Exploring digital technology in manufacturing SMEs in South Africa

M Cronje

orcid.org/ 0000-0001-5733-4501

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Supervisor: Dr JA Jordaan

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Student number: 33461538

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ABSTRACT

Industry 4.0 describes a new paradigm for operations management based on the convergence of physical equipment and digital communication technologies. Manufacturing companies struggle to implement Industry 4.0 technologies as it is a multi-faceted challenge. This has led to the development of various maturity models, frameworks and strategic roadmaps used to implement Industry 4.0 technologies

This study's main objective is to identify a strategic framework to guide manufacturing SMEs in South Africa to implement Industry 4.0 technologies and principles to improve business success. The study is structured along four secondary objectives to achieve the main objective.

This study follows a qualitative research approach collecting qualitative data through a scholarly literature review and semi-structured interviews. The literature review (Chapter 2) provides background and insight into the definition of Industry 4.0. The study further looks into the strategic requirements manufacturing SMEs in South Africa need to implement Industry 4.0 technologies successfully. A Technology Roadmap is identified as a possible strategic framework to guide SMEs in implementing Industry 4.0 technologies.

Interviews were held with five manufacturing companies (manufacturing SMEs) in the Western Cape, North West and Gauteng provinces. The interview data is analysed using the KJ Method and presented within the three perspectives of a Technology Roadmap. The data analysis identified thirteen challenges South African SMEs face and eighteen requirements SMEs should consider for successful technology implementation.

The study concludes with recommendations that can help South African manufacturing SMEs to implement Industry 4.0 technologies successfully. The key recommendation is for an SME to use a Technology Roadmap to align technology resources with its strategy and value offering. Some remaining areas of research are also identified.

Keywords: Industry 4.0, manufacturing, small and medium-sized enterprises, Technology Roadmap, KJ Method

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CHAPTER 1 INTRODUCTION

This study explores the use of digital technologies specifically for manufacturing small and medium enterprises (SMEs) in South Africa. These digital technologies form part of the concept referred to as Industry 4.0 (I4.0) or the Fourth Industrial Revolution (4IR).

This chapter (Chapter 1) provides background information to this study, followed by the problem statement and the main research question underpinning this study. The research question and the study's stated objectives in combination defined the scope of the research and used in selecting the research method. This chapter further identifies the study's limitations and concludes with a layout of the rest of the study by briefly describing the contents of the chapters to follow.

1.1 Background

Recent years have shown increased interest by businesses and governments across the globe in the so-called Industry 4.0 (Deloitte, 2016:9; Dewa *et al*., 2018:656). Existing research ventures into the sector-specific application of Industry 4.0 and specific aspects such as digital transformation, advanced manufacturing systems, integrated value chains and integrated vertical business processes. However, Industry 4.0 is not neutral regarding its relevance for different countries and regions of the world (Deloitte, 2015:10; Dewa *et al*., 2018:656).

According to the Industrie 4.0 Working Group report by Kagermann *et al.* (2013:77), the German Federal government coined the term Industry 4.0 in 2011 as part of the country's High-Tech Strategy 2020. The High-Tech Strategy 2020 consisted of several strategic initiatives to secure and maintain Germany's position as a global leader in the manufacturing equipment sector. The development of the strategic initiatives was based on innovation strategies and implementation roadmaps with the objective to embed manufacturing and plant equipment with information and communication technology (ICT) systems and automation engineering (Kagermann *et al*., 2013:5). The goal envisioned by the German government was to position itself where the German manufacturing industries can leverage their know-how into a new type of industrialisation: Industry 4.0.

In the present study, the author does not distinguish between the terms 'Industry 4.0' and 'Fourth Industrial Revolution' or '4IR'. Therefore, in this report, the author uses 'Industry 4.0' or 'I4.0' and the term 'Fourth Industrial Revolution' as used in the original referenced source.

As far as it concerns the manufacturing sector in general, it was historically concerned with improving the efficiency of individual processes, focusing on mass production, and leveraging economies of scale to drive down costs (Singapore EDB, 2017:12). Industry 4.0 came to expand this to include integrating processes in an organisation's operations, supply chain, and product lifecycle. For this reason, Industry 4.0 is heralded as the next leap forward in manufacturing flexibility and efficiency to converge into a single unified system. Data is shared, processed, and integrated across an organisation's product management, production, and enterprise layers (Singapore EDB, 2017:12).

In a concept paper prepared by South Africa's Council for Scientific and Industrial Research (CSIR) for the Parliamentary Round Table Discussions on the Impact of the Fourth Industrial Revolution on South Africa in 2018, it is stated that South Africa is leading the African continent regarding national readiness to adopt and implement Industry 4.0 technologies (Visser *et al*., 2018:10). It is believed that Industry 4.0 technologies can significantly impact South Africa's national competitiveness, export potential, job creation, and economic transformation (Visser *et al*., 2018:10).

The biggest challenges for implementing Industry 4.0 technologies on the African continent are the lack of digital skills, communications connectivity, and accessibility to technology (Visser *et al*., 2018:16). On the flip side, a Deloitte study (2016:4) titled: "Industry 4.0: Is Africa Ready for Digital Transformation" states that Africa and South Africa have great potential with manufacturing companies that can directly adopt Industry 4.0 technologies. It is argued that the adoption of digital technologies can lead to the development of unique, local high-tech products and services. Part of the reason for this is that legacy infrastructure issues do not constrain Africa and South Africa. Based on this notion, the CSIR recommended (Visser *et al*., 2018:17) that the South African industry follows a development path that addresses local challenges with indigenous (home-grown) resources balanced with digital technologies from abroad.

From a local perspective, Statistics South Africa (StatSA) defines manufacturing enterprises as organisations conducting activities in the manufacturing, processing, making, or packing of products; the slaughtering of animals, including poultry; and installation, assembly, completion, repair, and related work (StatSA, 2021:16). Thus, based on the classification of manufacturing sectors by technological intensity (UNIDO, 2021a), most South African manufacturing industries by output can be classified as low- or medium technology industries (StatSA, 2021:3).

It merits at this point to mention that beyond the African and South African contexts, the United Nations Industrial Development Organisation UNIDO reported (2021b:2) that the global manufacturing output shrank by nearly 7% in 2020 due to the outbreak of the COVID-19 pandemic. The pandemic forced countries around the world to restrict business activities and close international borders. These national containment strategies to combat the spread of the virus had severe impacts on both demand and supply in manufacturing and most other sectors of the economy. However, the manufacturing sector of most countries showed a recovery since the third quarter of 2020. It should be noted that, in addition to the pandemic's effects, global manufacturing was in decline since 2019 due to the trade and tariff uncertainties between the United States, China and the European Union (UNIDO, 2021b:3).

The recovery of global manufacturing output was gradual in the latter half of 2020, with growth jumping by 12% in the first quarter of 2021 (UNIDO, 2021b:2). In the same period, developing and emerging countries (excluding China) showed a 3.2% increase in manufacturing output, while African countries indicated a slight increase in manufacturing output of 0.8% (UNIDO, 2021b:7). The report further noted that limited data were available for African countries.

Interestingly, UNIDO reported (2021b:8) that medium-high- and high technology industries recovered faster (16.8%) in the first quarter of 2021 compared to medium-low technologies (10%) and low-technology (5.8%) industries. High-technology industries such as computer and electronics, electrical equipment, rubber & plastics, and chemical products showed remarkable growth in the first quarter of 2021. In the same period, low-technology industries such as textiles, wearing apparel and coke & refined petroleum products reduced output.

