been

researched from a use-case perspective in multinational companies and international SMEs by Ancarani et al. (2019) and Zelbst et al. (2019), with many value-adding use-case scenarios being presented, such as the 69 manufacturers that form the World Economic Forum's (2021) Global Lighthouse Network.

There are several IIoT platforms, and firms face a complex decision on which platforms to implement (Mora-Sánchez et al. 2020). A key factor is platform openness, which allows ubiquitous data interoperability (Mora-Sánchez et al. 2020). Two prominent examples of platforms in the IIoT, BDA and artificial intelligence domains are Siemens' Mindsphere proprietary solution and General Electric's open Predix platform (Lichtenthaler 2018; Olsen and Tomlin 2020). Understanding how the platform openness of systems affects DT strategies may improve knowledge of the adoption of DTs by manufacturing SMEs in South Africa.

Canhoto et al. (2021) note that the research regarding DTs in SMEs is fragmented. Furthermore, Mohd Salleh et al. (2017) found that research on information system adoption was focused predominantly on models designed for large firms and traditional technology-organisation-environment-based theories. Both groups of authors note that SME-specific information system research is lacking. Furthermore, there is little research on whether South African SME manufacturing firms have adopted DTs such as the IIoT (Maisiri and Van Dyk 2021).

Vial (2019) proposes that a research path exists to review the enabling mechanisms of DT through the theory of dynamic capability, as developed by Teece (2018a). This theory explains how firms maintain their competitive advantage in markets. Vial (2019) describes the challenge facing multi-sided or open platform owners who must ensure that they do not infringe on a party's rights to security and privacy in the process of fulfilling the needs of another party, while simultaneously maintaining their competitive advantage. The adoption of a proprietary platform may mitigate security and data leakage concerns; but this benefit may be negated by the risk of being locked into a vendor's platform, creating high switching costs (Behrendt et al. 2021).

In this paper we try to understand whether and why South African manufacturing SMEs adopt DTs. We also try to understand how this adoption (or lack thereof) is related to owner/ manager mindsets and platform openness. This paper consequently comprises four sections. In Section 1, we explore the literature on the adoption, or lack thereof, of DTs by manufacturers, as well as owner/manager-related factors affecting technology adoption. In Section 2 we introduce the paper's key research questions and describe the research methodology used to answer them. Section 3 presents the results of our primary research, while Section 4 analyses the key findings generated and their link to the DT literature. Section 5 concludes the paper.

2. Contextualising DTs in the South African SME Manufacturing Space

Industry 4.0 and its broad range of DTs can yield a competitive advantage for firms that digitally transform their business models (Kretschmer and Khashabi 2020; Tortorella et al. 2019). Tortorella et al. (2019) found that there are two bundles of Industry 4.0 technologies, namely material and information flow. These represent process-, and product- or service-related technologies respectively. IIoT bridges both bundles and provides the backbone for Industry 4.0 and data-driven business models (Tortorella et al. 2019).

Maisiri et al. (2021) see the adoption of Industry 4.0 in South Africa as being at a nascent phase, although they recognise that there is limited research on DT adoption amongst South African manufacturing SMEs. Becker and Schmid (2020) found that SMEs often lack digital strategies. A comprehensive literature review was therefore conducted to determine the extent of research on this issue and the relevant theories regarding DT and IIoT adoption; and to understand the impact that mindsets and platform openness have on SME technology adoption. The literature review initially focused on the competitive environment in which manufacturing firms operate, and the impact of innovation, entrepreneurship and mindsets on their competitiveness. Thereafter, the literature related to the enabling technologies, broadly known as Industry 4.0 and including DT, was analysed. The positioning of IIoT within business model development was researched, and a narrower review of DTs and IIoT in manufacturing SMEs was then conducted, followed by a review of the literature on platform openness and its effect on DT adoption. Finally, an exploration of several possible theories explaining the factors affecting DT adoption was completed.

Tidd and Bessant (2020:50) argue that product and process innovation are essential for a firm to remain relevant in a changing business environment, and emphasise that organisations must "digitalize or die". They illustrate that DT implementation can be undermined by the mismatch between traditional resources and capabilities available in a firm, and the resources and capabilities required in a digitalised business model. Digitalisation has a positive impact on firm performance in dynamic environments; however, many entrepreneurial SMEs have found it difficult to seize the opportunities offered by digitalisation (Cenamor et al. 2019). An innovative posture was found to be a critical factor for SMEs to create market opportunities, especially in times of crisis such as the COVID-19 pandemic (Eggers 2020). However, Kretschmer and Khashabi (2020) warn that it is too early to determine the impact of digital transformation on markets, and that there is a risk of hyper-competitiveness driving consumer surplus and reducing firm benefits. They extend this warning to SMEs that may be resource constrained, and therefore unable to fully embrace DTs.

Ringberg et al. (2019) argue that mindsets and technology are interconnected and co-constitutive and lead to various potential levels of innovation. They claim that most industries still practise incremental innovation of business models due to the demands associated with identifying new processes or products. Supporting the view that certain mindsets are required

for innovative changes to business models, Martins et al. (2015) argue that business models are cognitive constructs, implying that they reflect management mindsets. Cutumisu (2019) identified that a fixed mindset is distinct from a growth mindset and that the effects of these two mindsets are distinct. Rydén et al. (2015) argue that mental models, or mindsets, affect how managers view and engage with social media. The mindsets of owners/managers could therefore influence the level of DT innovation by firms.

Digital transformation is necessary to remain competitive, and a growth mindset could allow individuals to master new technologies and therefore support the adoption of DTs (Jones et al. 2021). Dweck (2009, 2016) points out that a growth mindset positively correlates with positive learnings and that learning is an important determinant of success. This view is supported by Cutumisu (2019), who points out that a growth mindset positively moderates feedback-seeking behaviour and its impact on performance. Li et al. (2016) propose that mindset influences e-leadership in the technology-transformation alignment, as well as the service-level alignment, capability domains. Ghobakhloo and Iranmanesh (2020), on the other hand, found that digital maturity and external support of SMEs were critical to successful DT implementation. Surbakti et al. (2020) point out the paucity of research on the factors influencing DT adoption, and propose several themes for future research, including a focus on organisational systems, and the human aspects of perception, culture and beliefs.

In respect of the IOT specifically, Ng and Wakenshaw (2017:6) argue that the transmission and storage of data are analogous to the liquification of the object described by the data, defining IoT as uniquely identifiable objects capable of being represented virtually, interconnected through the internet through real-time, remote “locating, sensing, and/or operating”. Industry 4.0 similarly describes the integration of cyber-physical systems (CPS) in a manufacturing context through connected intelligent devices and systems to achieve the long-run sustainability and competitiveness of the industry (Kagermann et al. 2013). Ancarani et al. (2019:849) argue that IoT is “one of the pillars of Industry 4.0”, while Sturgeon (2021) explains that IIoT is characterised by ubiquitous data collection and network connectivity. The collection of various types of factory data, from sensor data to images and video of products and processes, can be used in a wide variety of advanced applications to improve processes, augment human-machine interaction and predict machine or component failure. Sturgeon (2021) explains that the difference between IIoT and IoT relates to the requirement for modularity and the interchangeability of functional elements in the process environment, and the limited scalability of the production environment and plant due to the physical properties of the products and manufacturing equipment. These physical properties of the product and plant conflict with the information goods (data) of an IoT platform, which has almost zero incremental cost. While IIoT has been positioned within the set of DTs comprising Industry 4.0, the successful adoption of IIoT by manufacturing SMEs requires digital transformation.

In a study of 43 European SMEs, including manufacturers, Canhoto et al. (2021) investigated digital strategy alignment through the lens of dynamic capabilities. They suggest five phases of digital strategy alignment in SMEs, ranging from 'passive acceptance' to 'transformation'. Becker and Schmid (2020) did not identify differences in their research on the understanding of digital transformation between SMEs and large manufacturers, noting that SMEs and large manufacturers fundamentally understood the core concept of digital transformation and the requirement for a digital transformation strategy. Canhoto et al. (2021:11), however, identified digital maturity as a two-factor measure. A purposeful approach to technology adoption, coupled with an integrated degree of DT use, was defined as 'transformation' (or digital transformation maturity). In contrast, a reactive approach to technology adoption, coupled with ad hoc technology use, was defined as 'passive acceptance' (or digital transformation immaturity). The five phases of Canhoto et al.'s (2021) model of digital strategy alignment in SMEs (in order of adoption maturity) are passive acceptance; connection; immersion; fusion; and transformation. In the final phase, a culture of strategic disruption is instilled in the firm, thereby maintaining a constant state of readiness to adapt to new market requirements.

An alternative digital transformation maturity model for manufacturing was developed by Frank et al. (2019), who argue that the adoption of Industry 4.0 progresses through three stages based on the level of complexity of the technology. Stage 1 includes vertical integration using enterprise resource planning (ERP) systems, sensors, PLCs and traceability systems. Stage 2 is reached when processes are automated and AI is used in production and maintenance. Finally, stage 3 is characterised by using flexible production lines and additive manufacturing.

Müller et al. (2018) found that, despite the significant value-creation potential of DTs, manufacturing SMEs in Germany were frequently deterred from implementing IIoT systems due to the perceived high cost and the technical complexity of integrating sensors and applications. They further identified that those SMEs that adopted IIoT as a driver of business model innovation were either internally motivated by perceived market opportunities, or externally motivated by their larger customers who demanded adoption. Unlike Canhoto et al. (2021), whose digital maturity model was based on an SME's approach to the adoption of DTs and their type of technology use, Müller et al. (2018) focused on SME responses to DT. These ranged from craft manufacturers who did not engage with DT, to full-scale DT adopters who wanted to be leaders in their sector and believed that they had to use DT to achieve this.