At the end of 2020, manufacturing sales in South Africa was approximately R2,150,000 million (StatSA, 2021:11). Between 2015 and 2020, there has been a steady increase (between 4-7% year on year) in manufacturing sales (StatSA, 2021:2). However, in February 2021, the year-on-year manufacturing sales decreased by nearly 10%. According to the UNIDO, in 2020, South Africa was ranked 52nd out of 152 countries based on the Competitive Industrial Performance (UNIDO, 2021a). This suggests that South Africa's manufacturing output did not recover at the same rate as that of other emerging countries (excluding China) or even the rest of Africa.

Considering the economic climate and the demands coming with Industry 4.0, it would appear that SMEs may increasingly have to consider appropriate levels of digital production technologies (e.g. digitally connected manufacturing equipment, data analysis and digital twins) for flexibility, quality improvement and productivity in balance with the unique socio-economic context and local skills. This understanding follows the observation from Mittal *et al*. (2018:194), who predict that Industry 4.0 is expected to create new technology-related challenges and opportunities for SMEs. The challenges and possible drawbacks need to be weighed against the benefits and opportunities these technologies are expected to bring.

The Revised Schedule 1 of the National Small Business Amendment Act No. 29 of 2004 defines a small enterprise as a separate and distinct business entity managed by one owner or more predominantly in the sectors or sub-sectors of the economy in accordance with the Standard

Industrial Classification (SIC) (StatSA, 2012). Further to this definition, an SME is determined using two proxies: (1) the number of full-time equivalents of paid employees and (2) the total turnover of the enterprise. Thus, for the purpose of this study, the definition of an SME in South Africa has one or more of the following characteristics:

- Fewer than 250 full-time equivalents of paid employees.
- Annual turnover of less than R170 million.

One can approach the above's complexities to suggest for SMEs in general and in South Africa, specifically, in many ways. In terms of scholarly research, there is value in having a company-level strategic framework to support long-range planning as well as the eventual implementation of a company's technology strategy. This strategic framework may serve to meaningfully guide manufacturing SMEs through the complex and fast-evolving landscape of Industry 4.0. The strategic framework proposed in this study is selected with manufacturing SMEs in South Africa in mind.

1.2 Problem Statement and Research Question

As alluded to above, manufacturing companies, in both the developed and developing world, struggle to successfully implement Industry 4.0 technologies and principles as part of their strategy to transform the organisation digitally (Issa *et al*., 2018: 974). Issa *et al*. (2018:974) state in this regard that companies need to act in a dynamic and competitive market. This requires the adoption of a digital transformation strategy. However, the German Mechanical Engineering Industry Association (VDMA - Verband Deutscher Maschinen- und Anlagenbau) reports that not even advanced German companies can see the objectives, specific benefits, and solutions that Industry 4.0 can provide (VDMA, 2016:9). It follows that, in practice, many manufacturing organisations struggle to implement Industry 4.0 as it is (at least at present) a mere concept rather than a ready-to-implement solution. It appears that the problem is multi-faceted as Issa *et al*. (2018:974) identify the following challenges for the implementation of Industry 4.0:

- The horizontal value chain and the vertical production business processes need integration in and outside a manufacturing organisation.
- Change management is required to transform the culture of the organisation. Pilot projects implemented in companies resemble feasibility studies. They cannot show the full potential of digital transformation as they ignore key aspects in the organisation, such as structure and culture.

- Confirmed cases of actual digital transformation are still rare within manufacturing companies.

While the above challenges pertain to Germany specifically, the problems in implementing Industry 4.0 are plaguing organisations everywhere (Issa *et al*., 2018:974). Issa *et al.* (2018:974) further reported that, on average, less than 20% of big companies succeed in their digital transformation efforts, let alone SMEs. This has led to various researchers developing Industry 4.0 maturity models for SMEs, among other types of companies, to develop their own digital transformation strategies (Mittal *et al*., 2018:194, Issa *et al*., 2018:973).

In the manufacturing sector, the focus of digital transformation has shifted from focusing on manufacturing processes to the whole value chain and decision-making hierarchy in a company. Issa *et al*. (2018:973) argue in this regard that the focus of Industry 4.0 has moved from a technology problem to a business and added-value problem. However, the vexing question is the suitability of existing models for the specific business management approaches, features, and challenges of manufacturing SMEs in developing countries, specifically.

Against the backdrop of the above, the core research question of this study is: how can existing Industry 4.0 roadmaps/models be used for digital transformation in manufacturing SMEs in South Africa to help secure success potential?

1.3 Objectives of the Study

This study's main objective is to identify a strategic framework that can guide manufacturing SMEs in South Africa to implement Industry 4.0 technologies and principles to improve business success. To achieve the main objective, the research is further structured along with the following secondary objectives:

- To identify the requirements for the strategic leadership of an organisation to improve the successful implementation of Industry 4.0 technologies.
- To identify or develop a definition of Industry 4.0 to assist with concept clarification.
- To identify some of the perceived and actual difficulties and barriers South African manufacturing SMEs face with the implementation of Industry 4.o technologies and principles.
- To identify and peruse the literature on technology implementation models and propose aspects suitable for technology implementation within a South African manufacturing SME context.

1.4 Scope of the Study

This research focuses on implementing Industry 4.0 technologies specifically for SMEs in the manufacturing industry in South Africa. In addition to this focus, the research will be narrowed down to identifying strategy analysis practices and tools for organisation leaders in the manufacturing sector. The manufacturing SMEs considered for the research sample are limited to the regions of North-West, Gauteng and the Western Cape.

1.5 Research Methodology

A research design is a plan to answer one's research question, while a research method is a strategy used to implement that plan for the research design (Bryman *et al*., 2018:100). This section serves as an introduction to the research method adopted in this study. The research method is, however, more extensively dealt with in Chapter 3 - Research Methods.

A qualitative research approach was chosen to answer the main research question, namely, how can existing Industry 4.0 roadmaps/models be used for digital transformation in manufacturing SMEs in South Africa to help secure success potential? The methods considered to collect relevant qualitative data were a scholarly literature review and semi-structured interviews with the identified study population. The sequence of the main steps outlined in Figure 1-1 below guided the structure of the qualitative research.

Although the qualitative research approach described above was adopted as a general orientation for the research, the focus was on understanding the theory on Technology Roadmaps rather than generating a new theory for the implementation of Industry 4.0. It follows that this study adopted a mixed-method (Bryman *et al*., 2018:31) research approach.

The scholarly literature review was performed to investigate current knowledge and information on five themes identified as important to the research question and research objectives:

1. The definition of Industry 4.0.
2. The concept of digital technologies in the manufacturing environment.
3. The concept of Technology Roadmaps.
4. Industry 4.0 in the South African context.
5. The strategic requirements for successful Industry 4.0 implementation in SMEs?

The literature review and its findings are presented in Chapter 2 - Literature Review.

Chapter 3 - Research Methods presents additional detail on the target population used in this study, the sampling strategy and the data collection methods.

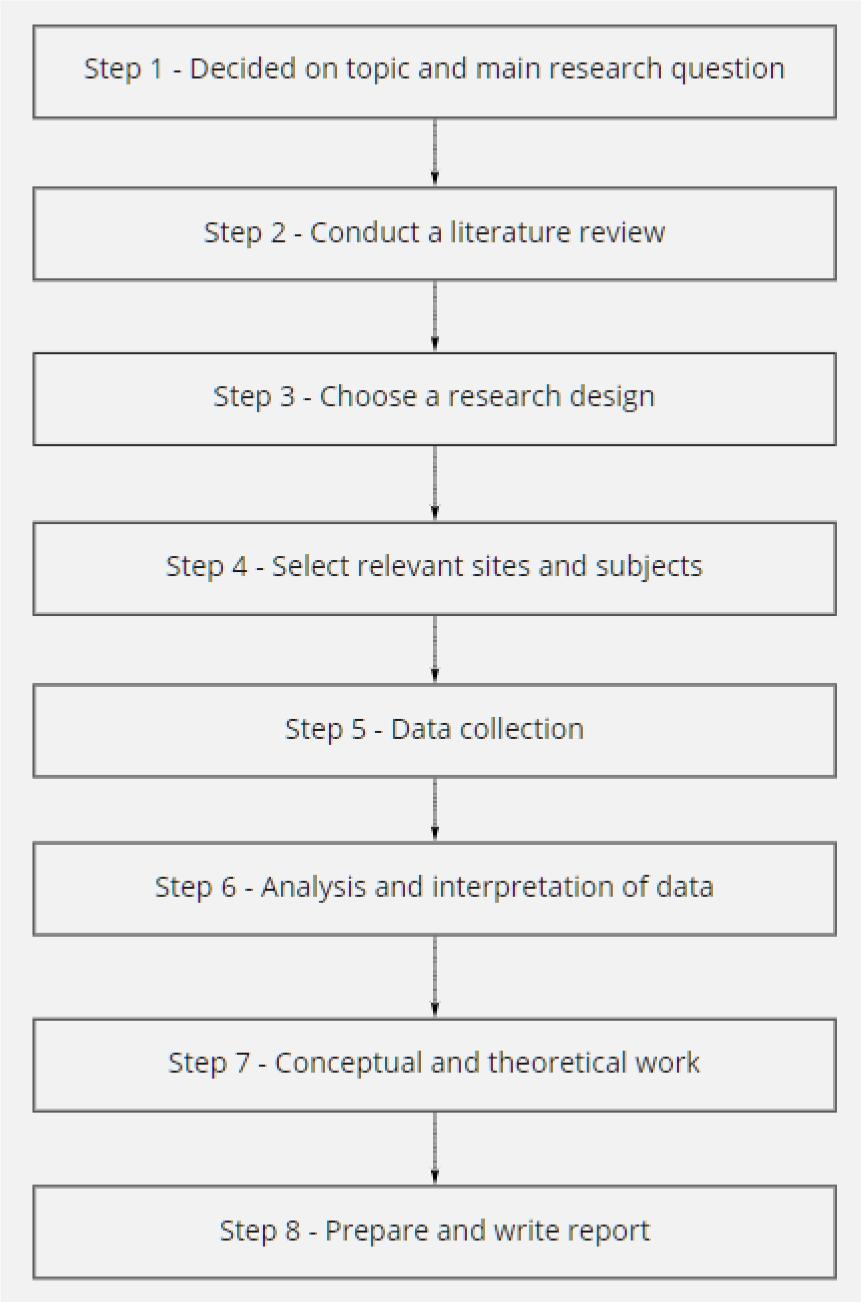


Figure 1-1: Outline of main steps of the adopted research approach (adapted from Bryman *et al*., 2017:41).

1.6 Limitations of the Study

Although some authors identified the scarcity of literature on the successful implementation of Industry 4.0 frameworks (Issa *et al., 2018:974*), this study has not exhausted all the available literature on the topic. The literature review had to be limited in line with the effort associated with a mini-dissertation.

As further explained in Chapter 3 – Research Methods, semi-structured interviews were held with five manufacturing SMEs. The number of interviews was limited by the available time and the scope of this study. In addition, the sample of the study population was limited to organisations within the researcher's network, and manufacturing organisations (SMEs) identified within the Potchefstroom area where the researcher resides. Due to the limitations imposed by the COVID-19 pandemic, all interviews were conducted virtually.

1.7 Layout of the Study

Chapter 1 - Introduction, the present chapter contextualises the study and introduces its objectives, scope, and method with reference to the main research question.

Chapter 2 - Literature Review offers an overview of the existing literature relevant to this study to clarify key terms and garner insights into the theoretical underpinnings of the aspects covered by the research question. Further to this, Chapter 2 presents an argument to lead the reader's understanding of the issues associated with implementing Industry 4.0 technologies in manufacturing SMEs in a South African context.

Chapter 3 - Research Methods presents in detail the methods used to gather the data presented in this study. This chapter also explains how the methods helped to understand the environment of the interviewees' organisations in terms of technology implementation.

Chapter 4 – Findings presents the data collected via semi-structured interviews. Further, this chapter summarises, interprets and coherently discuss the research results.

This mini-dissertation closes with Chapter 5 – Conclusion, a summary of the content of this study. This chapter also presents recommendations subsequent to reflecting on South African manufacturing SMEs' key challenges with the technology paradigm referred to as Industry 4.0 and some of the opportunities identified. The chapter also offers a view of how the data (presented in Chapter 4) assisted with confirming findings, correlations, and contradictions to the literature (as reviewed in Chapter 2).

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

As indicated in Chapter 1, the primary research question this study seeks to address is: "how can existing Industry 4.0 roadmaps/models be used for digital transformation in manufacturing SMEs in South Africa to help secure success potential?". In support of this question, a literature review was conducted to review and evaluate the scholarship in this field. The literature review was conducted to inform the following subsidiary research questions:

- What is the generally accepted or dominating definition of Industry 4.0, also referred to as I4.0 or 4IR?
- What are digital technologies in manufacturing?
- What does the concept of a technology roadmap mean?
- What is the dominating Industry 4.0 technology implementation perspectives in a developing country and, more specifically, South Africa?
- What seems to be the requirements for the strategic leadership of an organisation to improve the successful implementation of Industry 4.0-specific objectives?

The objectives of the literature review were to critically review the relevant literature in response to the questions above and to further:

1. Establish the concepts and definitions of Industry 4.0 and Technology Roadmaps.
2. Establish and critically evaluate the focus and trends in the existing scholarly discourse.
3. Determine how to apply and integrate the existing information and knowledge with the proposed study's planning to complement the present research question and study objectives.

A systematic approach to the literature review was followed to obtain evidence-based information in the existing literature to inform the present research meaningfully. The three main steps followed, and as initially proposed by Bryman *et al.* (2018:95), were:

1. Specifying the research question(s) and plan the review.
2. Conducting the review.

3. Reporting and dissemination of the review.

However, features in the literature review associated with the so-called narrative review were also considered to overlap with the systematic approach to obtain a more interpretive and qualitative overview of the available literature (Bryman *et al*., 2018:97).

2.2 Industry 4.0 defined

Many a definition of Industry 4.0 exists in the literature. This study reflects on some of these definitions to assist with concept clarification and to help delineate the angle of analysis of the remainder of the research.

It merits to mention at this point that Benitez *et al*. (2019:192) found that the main limitation of their research was the subjectivity of the results around (a) the question of what Industry 4.0 is and (b) the technologies that Industry 4.0 comprise of. Their survey-based research also revealed the scarcity of literature on some Industry 4.0 topics. The researcher has to agree with Benitez *et al*.'s (2019:193) observation that a confusing mix of Industry 4.0 definitions and descriptions exist in the literature.