A lack of either internal or external motivators could provide insight into the poor adoption of DTs by South African manufacturing SMEs. Furthermore, a lack of awareness of the technology, as found by Stentoft et al. (2020) and Qi et al. (2019), may be a critical factor. Stentoft et al. (2020) further determined that cost reduction was a prevalent driver of DTs amongst Dutch manufacturing SMEs, with this supported by evidence from other countries

(Moeuf et al. 2018; Olsen and Tomlin 2020). In contrast, Stentoft et al. (2020) determined that, although SMEs adopted the basic functionality of Industry 4.0, few SMEs used advanced technologies such as artificial intelligence and simulation. Moeuf et al. (2018) found that SMEs focused their use on production monitoring or cloud computing, while not exploiting the full potential of DTs. This is supported by Frank et al. (2019), who identified two types of technology adoption by manufacturing firms. Their first set of base technologies included front-end technologies, such as smart manufacturing and smart products, which are readily adopted. Their second set of base technologies, including IIoT and BDA, are less readily adopted.

Irrespective of firm size, Björkdahl (2020) found that manufacturers were generally not ready for digital transformation and that they had difficulty sensing and seizing opportunities for growth using DTs. Instead, DTs were used to improve efficiencies, rather than transforming the entire business model. Becker and Schmid (2020), in contrast, found that, despite having similar understandings of DTs, large enterprises had significantly different strategies and technology requirements relative to SMEs. While SMEs typically required new software solutions, their larger counterparts already had solutions and instead focused on optimising their information technology (IT) infrastructure. Another key difference was that SMEs were less likely than their larger counterparts to create value through the servicification of their products.

DT challenges are not limited to developing countries. Raj et al. (2020) argue that resource scarcity and the lack of a clear digital strategy are critical challenges in developed and developing countries. Globally, SMEs have been found to lack expertise related to Industry 4.0, along with other weaknesses including a lack of resources, inexperience in the management of complex digital systems, and an absence of production process experts (Frank et al. 2019; Ghobakhloo and Iranmanesh 2020; Moeuf et al. 2018). This explanation is supported by Cenamor et al. (2019), who found that a lack of resources and poor capabilities impede the digitalisation process in SMEs. SMEs tend to fund digital transformation primarily through the sale of products and services (O'Dwyer and Gilmore 2018), and the cashflows generated by these activities (Becker and Schmid 2020), limiting the potential for rapid advancement. Furthermore, Jones et al. (2021) explain that leaders must note the impact of pervasive mindsets within their organisations before adopting DTs. These authors developed a three-pillar model to elaborate on these pervasive mindsets, with each pillar relating to the leaders' perception of technology; their perception of their own digital competence (a fixed or growth mindset); and their perception of the potential disruption which could be caused by DTs.

Finally, various factors have been found to potentially impede the successful implementation of DT projects at SMEs. For example, Gebauer et al. (2020) describe how DT vendors, such as IIoT platforms, encounter a dilemma created by the requirement for modular, standardised

components for cost effectiveness, while simultaneously requiring expensive, highly configurable, non-standardised components for customisation to client requirements. This trade-off may be a contributing factor to SMEs failing to adopt DTs.

The impact of perceived security risks in cloud-based technologies has been researched well (Surbakti et al. 2020). Ng and Wakenshaw (2017) propose that the impact of security concerns on the adoption of IoT technology lies not in privacy, but in vulnerability. They suggest that research is needed into vulnerability from three perspectives: the individual; the firm; and the regulatory body responsible for controlling and protecting those in the system. Ng and Wakenshaw (2017) note that there is a trade-off from an individual's perspective between the choice of platform and data vulnerability.

Cloud-based IoT platforms are primarily data aggregators, and the complexity associated with interoperable IoT systems has been found to be an obstacle for successful IoT implementation. Zdravković et al. (2018) suggest that the central management of IoT systems and data often leads to less openness, resulting in greater costs to successfully integrate these systems into the business. IoT interoperability, however, requires platform openness, which increases security requirements and may be a factor in the perception of the security of data and the risk of a data breach. Zdravković et al. (2018) propose a five-category regulatory framework based on connectivity, privacy, security, standards and ownership. They argue that open standards are essential for interoperability and the realisation of ubiquitous IoT.

Various theories provide insight into technology adoption. Davis (1989) determined that both perceived ease of use and perceived usefulness were significant factors in determining a user's likelihood of adopting IT. This technology adoption model (TAM) later evolved to become technology adoption model 2, with Venkatesh and Davis (2000) incorporating socially influencing processes and cognitive instrumental processes in the TAM. Venkatesh et al. (2003) furthered technology adoption research and proposed the unified theory of acceptance and use of technology (UTAUT) based on a review of previous research. The theory was premised on four constructs: expected performance, expected effort, influence of other social actors, and facilitating conditions. They adapted this theory to UTUAT2 by modifying the constructs and context to include consumer technology and its use (Venkatesh et al. 2012).

Venkatesh et al. (2007) noted that the TAMs adopted a narrow unit of analysis, the individual, and although this is suitable for studies relating to software or consumer technology, it may not be suitable for explaining the adoption of advanced manufacturing technologies such as IIoT in manufacturing organisations.

Contingency theory posits that organisations are most effective when their internal characteristics fit with the environment in which they operate (Donaldson 2001). Manufacturing contingencies include firm size, age and supply chain level. However, it has

been argued that firm size does not explain the differences in the effect of DTs on SMEs and large manufacturers (Donaldson 2001; Tortorella et al. 2019). Supporting the contingency theory, Eggers (2020:206) argues that SMEs face challenges due to their "liability of smallness", which is further exacerbated in times of crisis. Eggers (2020) also found that externally induced crises, such as the supply chain problems induced by the COVID-19 pandemic, resulted in the reluctance of financiers to fund SMEs. However, SMEs are more flexible and able to react more quickly than larger firms. Tortorella et al. (2019) posit that, although contingency theory is a popular lens for researching different approaches to operations management, the availability of data on the impact of contingencies on digital transformation is lacking. They argue that the position of a firm in the supply chain is the only significant determinant (Tortorella et al. 2019). Contradicting this, Bag et al. (2021) used firm size and age as two control variables in their research into DT adoption and advanced resource utilisation capability by South African manufacturers. They argue that firm size and age are positive determinants of DT adoption.

Müller et al. (2018) confirmed the negative impact of size and resource scarcity on the adoption of Industry 4.0 technologies in German SMEs. They reported that manufacturing SMEs do not have the necessary real-time information from their production plants to determine their need for DTs. They also found that manufacturing SMEs were reluctant to adopt these technologies due to the perceived cost and resource requirements of implementing DTs.

Wernerfelt (1984) introduced the concept of dynamic resource management, arguing that a firm should find the balance between exploiting its resources and developing new resources to ensure firm growth and profitability. Although the resource-based view of the firm was a new approach to exploring competitiveness, Barney (1991:99) argued that it was important to understand "the link between firm resources and sustained competitive advantage". Barney (1991) identified four properties of a firm's resources that contributed to its sustained competitive advantage: its value, its rarity, its imitability, and its non-substitutability (VRIN resources). Two important requirements for a sustained competitive advantage emanate from Barney's research. First, Barney (1991) identified that first-mover advantage is gained by being the first firm to implement a competitive strategy which, in a competitively homogeneous resource environment, requires the firm to gain insights into new opportunities before competitors do. This relates to the sensing role of dynamic capability development. Second, a resource is only valuable when it enables a firm to develop a competitive strategy by exploiting opportunities for efficiency improvement or overall firm effectiveness. This relates to the seizing phase of the firm's dynamic capability development.

Teece et al. (1997:509) argue that, in an environment of rapidly changing technology, wealth creation depends more on a firm's ability to hone the "internal technological, organizational, and managerial process inside the firm" than merely strategising. According to them, the

accumulation of valuable resources does not necessarily confer competitive advantage on a firm, and this led them to develop the dynamic capabilities framework. Teece et al. (1997:518) note that building a competitive advantage requires firms to alter their processes. These "organizational processes have three roles: coordination/integration (a static concept); learning (a dynamic concept); and reconfiguration (a transformational concept)". Importantly in relation to this study, they argue that technological opportunity recognition is path dependent and driven by structures and linkages with various knowledge institutions. Developing this framework further, Teece (2007) used the social and behavioural science lens to specify the micro-foundations and higher-order capabilities that enable the adjustment of ordinary capabilities and the sensing, seizing and reconfiguring of capacities. Teece (2007) suggests that the sensing of opportunities (including new technologies) should not be the responsibility of an individual, but that processes should be established that facilitate the acquisition of the knowledge necessary to determine such opportunities. Seizing requires the firm to commit resources at the right time and to create or alter its business model in line with its new strategy. Linking this to firm management and culture, Bendig et al. (2018) argue that the key individual in this process is the chief executive officer, whose personality contributes to the development of a firm's knowledge-based capital, which is a micro-foundation of dynamic capabilities.

Helfat and Martin (2015) note that differences between managers have different effects on firm strategy and performance and may alter the path dependence of a particular set of dynamic capabilities. This supports Teece's (2007:1336) argument that, in functional structures, "day-to-day problems tend to distract management from long-run strategic issues", and that an entrepreneurial management mindset is a prerequisite for the sustainability of dynamic capabilities. Building on this argument, Teece (2018a) emphasises that the role of management in economic theory is under-researched, and that economic theory does not account for internal differences between firms, nor the impact of management on the building of dynamic capabilities.

Supporting Teece (2018a), Ngo et al. (2019) determined that firms require the capability to adapt dynamically to compete in complex, emerging markets through both technology and market-sensing capabilities. Warner and Wäger (2019) similarly found that agility is a core ability in the development of digital dynamic capabilities. Several recent studies have shown that digitalisation positively moderates the dynamic capability of the firm (Cenamor et al. 2019; Vial 2019), and that dynamic capability and digital maturity may enable the successful adoption of DTs such as IIoT (Jones et al. 2021).

First introduced by Adner and Helfat (2003:1020), the dynamic managerial capabilities concept was closely aligned with the three dynamic capabilities of sensing, seizing and reconfiguring resources; however, these capabilities are based on "managerial human capital, managerial social capital and managerial cognition". The dynamic managerial capabilities

concept extended dynamic capabilities theory by focusing on the heterogeneous business outcomes that occur due to management's influence on strategic changes (Helfat and Martin 2015). Central to the dynamic capabilities concept is the notion that managerial cognition (based on biases, heuristics and emotions) guides managerial acquisitions of information and the sensing of opportunities and changes (Helfat and Martin 2015). The social capital of management affects their ability to sense, seize and reconfigure through the goodwill acquired by way of their relationships with other staff and their business relations. Finally, their managerial human capital is built through education, experience and psychology. Teece (2018b) validated the existence of dynamic capabilities at the individual manager level, as proposed by Adner and Helfat (2003).

Li et al.'s (2016) integrated model of DT adoption by SMEs asserts that entrepreneurial SME owners may have poor managerial cognition and therefore need to develop themselves before embarking on a DT journey. This theory was identified as a possible basis to provide insight into the decision by SMEs to either adopt or delay the introduction of DTs. The dynamic capabilities framework, which encompasses business models and strategy (Teece 2018a), provides the broadest theoretical base linking competitiveness with DTs and was therefore selected as the base theory for this study.

3. Research Questions and Methodology

As the aim of the study was to understand whether South African manufacturing SMEs adopt DTs such as IIoT, and to explore which strategies they develop to implement these technologies, three questions formed the basis of our research:

1. Do SMEs in the South African manufacturing sector implement DTs such as IIoT? Why do they, or why do they not, implement such DTs?
2. What digital transformation strategies are implemented by manufacturing SMEs in South Africa?
3. How do platform openness and owner/manager mindsets influence an SME's intention to adopt DTs such as IIoT?

The questions were developed to build a rich understanding of the adoption of DTs by South African manufacturing SMEs, thereby contributing to the limited body of knowledge on DT adoption by SMEs in the South African (and international) manufacturing sector. The questions dictated an exploratory study. In similar research on the design and implementation of digital strategies by SMEs and large enterprises, Becker and Schmid (2020) adopted a qualitative exploratory research design based on 29 interviews with business executives.

An interpretivist philosophy was adopted from a constructionist epistemological perspective. SME owner/managers were considered social actors (Saunders and Lewis 2018), with the

research aiming to understand how their mindsets and perceptions of platform openness influence their decisions to digitally transform their companies. Furthermore, an inductive approach was utilised, as the research adopted a 'bottom-up' method to contribute to the existing theory on DT adoption. A mono-method qualitative exploratory study was conducted due to the inductive nature of the research.

Ployhart and Vandenberg (2010) argue that most organisational science and related theories are longitudinal in nature, and that cross-sectional studies should be avoided. However, a cross-sectional design was chosen in this study due to the nature and scope of the questions. The mindset of an owner/manager of an SME may change with time, and the study intended to determine the role of mindsets on the owner/manager's intention to adopt DTs at the time of the interview. We did not seek to predict or explain changes in intention to adopt DTs. In their research involving SMEs and the owner/manager's identification of opportunities for growth, Hulbert et al. (2013) similarly adopted a cross-sectional design.

The classification of SMEs in South Africa is based on the total number of full-time equivalent paid employees (FTEE) and the turnover of the enterprise (Department of Small Business Development 2019). Per the definition of the Department of Small Business Development, the FTEE threshold for participation in the study was set at 250, while the turnover threshold was set at R170 million. The population for the study comprised all SMEs in the South African manufacturing sector. The research problem relates to the SME strategy developers and decision makers, and the population therefore encompassed all decision makers who dealt with strategy or decision-making in manufacturing SMEs in South Africa.

The unit of analysis of this study was the manufacturing SME, although it was the owner/manager or manager who was interviewed as the representative of the firm. It was impractical to identify the entire population for the study due to the large number of small-scale manufacturing SMEs. Non-probability purposive sampling was therefore used. This is a commonly used sampling approach for case studies (Gentles et al. 2015) and has been used in similar studies (Hulbert et al. 2013). Flick (2009) proposed that the use of a heterogeneous purposive sampling method improves the diversity of the data collected and is likely to introduce diverse themes. It therefore was determined that semi-structured interviews would take place across a spectrum of SME firm sizes and a diverse range of manufacturing sub-sectors. This is exhibited in Table 1.

Guest et al. (2006) found a lack of guidance on the selection of a sample size in non-probabilistic sampling. However, they noted that saturation was often used to determine the endpoint of the interview process. They found that the basic elements for meta-themes were found after as few as six interviews, although saturation typically occurred within 12 interviews. Gentles et al. (2015) similarly suggested that researchers using a case study strategy should plan for between four and 10 cases. In total, 12 SME owner/managers or managers were interviewed (see Table 1). In addition, four interviews were conducted with

senior managers or owners of DT vendors. These interviews were undertaken to complement the SME interviews, and improved the diversity, heterogeneity and richness of the data.

The measurement instrument for this study was a semi-structured interview. This allowed for the in-depth exploration of topics, enabling rich case studies (Myers and Newman 2007; Saunders and Lewis 2018). Secondary data was used to triangulate the results. The secondary data included other research regarding DTs and SMEs, semi-structured interviews with DT platform vendors, government statistics, and other data from DT practitioners and organisations. Data gathering was done according to the process proposed by Jacob and Furgerson (2012). After completing two pilot interviews (one SME owner/manager and one DT vendor), a list of potential SME owner/managers or managers in the manufacturing sector was compiled.

The interview guide (see Appendix A) comprised questions relating to the SME's DT strategy decision-making process, as well as questions focused on understanding the enablers and inhibitors of DT implementation. Ten of the interviews were conducted using the Zoom® online video-conferencing platform. A footwear SME was interviewed telephonically, and a medical SME was interviewed face to face. Permission was requested verbally from each participant before recording the interviews, which were automatically uploaded to the Otter.ai online transcription service for verbatim transcription. Following each interview, the transcript from Otter.ai was downloaded digitally and corrections were made for language, grammar, and other misinterpretations. This was performed by a transcriber who was duly appointed, subject to a non-disclosure agreement. The corrected transcripts were then analysed and coded. As the interviews progressed, the number of codes were evaluated to identify when data saturation was achieved. No new codes were found during the 12th interview, and no further participants were enrolled thereafter. After the transcripts had been coded and themes developed, the recordings were deleted from Otter.ai to ensure data security. The digital transcripts and codes were stored in ATLAS.ti, and on a OneDrive online storage account.

Per Spiggle (1994), the research comprised two components: breaking down the data into its constituent parts; and interpreting the discrete parts to find meaning in the data. The constituent parts comprised short phrases capturing salient points in the interview transcripts. To achieve depth of analysis following the coding phase, descriptive codes were allocated to significant interview segments using the thematic analysis approach described by Braun and Clarke (2006) and Friese et al. (2018). The wide variety of descriptive codes resulted in some passages of text being linked to more than one code, although in these instances none of the linked codes were mutually exclusive. The codes generated during the first round of coding were also prefixed with topics relating to the three research questions. Initial codes were generated from the underlying data (see Appendix B), and only then were codes evaluated against each research question. This process ensured the coding was inductively

driven. After the first round of coding, all coded sections of the interviews were reviewed, and unnecessary/inappropriately linked codes were corrected or unlinked from the text. This process included the merging of codes where separate codes offered no distinct value in terms of the research questions.

After cleaning and rationalising the codes, each interview transcript was allocated to several document groups in ATLAS.ti. These document groups represented discrete, mutually exclusive properties of the participant or the firm represented by the participant. These properties were later used to provide context to the codes and categories. Thereafter, each code was allocated to a code group (category), and these groups were reviewed repeatedly as primary themes started to emerge. After two rounds of revision, 16 code categories had emerged. Per Flick (2009), these categories were then analysed further together with the document groups to identify primary themes.

4. Primary Research Findings

The profile of the 12 SMEs and the associated interviewees is presented in Table 1. As highlighted, there is a wide spectrum of manufacturing firm type, although nine of the firms were located in KwaZulu-Natal, with two in Gauteng and one in the Western Cape. Firm sizes also ranged considerably in respect of sales (from less than R5 million in sales to over R100 million) and employment (from less than 10 to over 150). Ten of the participants were owner/managers of their firms, with all but one of the 12 participants having a tertiary qualification. Most of the participants also had six or more years' service in the SME. Participants from the vendors were either senior managers or owner/managers with direct responsibility for DTs.