In layman's terms, the VDMA defines Industry 4.0 as the combination of information technologies and production engineering (VDMA, 2016:3). The implementation of Industry 4.0 is described as challenging as its realisation depends on integrating various technologies. Some of the challenges also go beyond the technical realm as data management needs to adhere to the applicable legal frameworks, for example (VDMA, 2016:3).

A Deloitte report, titled: "Industry 4.0: challenges and solutions for the digital transformation and use of exponential technologies" on the challenges and solutions for digital transformation provides four main characteristics of Industry 4.0 (Deloitte, 2015:6):

- Vertical networking of intelligent production systems with a focus on resource efficiency (Deloitte, 2015:7).
- Horizontal integration through value chain networks enables integrated transparency and a high level of flexibility and value chain optimisation (Deloitte, 2015:7).
- Enabling new synergies between product development and production systems through engineering across a product's lifecycle (or service) (Deloitte, 2015:7).
- Acceleration of solutions, flexibility, and cost savings of industrial processes through exponential technologies (Deloitte, 2015:8).

On the basis of the above, Industry 4.0 is deemed the development and management of the value chain activities in an organisation (Deloitte, 2015:3). A more recent Deloitte report (2020:3) further defined Industry 4.0 as the integration of physical and advanced digital technologies that allow for communication and data analysis for value chain stakeholders. Such integration typically enables organisations to be more flexible and responsive through intelligent, data-based decision-making. To fully grasp the extent of this definition, it merits to also briefly describe the concepts of vertical integration, horizontal integration, and through-engineering across the product lifecycle.

Value chain activities are the operations that encompass the planning and execution of processes that lead to the production of goods and services. The Singapore Economic Development Board (EDB) describes vertical integration as the integration of processes and systems across the hierarchical levels of an organisation (Singapore EDB, 2017:14). Therefore, vertical integration establishes a connected, end-to-end data thread that allows for automated decision-making processes.

Horizontal integration refers to the integration of enterprise processes across the organisation and with other stakeholders along the value chain (Singapore EDB, 2017:12). This integration includes, but is not limited to, the planning and management of raw materials and inventory levels from supplier through to the customer.

The Singapore EDB (2017:12) describes the product lifecycle as the sequence of stages that every product goes through, from its initial conceptualisation to its eventual removal from the market. Through-engineering integrates people, processes, and systems throughout the product lifecycle (Singapore EDB, 2017:12). The data collected from integrated vertical processes and horizontal value chain activities at different product lifecycle stages create a digital twin (Singapore EDB, 2017:12). The digital twin is a virtual representation of the physical assets, processes, and systems involved throughout the product lifecycle (Singapore EDB, 2017:12). The digital twin allows for information generated to be shared, and it removes the limitations of working with physical prototypes (Singapore EDB, 2017:12).

Following the descriptions above, the Singapore EDB describes Industry 4.0 as the management of production processes along the value chain through the use of digital technology and autonomously communicating devices (Singapore EDB, 2017:45). The organisation expands on this Industry 4.0 definition with six design principles: interoperability, virtualisation, decentralisation, real-time capability, service orientation, and modularity. In short, Industry 4.0 describes a new paradigm for operations management based on the convergence of physical equipment and digital communication technologies (Singapore EDB, 2017:4).

Basl (2018:3) states that the concept of Industry 4.0 characterises a transformation of production from separated automated processes and factories into fully automated and optimised manufacturing environments. Production processes are linked vertically and horizontally in enterprise systems allowing for near real-time data sharing, information sharing, and continuous communication. Basl's definition of Industry 4.0 (2018:3) as industrial integration mediated by information technology arguably serves to capture the essence of the concept of Industry 4.0. To put this in layman's terms: Industry 4.0 is the integration of Operations Technology (OT) with Information and Communication Technology (ICT).

Andreoni and Anzolin (2019:1) describe the Fourth Industrial Revolution as different technologies that alter activities in the value chain of production and service delivery. They emphasise the point that these technologies have the capabilities to merge the physical and digital realms of production and products. The researcher views Andreoni and Anzolin's inclusion of the primary activities in the value chain in their definition of Industry 4.0 as key to this study. In addition, the researcher views the Singapore EDB (2017:4) definition of Industry 4.0 as sufficiently broad to include primary and secondary activities in the value chain. For purposes of this study, the emphasis falls on the primary value chain and secondary support activities to the extent that it allows for effective strategic decision making.

From the definitions provided, one can form a solid idea of what Industry 4.0 entails. Some definitions extend to include processes and systems that stretch across the entire horizontal value chain and the vertical business processes. However, there is a danger that some Industry 4.0 definitions can be too narrow or too broad.

Based on the literature review conducted, the researcher defines Industry 4.0 for the purposes of this study as "*the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies".*

This definition of Industry 4.0 necessarily triggers the following questions: what are digital production technologies, how does the latter fit in a South African context, and what are the requirements for a strategic roadmap for the digital transformation of a manufacturing SME in South Africa?

2.3 Digital Technologies in Manufacturing

According to the Singapore EDB (2017:6), Industry 4.0 brings a paradigm shift in manufacturing technologies. The Third Industrial Revolution focused on improving the efficiency and scale of manufacturing using pre-programmed logic. Industry 4.0 technologies now aim to enable manufacturing machines and devices to communicate and perform autonomous, intelligent decision-making. The Singapore EDB (2017:6) further claims that rigid, centralised factory control systems associated with the Third Industrial Revolution gave way to decentralised intelligence and decision-making. This progressive paradigm shift is considered the basis of changing business success potential from scale to flexible manufacturing.

A World Economic Forum (WEF) report on the readiness for the future of production lists twelve emerging technologies associated with Industry 4.0 (WEF, 2018:3). Production technologies and ICT technologies are considered the key strategic technologies to significantly impact commercial success in the next decade (Basl, 2018:3). Basl (2018:3) further states that Industry 4.0 will be based on innovative technology combinations in production, transport, and material handling activities and related processes. Other technologies relevant to manufacturing listed by Basl (2018:3), as added to Table 1-1 below, are cloud-based internet service, big data, simulation, digitisation, digital twinning, and various autonomous solutions.

The World Economic Forum (WEF) highlights that the risks associated with the implementation of emerging technologies (Table 2-1) require anticipation, monitoring, and mitigation (WEF, 2018:3). The performance of Industry 4.0 technologies in competitive manufacturing environments typically faces risks associated with system failures, such as artificial intelligence making manufacturing-related errors in judgment (WEF, 2018:3).

Table 2-1: Twelve key emerging technologies associated with digital production (WEF, 2018:1).

Technology	Description
Artificial intelligence and robotics	Development of machines that can substitute humans increasingly in tasks associated with thinking, multitasking and fine motor skills.
Ubiquitous linked sensors	Also known as the "Internet of Things." The use of networked sensors to remotely connect, track and manage products, systems and grids.
Virtual and augmented realities	Next-step interfaces between humans and computers involving immersive environments, holographic readouts and digitally produced overlays for mixed-reality experiences.