Table 1: Profile of participant SMEs and interviewees

	SME pseudonym	Participant position	Age	Education	SME location	Years of service	FTEEs	Revenue (Rm)
1	Textile	Owner/manager	35-50	Postgraduate	KZN	2	0-10	25-100
2	Rubber	Owner/manager	35-50	Postgraduate	WC	2.5	11-50	25-100
3	LaserCut	Owner/manager	35-50	Tertiary	KZN	10	0-10	0-5
4	Medical-1	Owner/manager	50-65	Tertiary	GP	12	11-50	5-25
5	Chemical	Manager	35-50	Postgraduate	KZN	8	151-250	100-170
6	Packaging	Owner/manager	< 35	Tertiary	GP	8	51-150	5-25
7	Plastics-1	Owner/manager	50-65	Tertiary	KZN	6	0-10	0-5
8	Pallet	Owner/manager	35-50	Tertiary	KZN	13	0-10	0-5
9	Footwear	Owner/manager	50-65	High school	KZN	15	151-250	25-100
10	Medical-2	Owner/manager	50-65	Tertiary	KZN	11	0-10	0-5
11	Auto	Owner/manager	35-50	Tertiary	KZN	25	51-150	5-25
12	Plastics-2	Manager	35-50	Tertiary	KZN	10	51-150	100-170
	Mode	Owner/manager	35-50	Tertiary	KZN	10.2	0-10	0-5

Note: All interviews completed from September to December 2021. Only SME participants included. Years of service average is mean, not mode.

Following the interview grouping, the transcripts were allocated to mutually exclusive document groups based on the content of the interviews and the profile questions. These document groups formed the first, high-level categories. One of the document groups described whether the SME had fully, partially or not adopted DTs. This was based on an analysis of the interviews and participant statements regarding levels of adoption. Following Canhoto et al.'s (2021: 7) five-phase model of DT adoption, the full adoption of DTs was recognised as being achieved when the SME entered the fusion phase (characterised by the extensive use of cross-functionally integrated technologies and the adoption of e-commerce and measurement instruments). By contrast, those firms that exhibited only limited use of technology, such as email and search engines, were categorised as not having adopted DTs. All other SMEs were then categorised as having partially adopted DTs. The interview grouping is presented in Table 2.

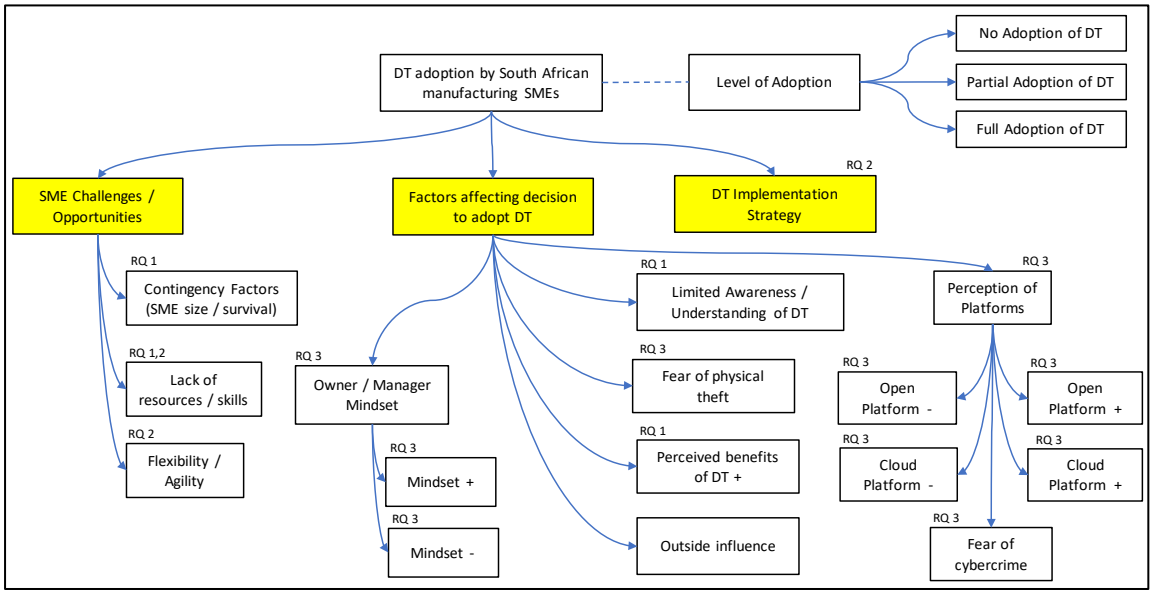
Table 2: Document groups (based on participant/firm properties)

Document group	Documents	Relates to RQ	Document group	Documents	Relates to RQ
Participant is a vendor	4		Mindset: Growth	11	3
Participant is a SME	12		Mindset: Fixed	1	3
Participant role: Manager	2		DT: Adopted	1	1
Participant role: Owner/ manager	10		DT: Not adopted	5	1
			DT: Partially adopted	6	1
Automation: Adoption	2	1	Platform preference: Open	6	3
Automation: Partial adoption	7	1	Platform preference: Proprietary	5	3
Automation: No adoption	3	1	Platform preference: Uncertain	1	3

Five of the six document groups contained 12 interview transcripts each, validating that all 12 interviews had been allocated to a mutually exclusive group. The first document group contained 16 interviews, as this group included the four interviewed vendors. The vast majority (11 of 12 participants) displayed growth mindsets, with this determined by their answers to the question: "Do you believe that you could achieve your desired ability to use these technologies; and will you do so if required?" Furthermore, there were 37 first-round quotations coded with a growth mindset code, thereby supporting this assertion. Only one of the 12 SMEs had adopted DTs, while six had partially adopted DTs, predominantly in the information systems or online sales domain. This level of DT adoption was closely matched by the level of adoption of production equipment automation, where only two participants had fully adopted automation, while seven had partially automated their production equipment. There was an almost equal preference for proprietary and open platforms.

First-round coding and category development were conducted, whereafter themes were developed and refined using a latent, constructionist approach per the method of Braun and Clarke (2006). The themes that emerged are shown in Figure 1 and fall into three main areas: the challenges and opportunities facing manufacturing SMEs in South Africa; the factors affecting SME decisions to adopt (or not) DT; and the DT implementation strategies adopted.

Figure 1: Code map



The second round of code analysis resulted in a total of 16 code groups (categories). The catch-all category, 'Other', contained all codes that did not fit into the scope of the research questions, such as the code 'COVID impact: Community focus', and are not included in Figure 1. The theme 'DT implementation strategy' initially emerged as a category and was therefore included in Table 3, but excluded as a category in Figure 1, which shows it only as a primary theme. Also shown in Table 3 are the number of codes that form part of each category, and the number of linked quotations in the interviews to which the category refers. Although the

number of quotations could not be used as an absolute, quantitative measure, they were relatively indicative of the salience of the code groups relative to each other. This number was based on the number of times participants responded with a related phrase or term. The top four code categories were 'Contingency factors (SME size/survival)', 'Positive views of cloud platform', 'Perceived benefits of DT', and 'Lack of resources/skills'.

Table 3: Code groups (categories)

Code group (Category)	Codes	Quotations	Relates to research question
Flexibility/agility	16	61	RQ 1
Limited awareness/understanding of DT	13	59	RQ 1
Lack of resources/skills	9	73	RQ 1
Contingency factors (SME size/survival)	44	139	RQ 1
Outside influence important for adoption	11	28	RQ 1/2
Perceived benefits of DT	19	74	RQ 1/2/3
Fear of cybercrime	12	50	RQ 1/3
Fear of physical theft	2	9	RQ 1/3
Negative mindset	13	42	RQ 1/3
Positive mindset	12	48	RQ 1/3
DT implementation strategy	6	16	RQ 2
Negative view of cloud platform	3	13	RQ 1/3
Positive view of cloud platform	20	108	RQ 1/3
Negative view of open platform	4	10	RQ 3
Positive view of open platform	7	20	RQ 3
Other	19	41	

The number of times an individual code was linked to a participant's response was also evaluated to determine the validity of the analysis, and to identify individual codes related to a participant's responses. This is shown in Table 4, which illustrates that the top three codes were 'Mindset: Growth', 'Busy/operational challenges', and 'Technology opportunity: Other'.

Table 4: Frequency of code use

Code	Grounded	Code groups (categories)
Mindset: Growth	32	Positive mindsets
Busy/operational challenges	30	Lack of resources/skills
Technology opportunity: Other	28	Perceived benefits of DT
Remote data access	27	Positive view of cloud platform; flexibility/agility
Cost focus	27	Contingency factors (SME size/survival)
Staff issues/skills	26	Contingency factors (SME size/survival)
DT challenge: Lack of DT skills/maturity/communication	23	Lack of resources/DT skills, awareness/IIoT/ negative view of cloud platform
DT challenge: We have always done it this way	19	Negative mindsets
Mindset: Fear of online security risks	16	Fear of cybercrime
Technology opportunity: Monitor outputs (OEE, environment, productivity, quality, etc.)	16	Perceived benefits of DT
Mindset: Belief online data security can be achieved, or risk is low	14	Fear of cybercrime

Benefits of cloud or IIoT platforms: Limited knowledge, unaware	14	Awareness of DT/IIoT/negative view of cloud platforms
Resources: Use cloud for current activities	14	Positive view of cloud platforms
Technology opportunity: Business intelligence reporting	12	Perceived benefits of DT
Platform openness: Proprietary +	12	Positive view of cloud platforms
Online sales	12	Positive view of cloud platforms
Benefits of cloud or IIoT platforms: Secure offsite storage	11	Positive view of cloud platform, fear of cybercrime
DT driver: Customer driven: General	11	Outside influence important for adoption
DT challenge: No clear use case/knowledge	11	Awareness of DT/IIoT/negative view of cloud platforms
Technology opportunity: Supply chain management	10	Perceived benefits of DT

Note: Only the top 20 codes are shown.