Additive manufacturing	Advances in additive manufacturing, using a widening range of materials and methods.
Blockchain and distributed ledger technology	Distributed ledger technology based on cryptographic systems that manage, verify and publicly record transaction data; the basis of "cryptocurrencies" such as Bitcoin.
Advanced materials and nanomaterials	Creation of new materials and nanostructures for the development of beneficial material properties, such as thermoelectric efficiency, shape retention and new functionality.
Energy capture, storage and transmission	Breakthroughs in battery and fuel cell efficiency; renewable energy through solar, wind, and tidal technologies; energy distribution through smart grid systems; wireless energy transfer; and more.
New computing technologies	New architectures for computing hardware, such as quantum computing, biological computing or neural network processing, as well as innovative expansion of current computing technologies.
Biotechnologies	Innovations in genetic engineering, sequencing and therapeutics, as well as biological computational interfaces and synthetic biology.
Geoengineering	Technological intervention in planetary systems, typically to mitigate effects of climate change by removing carbon dioxide or managing solar radiation.
Neurotechnology	Innovations such as smart drugs, neuroimaging and bioelectronic interfaces that allow for reading, communicating and influencing human brain activity.
Space technologies	Developments allowing for greater access to and exploration of space, including microsatellites, advanced

	telescopes, reusable rockets and integrated rocket-jet engines.

Implementing the technologies captured in Table 1-1 in a manufacturing environment aims to achieve increased productivity, agility, and production speed (Singapore EDB, 2017:4). Manufacturers can achieve these benefits by creating a connected industrial value chain with enterprise systems that manage data and information in continuous communication (Singapore EDB, 2017:10). The primary purpose of this connected industrial value chain is to allow for the analysis of data, which is the foundation of effective decision-making (Ullman, 1996:32).

With the above mentioned in mind, complex integrated technology systems management is a highly demanding task for manufacturing organisations in a developing country, such as South Africa (Andreoni & Anzolin, 2019:5). Andreoni and Anzolin explain that digital transformation of manufacturing systems had been made more challenging by raising the capability threshold that companies need to achieve and maintain to use Industry 4.0 technologies effectively. Andreoni and Alzolin (2019:2) state that the digital transformation of production activities will depend on the degree of routinisation where only routine tasks will drive automation and not necessarily the fact that tasks are manual.

Andreoni and Anzolin (2019:11) state that production technologies are the subgroup of technologies on which developing countries need to focus. These production technologies do not necessarily refer to emerging technologies such as those presented in Table 1-1 but extend to existing technologies. Therefore, it is important to distinguish between production technologies and digital production technologies:

- Production technologies refer to the wide range of machinery, tools, and complementary equipment that works in a coordinated way to produce tangible assets at the volume and quality required of the organisation (Andreoni & Anzolin, 2019:11).

- Digital production technologies refer to the development of traditional industrial production technologies through innovation in machinery hardware, software, and the connectivity of these machines' functionality using cyber-physical systems. The connectivity extends to other production technology and products to create an integrated production system (Andreoni & Anzolin, 2019:11).

Andreoni and Anzolin (2019:17) further state that the three components of digital production technologies, that is, hardware, software, and connectivity, need integration on a technological and organisational level. The authors also point out that these digital production technologies require retrofitting with existing production technologies.

VDMA provides an Industry 4.0 toolbox for product and production innovations based in Industry 4.0 (VDMA, 2016:9). The so-called VDMA Industry 4.0 toolbox divides the production processes into six application levels (VDMA, 2016:15): (1) data processing in production, (2) machine-to-machine communication, (3) company-wide networking with the production floor, (4) infrastructure of information and telecommunications technologies in production, (5) human-machine interfaces, and (6) efficiency for small batches. The goal with production technologies is to optimise production processes and reduce costs (VDMA, 2016:11). Therefore, each application level is broken down into sequential stages of development.

As mentioned above, the generation of data and the availability (connectedness) of data is at the core of digital production technologies. Andreoni and Anzolin (2019:13) highlight that data is central to through-engineering of value chain activities, such as tracking the production of products internally to an organisation and externally along its supply chain. The increased utilisation of data has been leveraged by die decrease in the cost of sensors and lower power bandwidth requirements for data transfer. However, organisations cannot efficiently use data without a reliable infrastructure connection. In a South African context, Andreoni and Anzolin (2019:14) cite the lack of high-speed data access as an obstacle for deploying emerging technologies, such as those listed in Table 1-1, in the machinery and equipment sector.

Taking a step back, it merits to mention that the previous three industrial revolutions were made possible by advanced technologies in steam power in the first industrial revolution, electrical power in the second industrial revolution, and electronics and information technology in the third industrial revolution (Singapore EDB, 2017:10). Although Table 1-1 lists several diverse technologies, the use of ubiquitous linked sensors, that is, the internet of things symbolises the trends that mark Industry 4.0 (Basl, 2018:3).

The third group of technologies to consider is product technologies, where new product innovations are possible using the emerging technologies listed in Table 1-1. With regards to the use of innovative technologies on or with a product, the VDMA Industry 4.0 toolbox identified six application levels for products: (1) integration of sensors/actuators, (2) communication/connectivity, (3) functionalities for data storage and information exchange, (4) monitoring, (5) product-related IT services and (6) business models developed around the product.

The VDMA (2016:7) suggests that an intelligent combination of the emerging technologies implemented within the digital production environment will unfold the business success potential for SMEs. However, the VDMA reports that many companies are unaware of digital technologies or the roadmap(s) that may lead them to implement these technologies successfully. In light of the challenge of a) identifying technologies and b) implementing these technologies in a manufacturing environment, this study investigates possible roadmaps (guidelines) that may assist SMEs in South Africa with implementing Industry 4.0 technologies.

2.4 Roadmaps (Industry 4.0 Roadmaps and Technology Roadmaps)

Manufacturing organisations have difficulty in defining the steps to become an Industry 4.0-oriented organisation. This observation is confirmed in research by Benetiz *et al*. (2019:197), where the respondents in the study were able to determine the need for vertical integration following three steps of (1) automation of the process, (2) integration through digital connection, and (3) analysis of data collected. However, the respondents failed to identify the necessary steps beyond this, such as horizontal value chain integration. However, research in this field is scant. The researcher has to agree with Benetiz *et al*. (2019:197), who observe that the existing literature lacks studies that detail the implementing steps necessary to establish an Industry 4.0-oriented organisation.

Implementing Industry 4.0 methodologies and technologies into products and production processes requires a diverse range of skills and an understanding of technology. These technologies are generally not internally present in SMEs. Issa *et al.* (2018:974) further criticise the use of pilot projects to demonstrate Industry 4.0. They argue that these projects fall short of showing the benefits of digital transformation and tend to ignore an organisation's structural and cultural features. The authors show that confirmed cases of actual digital transformation in German manufacturing companies were still rare at the time of their research. This point to some challenges. Where large organisations can internally fund Industry 4.0 practices from a review, research, and implementation viewpoint, SMEs cannot necessarily devise a strategy quickly and effectively for implementing Industry 4.0 methods. This raises the question of how can SMEs implement Industry 4.0 technologies to reach their strategic objectives in a structured, standardised, and cost-effective manner?

Leineweber *et al.* (2018:404) state that many SMEs in the manufacturing industry are still unaware of the new technology paradigm (i.e., Industry 4.0 or the Fourth Industrial Revolution). SMEs are often overwhelmed with decisions and may not know how to transform their organisations in line with this new technology paradigm: where to start, how to proceed, or where to go (Mittal *et al*., 2018:196). As a start, Basl (2018:3) lists sixteen Industry 4.0 readiness models available that deal with different ways to measure and evaluate the readiness of companies to transform using Industry 4.0. However, these models merely provide organisations with a method to analyse their existing situation and measure their technology maturity. Unfortunately, the models tend not to identify (or address) objectives and constraints, they do not assist in generating routes to objectives, and do not propose options for delivering the objectives. Despite these drawbacks, Basl (2018:5) argues that measuring the progress towards Industry 4.0 could speed up an organisation's eventual Industry 4.0 implementation.