In respect of RQ 1, the findings indicate a low level of DT adoption by manufacturing SMEs in South Africa, suggesting firms do not typically adopt advanced DTs. Reasons for the low levels of DT adoption were investigated by analysing the code categories comprising the themes of 'SME challenges/opportunities', and 'Factors affecting decision to adopt DT'. South African manufacturing SME owner/managers and managers indicated that their organisations tended to be very operationally focused and spent significant amounts of their time solving short-term problems. They consequently did not have time to focus on strategy, especially in respect of DTs. This challenge was best exemplified by Rubber-SME, who argued that: "Everyone is running around flat out all day and no one is looking at strategy."

The further up the supply chain that the business operated, the more the interviewees appeared to understand advanced production techniques and digital transformation. This was driven by the customers' requirements. Auto-SME, which supplies a large South African automotive manufacturer, demonstrated knowledge of DTs and advised that customer requirements exposed them to DTs, arguing that "… digital technologies I think are coming through ... collecting data is important, is very important for tracking trends in your business and then checking quality and checking and tracking performance". Similarly, Footwear-SME explained how a large corporate customer was driving the implementation of a digital traceability platform in their business. Plastics-SME-1 was one of the smallest manufacturing SMEs in the study, and the company was positioned higher up the value chain, yet it had the most advanced adoption of DTs and IIoT. It had integrated DTs such as e-Commerce, digital supply chain management, and IIoT. This advanced adoption of DTs was driven by challenges with "supply chain stability, price point stability, and logistics".

At least six of the manufacturing SMEs were focused on survival, emphasising that sales were their focus area. SMEs also faced challenges securing funding, with five of the participants mentioning funding challenges despite no questions being asked in respect of the financing of the firm.

Despite not adopting DTs extensively, all of the manufacturing SMEs used some form of mobile and/or cloud-based services. However, their use of these services is operationally

driven. They typically used DTs to solve problems for which manual solutions where either unavailable or were too cumbersome to use. Most of the participants reported using computer or cloud-based ERP systems to replace manual systems. The SMEs indicated that they used technology such as cloud storage, mobile devices and ERP systems to assist in making quick, agile decisions. The technologies that the SMEs chose were based on the suitability of the technology for their existing business needs. Manufacturing SMEs used cloud services such as file storage and ERPs for ease of access, with even the smallest SMEs using cloud-based file storage systems. However, none of the SMEs mentioned that they followed any special process to identify and select their cloud-based systems.

The usefulness of cloud-based storage and ERP systems was further enhanced by the experiences of some of the SMEs that had suffered the loss of data on their own devices or at their place of work. This was a significant factor in DT adoption by these SMEs, who believed that cloud-based storage was more reliable than traditional methods.

Several manufacturing SMEs used online platforms and social media platforms to support sales. Most SMEs emphasised they were highly customer-centric and that online sales platforms had a positive effect on their business processes and customer reach. However, some of the SMEs noted challenges with cloud platforms when interacting with customers, and one preferred to use traditional face-to-face methods of marketing. Despite knowing about cloud-based resources such as file sharing and social media, manufacturing SMEs did not have in-depth knowledge of DTs. Only Plastics-SME-1 exhibited a thorough knowledge of DTs. The SMEs did, however, express an understanding of technologies such as 3D printing, remote machine access, and data gathering for quality performance. There was very little indication, however, of AI knowledge or the use of advanced algorithms for process or product improvement.

Although the manufacturing SMEs were clearly very cost conscious and were concerned about the cost of technology, it was primarily the DT vendors who were concerned about whether the SMEs saw benefit and business value in DT. SMEs did not explicitly raise concerns about the value for money of DT, but rather expressed their concern with the absolute cost of DTs and the lack of resources available to exploit DTs. As argued by Rubber-SME: “We would need to get bigger to justify going down that road, and more importantly, to be able to use the information to our advantage … because it’s not just about implementing the system; it’s more about using the information.”

Several SMEs expressed the view that they were partly responsible for creating employment in South Africa, or that they would be concerned about laying off staff due to digitalisation. There was an apparent awareness of the need to either reduce, or at least not exacerbate, the high unemployment levels in the country. Some of the manufacturing SMEs also understood use cases for DT. Footwear-SME explained, “when we have issues with

machinery, the guy logs on from Taiwan, or Russia, and immediately the problems are solved. When I say immediately, I mean, within an hour, within an hour maximum".

All the SME manufacturers acknowledged that they were likely to experience the impact of DTs in the future. Chemical-SME noted: "Definitely with the younger generation; the market as well. It's striving and pushing for us to implement technologies." Plastics-SME-1 concurred, arguing: "Honestly, I think it's adapt or die." However, several SMEs questioned the level of impact or the length of time until they would experience the impact of DTs.

In respect of RQ 2, which explored what digital transformation strategies manufacturing SMEs in South Africa have implemented, the key code categories demonstrate the limited scope of strategic planning adopted by the SMEs. While the SMEs were generally agile and able to adapt their business models, they often needed an external influence to drive DT adoption. The firms were found to lack resources and skills that inhibited their adoption of DTs, as well as the development of formal DT strategies. Those SMEs that adopted DTs appeared to select technologies that supported their flexibility and agility. This was largely in response to customer requirements. The manufacturing SMEs also used online collaboration tools and communication platforms to interact with their customers.

Manufacturing SMEs rely heavily on their internal staff, yet they often lack the requisite skills for DT transformation. Rubber-SME expressed this challenge as: "So, you've got people that are not necessarily in a zone where they feel that … they can elevate themselves. And that's the challenge we're facing because we don't want to see the people stagnating; we want to move them up. And we're figuring it out and we're moving forward, but it has been quite a battle." Packaging-SME similarly lamented the poor employee and supply chain skills available to them, stating that the "… supply chain has been monopolised now, due to dwindling skill sets so we're starting to see a massive challenge in the skillset market", and, "It's really challenging on the floor of the factory now, when you're trying to upskill, when you're trying to train, where the basic competencies are not met".

In addition to a lack of DT skills, Plastics-SME-1, who was the most advanced manufacturing SME with respect to DT, expressed frustration with network connectivity issues, arguing, "… the beauty of the cloud is it's there, it's very data rich, it's very easy and it works. But when data is not there, you're screwed [sic]". This resulted in the firm using the lowest level of digital communication protocols available for reliability.

Extending their concern with skills availability, the manufacturing SMEs believed that the younger generation was more technologically adept than the older generation, who made up a much larger portion of their employment base. When asked about the introduction of DTs into their organisation, Rubber-SME explained: "I think that would be a quite a big challenge in my organisation, because of the age and the type of people that we have."

The question of implementation strategies also emerged as one of the three key themes during the data analysis. One of the reasons for this was the glaring lack of reference by any of the participants to formal digital transformation strategies at their firm. Notwithstanding this, many of the code categories directly influenced the choice of informal digital transformation strategy by the manufacturing SMEs, and several implied strategies emerged from the interviews that were not encompassed by other code categories. For example, Packaging-SME explained that they adopted an incremental strategic approach to DT adoption: "Look, we've integrated sensors into our machines. We grew from being a manual manufacturer, to a semi-automatic manufacturer. And now we run an automatic manufacturing facility in the chemicals business. And I've just set up an automatic manufacturing plant in Johannesburg for plastics. So we've integrated little sensors that allow us counters just so that we can keep an eye on what's going on."

In summary, the surveyed SMEs used very limited and informal strategies for DT adoption. They focused on ensuring flexibility and agility in their manufacturing and sales processes, and tended to follow the lead of their customers. Their lack of resources restricted their ability to develop comprehensive strategies, while connectivity challenges in South Africa led to a pragmatic approach to connectivity using robust processes for cloud connectivity.

How do platform openness and owner/manager mindsets influence an SME's intention to adopt digital technologies such as the IIoT? This third research question sought to understand the impact of owner/manager mindsets and platform openness on the intention of manufacturing SMEs to adopt DTs. Two additional factors emerged as code categories and were found to affect SMEs' adoption of DT and moderate the impact of platform openness and owner/manager mindset. These code categories are owner/manager mindset and perception of platforms, cloud and fear of cybercrime. The interviews highlighted that manufacturing SMEs are concerned about cybercrime, with all the participants being aware of the risks related to this type of crime. However, three of the participants expressed their concern about physical theft of computers and IT servers, while others mentioned physical security risks to businesses in general in South Africa. There was a pervasive mindset of insecurity within the SMEs. Specifically, two out of 12 participants had experienced the physical theft of onsite computers and servers, and they used cloud platforms to mitigate the resultant loss of data. For example, Auto-SME noted: "… this year, we had a break in here at the business and some of the PCs got stolen … but it also sped up the process of … using OneDrive as … a source of storing our information."

Despite concerns about cybercrime and online data security, none of the participants believed that cloud-based data security was unachievable. All the manufacturing SMEs consequently saw digital and cloud platforms (including social media) as a future trend in manufacturing. However, their perception was that DTs were expensive to acquire and complicated to implement, requiring new skills that none of them reported having. Chemical-SME said: "In

terms of cost, it's a large cost factor," while Medical-SME-1 stated, "But the point is that, you know, [the production machines] work and … does it justify spending all that money to get a 2% improvement on production?" Medical-SME-2 concurred, saying "… it's expensive. Anything that you do with regard to sensors … it always costs a lot no matter what".

Finally, in respect of RQ 3, there were a variety of responses to the question regarding the SME owner/manager's perception of proprietary platforms relative to open platforms, and several seemed not to understand what was meant by these types of platforms. Interconnectivity is wanted, but so is security, which was perceived to be better with proprietary platforms. The SME owner/managers tended to believe that an open platform was more flexible and useable by customers and themselves. Some SMEs were also not aware of the DTs available on cloud-based platforms. For example, Medical-SME-2 admitted that "I've just never got to know how to do all the cloud-based stuff yet".

The owner/managers predominantly had growth mindsets, with only one having a fixed mindset. Furthermore, one of the two manager participants reported that their owners, as well as some of the older staff members, had fixed mindsets and that they adopted a very conservative approach to DT: "there's a lot of older people that have that skill set, and they definitely don't have the mindset that new is better. It's old is better."

The vendor participants provided insights that were used to triangulate the findings. All four vendors stated that they preferred to concentrate on new business opportunities with larger manufacturers, because SMEs had limited revenue potential and required disproportionately more work than their larger counterparts. The vendors also believed that SMEs did not assess platform openness when deciding whether to implement DTs, noting that this was a critical factor when choosing the most appropriate DT. The vendors explained that SMEs required specific digital transformation strategies. They suggested that SMEs should start small and capture value immediately by adopting DTs such as IIoT, and then scale their DTs to create incremental value. It was noted that the successful adoption of DTs was most likely when the owner/manager of the SME had an open mindset regarding technology.

5. Analysis of Key Research Findings

In this section we explore the survey results based on the current literature. The rich insights gained from the interviews are used to explain how manufacturing SMEs in South Africa are limited in their awareness and adoption of DTs such as IoT. Possible reasons are given for the lack of awareness and adoption of DTs, thereby contributing to the theory of dynamic capabilities related to manufacturing SMEs. Finally, several propositions are presented that provide potential research paths for future investigation.

Eleven of the 12 SMEs were in the immature passive or connection phases of the digital strategy alignment model of DT defined by Canhoto et al. (2021). They were also firmly in Stage 1 of Frank et al.'s (2019) Industry 4.0 adoption pattern framework. The low level of DT

adoption was compounded by the lack of evidence of the adoption of IIoT by the participants, with DTs primarily used for data storage, cloud-based ERP, and sales and communication on mobile platforms. The results indicate that manufacturing SMEs in South Africa are mostly unaware of the broad range of DTs available, although they are aware of mobile, cloud-based DTs such as file sharing and online enterprise resource planning (ERP).

The manufacturing SMEs face daily operational challenges and are short-term, inwardly focused. This aligns closely with the findings of Ates and Bititci (2011). Surprisingly, three of the manufacturing SMEs mentioned that physical theft of assets, including IT assets, was a challenge. They were negatively affected by a range of contingency factors, such as their firm size and lack of resources; but all mentioned the importance of flexibility or agility in what they produce and how they offer value to their markets. The average age of the firms was over 10 years at the time of the interviews, indicating their survival abilities. A short-term focus and a need for rapid decision-making aligns with Kahneman's (2012) System 1, short-term, automatic thinking, which is appropriate for crisis management, but can limit innovation and lead to inferior long-term outcomes (Bessant and Tidd 2011).

The influence of various contingent factors, such as firm size, supply chain position, technology intensity, firm age and factory size, on Industry 4.0 and firm survival have been researched recently (Bag et al. 2021; Tortorella 2019). After coding the interviews and the subsequent thematic analysis, the code group that emerged as the most used was 'Contingency factors (SME size/survival)'. This supports the view of contingency theory, namely that firms make decisions based on diverse situational factors (Donaldson 2001). However, Tortorella et al. (2019) note that the effects of contingencies on the adoption of Industry 4.0 are hardly researched. They found that SME firm size had less of an effect on the interaction between Industry 4.0 and lean practices than previous research indicated. This unexpected finding is supported by the results of this study, where the smallest firm in both categories of turnover and number of employees, Plastics-SME-1, had the highest level of DT adoption. In contrast, two of the four smallest firms, Medical-SME and Pallet-SME, were also the least mature adopters of DTs.

It is also striking that the smaller size of SMEs negatively influenced the amount of focus they garnered from DT vendors. The smaller revenues of the SMEs were perceived as less attractive to the DT vendors, who all preferred to service larger firms. This could explain the information asymmetry experienced by manufacturing SMEs. Recent research indicates that there is a preceding phase to the adoption of DTs – essentially an SME detecting and recognising the need to change (Canhoto et al. 2021; Cenamor et al. 2019). Without access to vendor information, SMEs were prejudiced by information asymmetry compared to their larger competitors. Bag et al. (2021) advanced the understanding of information access by manufacturers and contingency theory by demonstrating that firm size and age determine the firm's capability to process information. SMEs therefore face the dual challenge of a lack

of information related to DT, and poorer capabilities to process the information compared to their larger counterparts.

A significant contributing factor to the SME owner/manager's operational focus and lack of strategic focus relates to their firm's lack of resources. Five of the SME owner/managers reported that they struggled to fund their businesses, and all owners/managers mentioned their focus on sales and related transactions to survive. This finding concurs with Stentoft et al. (2021), who suggested that SMEs may miss opportunities for improvement through the adoption of Industry 4.0 due to their short-term operational focus. It also supports Eggers' (2020) findings that SMEs are challenged by a lack of resources and funding, which is exacerbated in times of crisis. The manufacturing sector in South Africa lost 53 083 (22.1% of total) SMEs in the year up to quarter 1 of 2021, indicating the shock of the COVID-19 pandemic (SEDA 2021:25).

South African manufacturing SMEs therefore appear to typically lack awareness of DTs, with only one of the 12 participants demonstrating a thorough understanding of DT. The extant literature indicates that SMEs may be slow to transform their business models, or lack the resources to exploit DTs, but there is little mention of a lack of awareness amongst SMEs (Cenamor 2019; Eggers 2020; Müller et al. 2018).

While SMEs understood the usefulness of some DTs, they also perceived DTs as costly to implement. They did not link the cost of the technology to the value that could be created or captured, instead referring to the absolute cost of the technology. In similar research, Stentoft et al. (2020) identified the same concerns amongst Dutch manufacturing SMEs.

The various technology-adoption models have been used successfully to explain users' intentions to adopt technologies such as software and consumer technology (Gimpel et al. 2020; Venkatesh et al. 2012). The primary constructs of these theories include ease of use, perceived usefulness, and the influence of social actors; however, the unit of analysis in these models was the individual. These theories (e.g. Venkatesh and Davis 2000) address the factors affecting the intention of an individual to adopt a particular technology. However, the research was premised on the user's existing awareness of the technology. In this study, we found that manufacturing SMEs chose to adopt DTs that solved operational problems, but were largely unaware of DTs such as IIoT. Their selection of technology was pragmatic and based on the owner/manager's or manager's perception of the suitability of the DT to solve an identified operational problem. Only one manufacturing SME had extensively exploited the potential of DTs. This is consistent with the findings of Moeuf et al. (2018), who identified that many SMEs limited their adoption of DT to cloud computing and IoT.

The results consequently suggest that manufacturing SMEs in South Africa adopt DTs as explained in the extant technology-adoption literature, particularly in relation to perceived usefulness and ease of use. However, it is proposed that awareness is an antecedent to DT

adoption decision-making. In addition, the SMEs were deterred from adopting DTs due to their perception of the absolute cost of these technologies, irrespective of their benefits. Most of the SMEs had consequently not developed formal DT strategies, choosing to adopt DTs in an ad hoc manner depending on immediate requirements.

Determining a firm's digital transformation strategy requires focus by top management (Teece 2018a). hHwever, the SME participants indicated that they lacked the time needed to develop these strategies. Several of the participants expressed their concern about the lack of skills in their workplace, and the data furthermore indicates that the owner/manager or manager is required to perform operational duties that would typically be performed by subordinates in a larger firm with more human resources (Becker and Schmid 2020). This, in turn, results in less time for long-term strategic planning by the owner/manager or manager, and a lack of resources is therefore proposed to be one of the primary reasons for poor strategic planning for digital transformation. This accords with the literature, which emphasises that a lack of strategic planning inhibits DT implementation (Warner and Wäger 2019) and the development of dynamic capabilities (Teece 2007), thereby affecting the firm's sustainable competitiveness.

Teece et al. (1997) identified that dynamic capabilities were key to the ability of a firm to adapt quickly to changes in its competitive environment to ensure sustained competitive advantage. Sturgeon (2021) identified four core DTs that enable operational flexibility and sustainable competitiveness: IoT and IIoT data collection and connectivity; cloud computing; BDA; and AI. The results show that all the participants mentioned flexibility or agility in their business processes, yet only one of the participants had adopted multiple DTs to enhance their flexibility, as suggested by Sturgeon (2021). This apparently contradictory finding indicates that manufacturing SMEs in South Africa achieve flexibility and agility through means other than DTs.

Two of the 12 SMEs indicated that they had adopted DTs because of outside influences. This supports the assertion by Müller et al. (2018) that SMEs may be externally motivated or pressured by larger customers to adopt DTs. It may also explain how SMEs become aware of DTs and are then able to explore the potential benefits and cost implications of these technologies. Contradicting Müller et al.'s (2018) finding, that externally motivated SMEs felt pressured to adopt DTs and did not necessarily see the benefit of DT adoption, Footwear-SME and Auto-SME acknowledged that they had seen the benefits of adopting these technologies. This suggests that external influence have be a positive effect on the adoption of DTs by manufacturing SMEs.

The data indicated that the manufacturing SMEs approached DTs with a very specific intention. They focused on using DTs to ensure flexibility and agility in their manufacturing and sales processes, and tended to follow the lead of their customers or industry bodies. Furthermore, they adopted DTs to solve existing problems, rather than developing long-term

strategies. It is suggested that their lack of resources, such as skilled staff and financial resources, restricted their ability to develop comprehensive digital transformation strategies.