As suggested above, analysing an organisation's technology maturity relative to Industry 4.0 is only a starting point. In this regard, Mittal *et al.* (2018:194) critically evaluated fifteen smart manufacturing and Industry, 4.0 maturity models. They determined that none of the assessed models was a good fit for the specific requirements of the digital transformation of manufacturing SMEs (Mittal *et al*., 2018:207). Manufacturing SMEs will accordingly require a roadmap that is fit for their purpose and size and that guides companies of this kind through viable phases of digital transformation as well as cross-linking with the company's purpose to a) show results that are both tangible and quantifiable and b) help secure success potential.

In what follows, four of the existing roadmaps are considered in greater detail, namely:

- The VDMA Guideline for implementing Industry 4.0 in small and medium enterprises (VDMA, 2016:1).
- The Singapore Economic Development Board's Smart Industry Readiness Index (Singapore EDB, 2017:1).
- The Industry 4.0 Roadmap developed by Pessl *et al*. (2017:193).
- The Technology Roadmap in the format presented by the Institute for Manufacturing at the University of Cambridge, UK (CTM, 2021).

The objective of the discussion of these roadmaps is to introduce the concept of each roadmap, that is, the main steps the roadmap consists of, the strengths and critique of the roadmaps.

2.4.1 VDMA Guideline

The German Mechanical Engineering Industry Association, VDMA, developed a guideline (VDMA, 2017:1) for SMEs to implement Industry 4.0 technologies. The VDMA proposed a chronologically arranged procedural model of five process steps, illustrated in Figure 2-1. The guidelines for SMEs presented by VDMA focuses on Industry 4.0 technology implementation for products and production processes (VDMA, 2017:9). The VDMA acknowledged SMEs' difficulty seeing the objective and benefits of implementing digital production technologies in their organisations. Therefore, the challenge was to develop a roadmap that consists of viable development stages that an organisation (SME) can implement as is. The goal was to assist the SME to identify the tangible benefits that digital production technologies, or combinations thereof, can bring to its organisation.

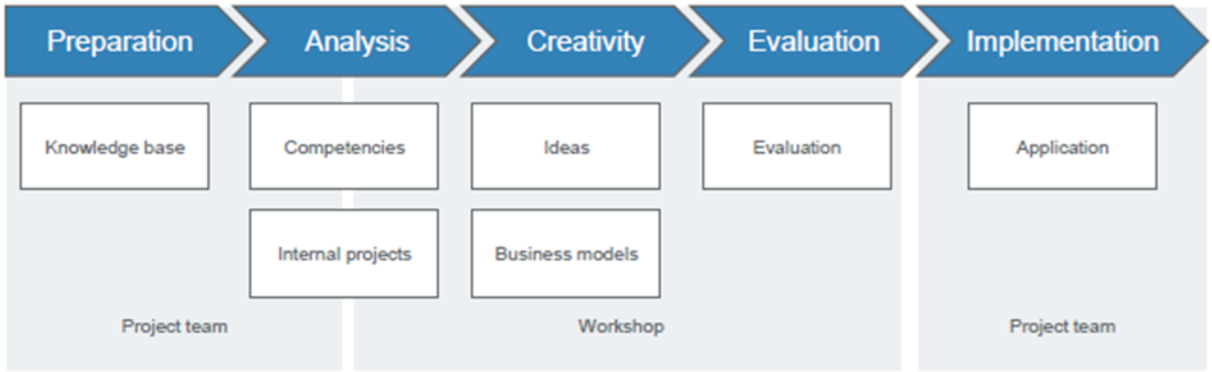


Figure 2-1: VDMA Guideline steps for implementing Industry 4.0 in SMEs (VDMA, 2017:10).

The focus of the VDMA Guideline is on (a) launching new, innovative products and (b) improving production processes in the company (VDMA, 2017:8) to also develop new business models. One of the points of departure is that the implementation of Industry 4.0 technologies requires the commitment of an organisation's senior management before implementing the processes suggested by the Guideline. The first implementation step is to establish a suitable, interdisciplinary project team consisting of company employees representing operations and information technology (VDMA, 2017:8).

The VDMA procedural model (as proposed in the Guideline) was tested in workshops at four (which appear to be non-SME) German companies along the lines of five proposed steps (VDMA, 2017:8). The five steps illustrated in Figure 2-1 can be summarised as follow:

1. Establishment of a project team (as a preparatory step) to develop knowledge of the relevant market (external) and the SME's own production (internal) capabilities. The objective of this project team should be to create a shared understanding of Industry 4.0 (VDMA, 2017:10).
2. Perform an analysis of the available digital production and product technologies expertise in the SME. The result of the analysis is the starting point of idea generation in later phases.

3. The creativity step concerns the generation and collection of new ideas in a structured workshop. The outcome of the creativity step feeds into the eventual adoption of a suitable Industry 4.0 business model.
4. The evaluation of Industry 4.0 business models concerns evaluating market potential, production potential, and resource requirements. The aim is to identify a business model that presents the most opportunity and the lowest resource requirement.
5. As a final step, proposals are developed by the project team and presented to the SME's senior management. The outcome(s) of the workshop should then subsequently be transferred to and communicated with the team responsible for implementation in the SME.

Mittal *et al.* (2018:202) critique the VDMA Guideline because it is confusing and makes the application of the toolbox proposed in the VDMA Guideline challenging. They further argue that the VDMA Guideline lacks steps to evaluate Industry 4.0 readiness as such and on how an SME can proceed on a sustainable Industry 4.0 journey (Mittal *et al.,* 2018:208).

2.4.2 Singapore Smart Industry Readiness Index

The Singapore Economic Development Board (EDB), in partnership with TÜV SÜD, created the Singapore Smart Industry Readiness Index (Singapore EDB, 2017:4). The index is a comprehensive analysis tool for all companies, regardless of size, to develop a vision, strategy, and systematic roadmap for implementing Industry 4.0 technologies.

The index covers the three core elements of Industry 4.0: technology, processes, and organisation (Singapore EDB, 2017:4). These three elements form the top layer of the index, illustrated in Figure 2-2. The three elements are underpinned by eight pillars of focus which map onto the 16 dimensions of the assessment. The aim of this index is for companies to use it as a self-evaluation tool.

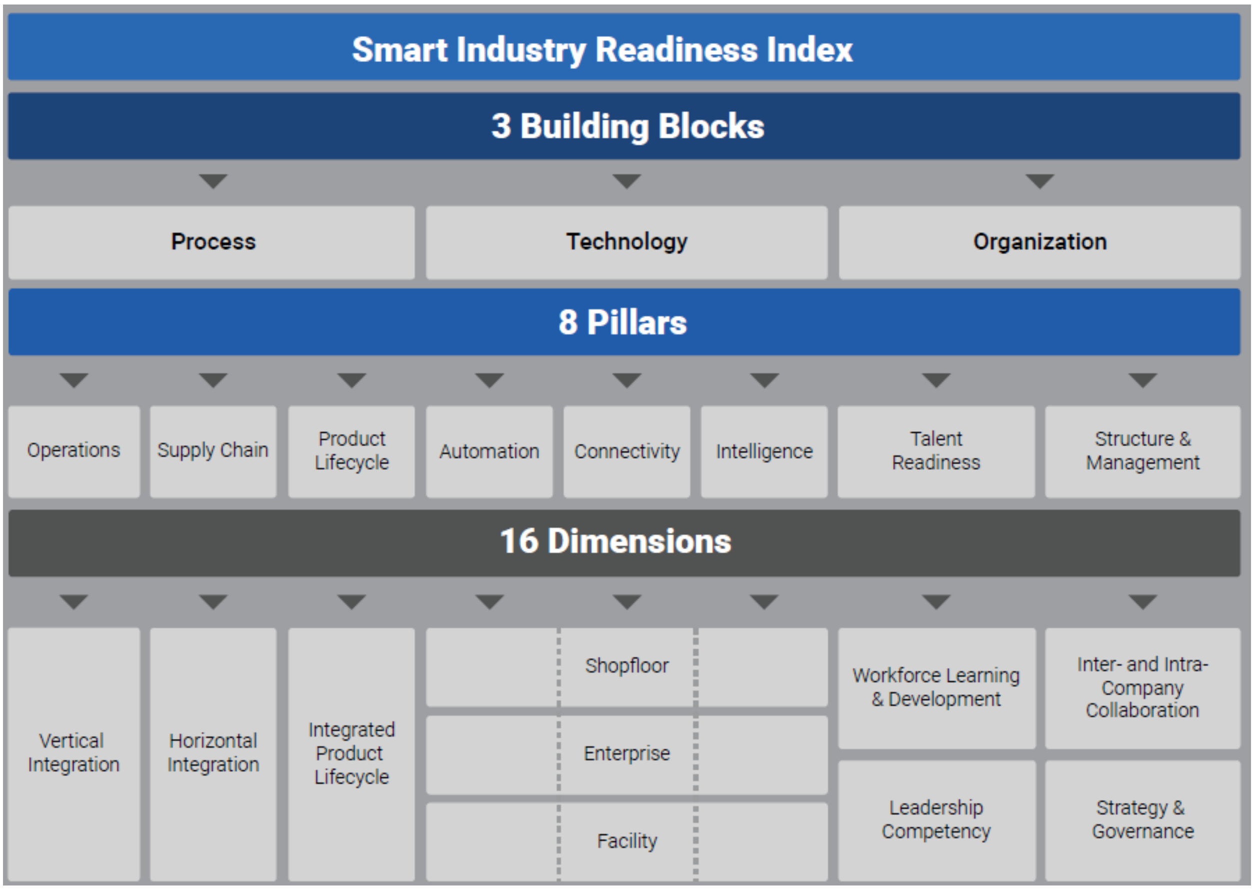


Figure 2-2: The framework of the Singapore Smart Industry Readiness Index (Singapore EDB, 2017:4).

The index is laid out in four steps in the Industry 4.0 transformation journey, also illustrated in Figure 2-3:

- Learn the fundamental concepts of Industry 4.0. This step seeks to increase the level of understanding of Industry 4.0 technologies. It also aims to establish a common understanding among stakeholders in an organisation (Singapore EDB, 2017:4).
- The 16 dimensions of the index are used to evaluate the current state of an organisation's processes, systems, and structures (Singapore EDB, 2017:4).
- An organisation can then develop or design (architect) an Industry 4.0 transformation roadmap from the self-evaluation results. The index should be used as a checklist where all dimensions need to be considered, serving as a step-by-step guide. The goal in this step is for organisations to identify high-impact initiatives, a suitable structure and implementation roadmap and to be able to define milestones (Singapore EDB, 2017:4).
- Once the organisation has developed the Industry 4.0 transformation roadmap, the delivery of the initiatives can be tracked using the index as the measure.

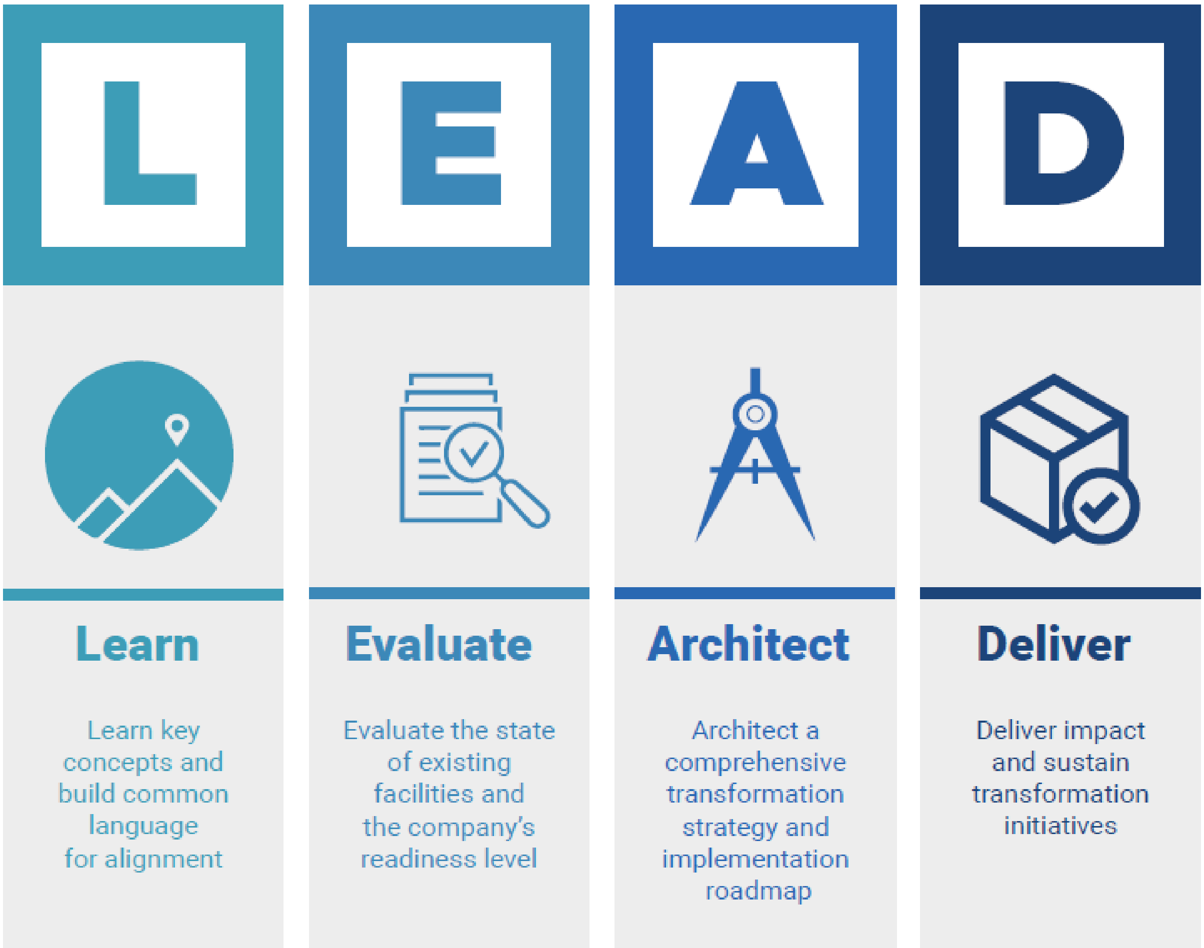


Figure 2-3: The LEAD framework proposed by Singapore EDB (2017:17).