Jones et al. (2021) suggest that manufacturers should view their firms as complex adaptive systems, thereby enabling them to effectively adopt digital transformation. They posit that digital transformation is a 'wicked problem' that must be managed continuously, as it cannot be solved completely. They further argue that some of the most formidable barriers to digital transformation are the three pervasive mindsets of the perception of technology and the firm's role in DT adoption; the leader's perception of their competence (their fixed or growth mindset); and the firm's perception of disruptive innovation. Similarly, Ringberg et al. (2019) propose that mindsets and technology are interconnected and lead to various potential levels of innovation.

While only one of the SME owner/managers or managers had a fixed mindset, the prevalent growth mindset exhibited by the SME owner/managers is clearly only a necessary, but insufficient, condition for successful DT adoption. The other two mindsets – of strategy and of technology – are also necessary (Jones et al. 2021). In this regard, it is striking that very few of the participants discussed their own role in DT adoption. The participants were specialists in their industries and communicated confidently in technical terms when describing their business processes, strategies and challenges, but they did not exhibit confidence when discussing DTs, which may be a causal factor in their externalising of responsibility for the digitalisation of their business models. Several respondents also believed that DT adoption could affect jobs and were concerned about the possible negative impact on employment opportunities. Jones et al. (2021) explained that a negative perception of technology can be created when the technology is perceived as replacing jobs.

An important emerging finding was the mindset of fear of theft of physical assets. Three of the SMEs had experienced physical theft and explained how they had utilised cloud-based platforms for ERP or data storage. They believed that this mitigated the risk of data loss caused by physical theft. The participants' fear of cybercrime and online data theft did not prevent their adoption of cloud-based storage and ERPs, and all the participants used some form of online storage, ERP, or retail sales platform. It therefore is suggested that physical crime in South Africa negatively affects the SME owner/manager's mindset, but may be an important driver of cloud-based DT adoption.

All participants expressed their positive perception of cloud platforms, and more specifically open platforms. This was due to their belief that open platforms had better data interconnectivity. It also supports Schenk et al.'s (2019) finding that more 'solvers' are engaged with open platforms than closed platforms, resulting in more potential solutions to interconnectivity issues between applications. The SMEs' positive perceptions of platform openness and interconnectivity were contrasted, however, by their concern that open platforms were inherently less secure than proprietary platforms. However, they did perceive

that the security benefit offered by proprietary platforms was offset by increased financial costs. It was also explained by the SMEs that interconnectivity was important within their network of customers and suppliers, and that most were using an open platform for their day-to-day communication and digital transaction needs. This supports the findings of Zdravković et al. (2018) that open architecture decreases costs and increases flexibility, but that security must be a centre point of IoT ecosystems. Although all of the SME owner/managers were concerned about the risk of data loss in the cloud, they acknowledged that the impact of data theft was low. This supports Ng and Wakenshaw's (2017) suggestion that the inhibitor of cloud-based DT adoption relates more to the perception of vulnerability than actual security.

From a vendor perspective, it was suggested that the benefits of using an open platform may outweigh the perceived risks of data loss by manufacturing SMEs. However, it was also noted that South African SME manufacturers had an immature understanding of open and proprietary platforms and focused mainly on platform costs, ignoring the potential benefits of proprietary platforms.

The thematic analysis of the interview responses provided deep insight into the research questions, which provided an opportunity to explore several propositions. Specifically, several codes that related to SME business model agility were linked to 24 quotations during the data analysis, thereby opening a pathway to investigate SME agility and the adoption of DTs through the lens of dynamic capabilities. We therefore propose a potentially virtuous cycle for the adoption of DTs by SMEs. Finally, several propositions were made regarding the factors influencing the adoption of DTs by manufacturing SMEs in South Africa. These propositions open several avenues for future research.

It is proposed that there are several challenges faced by manufacturing SMEs when attempting to build dynamic capabilities. The interviews with the manufacturing SMEs in South Africa suggest that these challenges strongly influence their adoption of DTs, covering all three dimensions of the dynamic capabilities framework: sensing, seizing and transforming.

In respect of sensing, SME entrepreneurs tend to be excellent learners and information processors who readily identify opportunities for decision-making (Li et al. 2018; Vaghely and Julien 2010). However, SMEs are inhibited by information asymmetry and may not have access to information about DTs, or the technical knowledge required to leverage this information. This study found that SMEs do not have a deep understanding of the DTs available to them. Their short-term, operational focus limits their ability to sense DT opportunities or market signals. This situation is further exacerbated by DT vendors, who focus their sales efforts on larger manufacturers.

In respect of seizing, manufacturing SMEs are agile and flexible in their business models and their approach to markets, adapting quickly when required to ensure business survival. They

can quickly adapt and refine their business models, such as LaserCut-SME, which changed its sales and distribution model to an online retail business model at the onset of COVID. This indicates the seizing capability of SMEs, which helps them build dynamic capabilities. However, their agility is driven primarily by their short-term operational challenges and their focused technical skills, rather than their development of a digital transformation strategy. The seizing process requires firms to commit resources to ensure that business strategy and redefined business model are implemented successfully (Teece 2018b). The manufacturing SMEs, however, believed that they did not have the resources necessary to mobilise and adopt advanced DTs. The lack of resources consequently hindered their adoption of DTs, which aligns with the findings of recent SME digital transformation research in several countries (Canhoto et al. 2021; Cenamor et al. 2019; Li et al. 2018; Raj et al. 2020).

Canhoto et al. (2021) suggest that SMEs in the immature passive acceptance phase of DT adoption may be motivated to adopt, or seize, DTs through access to government grants. These grants could provide the financial resource to digitally transform SME processes. Müller et al. (2018) agree that government support is required for SMEs; however, they suggest that the support may also be in the form of knowledge transfer and technological advice. Such assistance could mitigate the negative impact of resource scarcity and the lack of DT awareness amongst manufacturing SMEs.

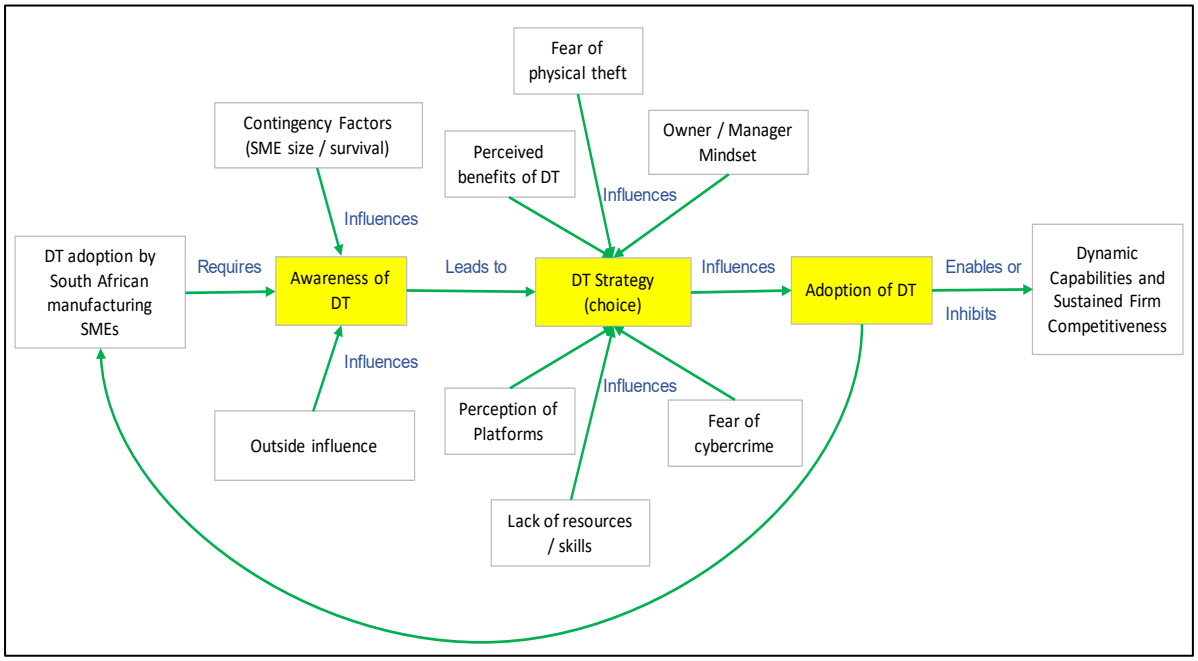
In respect of transforming, the transformation foundation of dynamic capabilities involves the reconfiguration of a firm's resources, structures and culture, underpinned by an improvement in the digital maturity of the organisation and workforce (Warner and Wäger 2019). Supporting the widely held view of the participants, that younger staff are better prepared for new DTs, Warner and Wäger (2019:338) suggest that organisations should involve younger "digital natives" in the digital transformation and structural realignment process, while balancing the use of external and internal human resources. Similarly, Mittal et al. (2018) suggest that SMEs seldom involve external consultants to assess their digital transformation readiness, and therefore lack the ability to objectively assess their digital maturity.

Exacerbating this lack of objectivity, the owner/manager, by virtue of his/her position, has significant influence on the firm's culture and human capital (Bendig et al. 2018; Vaghely and Julien 2010) and crisis management. The owner/manager is unlikely to drive the changes in culture and structure that are needed to improve digital maturity, unless they have sensed the threats and opportunities presented by DTs and seized them by redesigning their business models and allocating resources. Yet the findings of this research indicate that only one of the participating SMEs had transformed its business model and reconfigured its resources to maintain competitiveness.

Based on these observations, it is suggested that the adoption of DTs is one step in a virtuous cycle that should enable firms to access and process greater amounts of information, thereby

improving their ability to sense opportunities and threats. Having sensed these previously latent opportunities and threats, the firm seizes the opportunity or mitigates the threat by adapting its business model and committing resources to the new business model. Finally, by transforming the existing resource structure and culture, the firm enhances its dynamic capabilities. This leads to sustainable competitiveness and profitability, which increase the firm's resources and enable the sensing and seizing of new opportunities and threats, while adopting increasingly advanced DTs. This virtuous cycle enables sustained firm competitiveness. Our results suggest that there are three stages of adoption of DTs by manufacturing SMEs (see highlighted blocks in Figure 2). The virtuous cycle continues if the manufacturing SMEs continue transforming their business models and structures, thereby building their dynamic capabilities.

Figure 2: Proposed model of adoption of digital technologies by SMEs in the manufacturing sector



The first stage of the proposed model relates to the awareness of DTs by the SME and is a critical antecedent of DT adoption. This stage is influenced by contingent factors, such as firm size and position in the value chain; and is also influenced by outside entities such as customers, competitors, government, and industry bodies. The second stage relates to the SME's choice of strategy, which is influenced by six factors: the SME's access to resources and skills, the owner/manager's perception of the benefits of DT, the owner/manager's mindset related to physical security, the owner/manager's mindset related to cybersecurity, the owner/manager's growth or fixed mindset, and the owner/manager's perception of DT platforms, including platform openness.

The choice of strategy depends on the firm's level of digital maturity, ranging from the passive acceptance phase, where the SME plans to adopt DTs such as email or cloud storage, to the most advanced transformation phase, where the SME plans to adopt advanced DTs and shapes its business models and the environment in which it competes by exploiting these DTs. In the third stage, the manufacturing SME adopts DTs by executing the strategy determined in stage 2. The SME's choice of strategy influences the level of DT adoption and the extent of business model transformation.

The process of adoption of DTs by manufacturing SMEs results in an increased awareness of DTs through the searching and selection process, followed by learning through implementation. This awareness, in conjunction with successful DT adoption, drives the SME to sense and seize new DT opportunities and transform its business models and firm structure, thereby building its dynamic capabilities (Teece et al. 1997). It therefore is proposed that the level of adoption of DTs by manufacturing SMEs either enables or inhibits the development of their dynamic capabilities, which in turn enables or inhibits their further adoption of DTs. This leads us to put forward three propositions.

Proposition 1: DT awareness amongst manufacturing SMEs is inhibited by DT vendors, who fail to focus on SMEs.

The findings indicated that there was a lack of awareness of DTs by SMEs, and that this lack of awareness contributed to their low levels of adoption of DTs. It is proposed that the vendors' avoidance of marketing efforts targeted at manufacturing SMEs is a mediating factor in the SMEs' awareness of DTs. This, in turn, contributes to a lack of development of digital transformation strategies by manufacturing SMEs, as they can only adopt the DTs that they are aware of. Our results indicate that the lack of awareness of DTs may affect the owner/manager's mindset and perception of technology and disruptive innovation. This mindset was identified as a barrier to digital transformation (Jones 2021), but the impact of the DT vendor focus on the awareness of DTs by manufacturing SMEs is under-researched. Vial (2019), for instance, identified a similar potential research path created by the need to understand how firms stay up to date with DT adoption in their value networks.

This apparent gap in the literature provides an opportunity for further research. The findings of such research could contribute to the enhancement of the national government's strategy on digital transformation (South African Government 2020).

Proposition 2: The intention of manufacturing SMEs to adopt DTs is mediated by their lack of awareness of DTs and moderated by their perceptions of DT costs.

Two key code categories that directly inhibited the adoption of DTs by manufacturing SMEs were their lack of awareness of DTs, and their perception that the cost of DTs was high. Although several models of digital maturity and capability exist, and research has linked digital maturity to the adoption of DTs by manufacturers and SMEs (Cenamor et al. 2019; Müller et

al. 2018; Raj et al. 2020; Warner and Wäger 2019), their impact on the intention of manufacturing SMEs to adopt DTs has yet to be quantified.

It therefore is proposed that the intention of manufacturing SMEs to adopt DTs is mediated by their lack of DT awareness and moderated by their perception of DT costs. A research avenue therefore exists for quantitative research to test the moderating effect of SME owner/managers' awareness of DTs and the mediating effect of their perception of DT cost on their intention to adopt DTs.

Proposition 3: The availability of support structures and sector/government programmes increases awareness and adoption of DTs by manufacturing SMEs.

A lack of focus by DT vendors on manufacturing SMEs in South Africa has negatively affected DT adoption by these SMEs. This is exacerbated by the SMEs' inability to sense advanced DTs due to their short-term, operational focus. It is proposed that DT awareness is a positive mediator of the adoption of DTs by manufacturing SMEs, and that awareness could be improved through public programmes. As an example, the Department of Trade, Industry, and Competition in South Africa could incentivise DT upgrading by developing and promoting DT grants for manufacturing SMEs. Programmes could also be developed based on the World Economic Forum's (2021) global lighthouse network of advanced IIoT adopters.

It is proposed that outside agency initiatives positively mediate awareness of DTs by SMEs, and that a quantitative research opportunity exists to determine the extent to which these initiatives mediate manufacturing SMEs' awareness of DTs and intention to adopt DTs.

6. Conclusion

Manufacturing SMEs contribute significantly to economic activity and job creation in South Africa, but have recently performed poorly. The adoption of DTs has been identified as a key opportunity to improve the sustained competitiveness of manufacturing firms (Akhtar et al. 2018; Behrendt et al. 2021; Sturgeon 2021; Tortorella et al. 2019), including SME manufacturers in South Africa (SEDA 2020). Manufacturers in Europe and Asia have adopted DTs, improving their competitiveness and capabilities (World Economic Forum 2021). However, the level of DT adoption by South African manufacturing SMEs has not been well researched (Maisiri and Van Dyk 2021). A review of the DT adoption literature highlighted several potential barriers and enablers relating to the adoption of DTs by manufacturers. From a theoretical perspective, Vial (2019) suggests that a research gap exists in the mechanism by which dynamic capabilities support DTs.

The primary objective of this study therefore was to understand whether South African manufacturing SMEs adopt DTs, and why they do or do not do so. The secondary objective was to understand the impact of owner/manager mindsets and platform openness on their intention to adopt DTs. An exploratory qualitative research design was used to investigate the

three research questions posed, with our study suggesting that South African manufacturing SMEs have adopted DTs, although at an immature level when viewed through the lens of digital maturity frameworks (Canhoto et al. 2021; Frank et al. 2019). SME owner/managers' mindsets appear to have played an important role in influencing the adoption of DTs. The findings support Jones et al.'s (2021) suggestion that DT adoption is influenced by pervasive owner/manager mindsets. An unexpected result was the pervasive mindset of fear related to physical crime, in addition to a fear of cybercrime and data theft.

Of particular concern is the lack of awareness and understanding of DTs by manufacturing SMEs. The extant literature describes various challenges to SMEs during the process of DT adoption (Cenamor et al. 2019; Frank et al. 2019; Ghobakhloo and Iranmanesh 2020; Moeuf et al. 2018). However, it is focused largely on the post-awareness stages of DT selection and implementation. Our findings demonstrate the need for the development of DT awareness amongst manufacturing SMEs.

Overall, the SME owner/managers in our study had low awareness and understanding of the DT platforms available. Other than one SME, which had adopted DTs extensively based on the interconnectivity and low cost of implementing an open platform, it was not clear whether the perceived interconnectivity and cost benefits of an open platform would outweigh the perceived security of proprietary platforms in the other SMEs' intentions to adopt DTs.

Following the analysis of the results of the interviews, coupled with a review of the literature regarding DTs and manufacturing firm competitiveness, a model of the adoption of DTs by SMEs in the manufacturing sector was developed (Figure 2). The model represents a virtuous cycle, whereby the adoption of DT enables firm dynamic capabilities (per Teece 2018a), which in turn enables the sensing and seizing of more advanced DT opportunities and, ultimately, the transformation of the firms' structures and business models. It is proposed that this virtuous cycle leads to sustained manufacturing SME competitiveness.

The study has several management implications for manufacturing SMEs and DT practitioners. It demonstrates that SME owner/managers and managers should actively investigate the range of DTs available to improve their sensing abilities. SME owner/managers should also assess and develop their mindsets regarding technology, their competence, and their perception of the potential disruption that could be caused by DTs. External agents such as the Department of Trade, Industry, and Competition, as well as other government departments and larger customers, could encourage awareness of DTs amongst manufacturing SMEs, while there is an opportunity for DT vendors to investigate and develop new business models that target manufacturing SMEs.

Several limitations affect the study's findings. There was very limited adoption of advanced DTs by the surveyed manufacturing SMEs. A wider sample of SMEs that have adopted DTs may have provided a richer understanding of how manufacturing SMEs develop DT strategies.

Furthermore, this study is not necessarily generalisable to the entire population of manufacturing SMEs in South Africa due to the limited number of interviews conducted and the concentration of firms in KwaZulu-Natal. Several limitations are also inherent in exploratory research. Most importantly, this type of research results in findings that are not broadly generalisable, as the interview method limits the context of the study to the individual SMEs included (Gable 1994). This is further influenced by the limited number of interviews conducted and the open-ended questioning of the participants.

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DSI/NRF South African Research Chair in
Industrial Development (SARChI-ID)
JBS Park, Kingsway, Auckland Park,
Johannesburg, South Africa

General enquiries:
Koketso Manyane-Dlangamandla
Email: koketsom@uj.ac.za
Tel: +27 011 559 7454