2.4.3 Roadmap Industry 4.0 (developed by Pessl *et al.*)

Pessl *et al*. (2017:194) recognise that challenges associated with Industry 4.0 are the increase in digitisation, the adaption of existing product lines to new technologies, and defining the role of humans in the new processes. Pessl *et al*. (2017:195) list the following reasons why Industry 4.0 has not been implemented or used in an organisation:

- High investment costs due to a lack of Industry 4.0 suitability of the existing production infrastructure.
- Missing transparency and quantifiable benefits of Industry 4.0.
- Concerns about organisational changeability and IT security.

In response, Pessl *et al.* (2017:194) propose an approach that allows individual companies to develop their digital transformation process instead of following a general and one-size-fits-all rigid assessment. Their proposed Industry 4.0 roadmap was developed in partnership with and successfully applied in one company (Pessl *et al*., 2017:194). The focus was placed on the relevance of humans in the new processes, especially the new competencies required to implement Industry 4.0 technologies.

The proposed Industry 4.0 roadmap, illustrated in Figure 2-4, consists of three major phases, with each phase consisting of two steps (Pessl *et al*., 2017:196):

1. Analysis – Industry 4.0 awareness through workshops and learning followed by an assessment of the Industry 4.0 maturity of the organisation.
2. Targets – the results from the previous step are used to define the target state the organisation wants to achieve. Measures for each field of action are defined and evaluated based on effort vs benefit.
3. Realisation – objectives are defined, and measures relevant to the organisation's strategy are selected. Projects are identified, with initial pilot projects, to achieve the defined objectives.

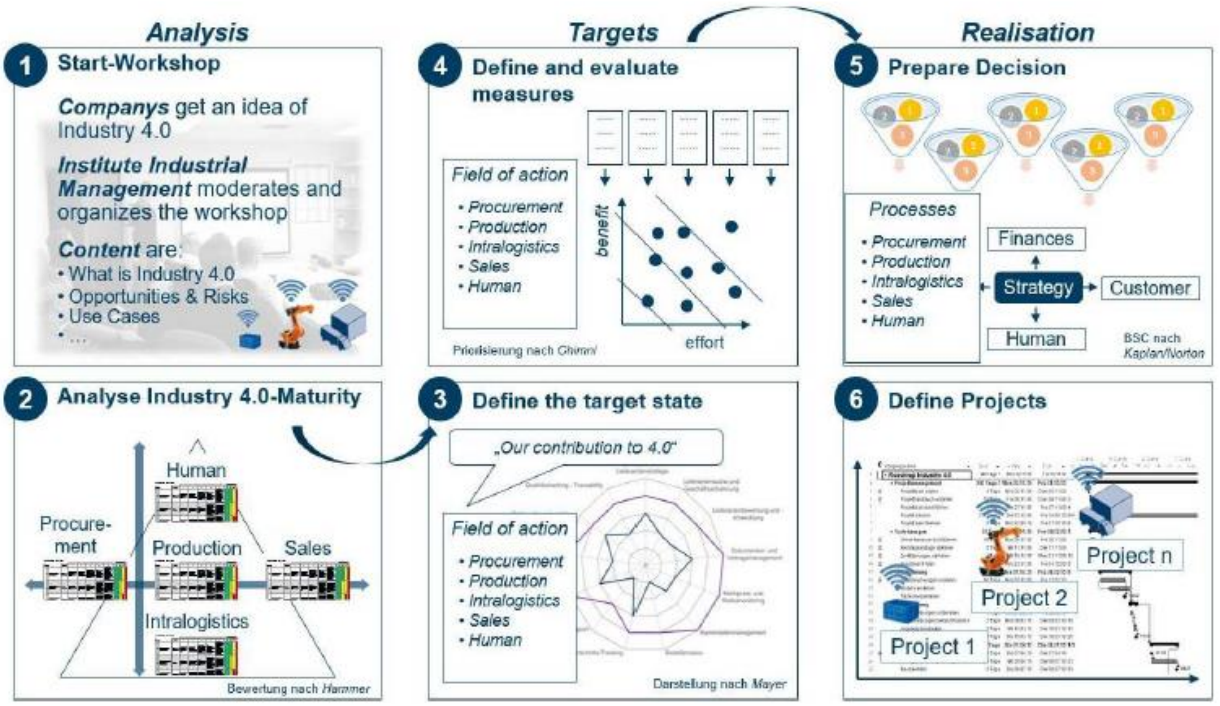


Figure 2-4: Roadmap Industry 4.0 proposed by Pessl *et al*. (2017:195).

This first step is similar to the VDMA Guiding Principles (Section2.4.1) and the Singapore Smart Index (Section 2.4.2.) presented above. Pessl *et al.* (2017:196) also recommend defining the scope of the planned Industry 4.0 implementation projects. It is through a recommended SWOT analysis that factors external and internal to the organisation are considered. The SWOT analysis aims to maximise the benefits of the strengths and opportunities and minimise the loss of weaknesses and threats.

In the next step, spider diagrams illustrate the current and targeted state of Industry 4.0 in the organisation (Pessl *et al*., 2017:200). Based on the gap analysis performed for each Industry 4.0 dimension, the organisation needs to decide which dimension should be further developed to reach a higher level of Industry 4.0 maturity. This step should be part of a digitalisation strategy that follows a systematic strategy process.

Pessl *et al.* (2017:200) observe that in one organisation where the Roadmap Industry 4.0 was tested, there was no top-down strategic approach to Industry 4.0. This lack of a strategic approach created uncertainty about increasing digitalisation within the organisation and led to a disparity in the level of digitisation between departments. Pessl *et al.* (2017:200) argue that the high level of willingness to learn points to a continuously learning organisation, making it easier to implement change through digitalisation.

2.4.4 Technology Roadmapping

Technology roadmapping is a powerful and popular management tool credited to work done at Motorola in the mid-1970s (Kerr & Phaal, 2020:2). The focus of the technology roadmapping process at Motorola was to align program investments with fast-changing technologies against commercial aspirations for product innovations (Kerr & Phaal, 2020:2). However, Kerr and Phaal (2020:14) point out that the roots of technology roadmapping is much older than acknowledged in the literature and can be traced to industrial engineering management in the 1960s and 1970s. In addition, organisations such as NASA, Boeing, GE, Lockheed, USAF, Rockwell International, and the US Department of Energy made significant contributions to technology roadmapping. It merits to halt for a moment to ask what is technology roadmapping or Technology Roadmaps.

Garcia and Bray (1997:12) distinguish between technology roadmapping and a technology roadmap. They describe technology roadmapping as a technology planning process driven by a need, not a solution. Technology alternatives are identified, selected, and developed to satisfy these needs, be they market, business, product, or technology needs. The technology roadmapping process provides an interdisciplinary team framework to organise and present information to make appropriate technology investment decisions.

A technology roadmap is a document generated from the technology roadmapping process (Garcia & Bray, 1997:12). This document identifies the critical system requirements, the product, process performance targets, the technology alternative, and milestones for meeting those targets. By identifying well-defined objectives, the technology roadmap helps focus resources on the critical technologies needed to meet those objectives. Although the term 'technology roadmap' is widely used and the dominant phrase (Phaal *et al*., 2003a:361) in the literature, the word 'technology' can be replaced with 'business', 'strategy' or 'innovation'.

The work by Garcia and Bray at Sandia National Laboratories as well the work done on technology roadmapping at Motorola, BP, Phillips, EIRMA, and Lucent Technologies, contributed to the development of the modern form of a technology roadmap consisting out of a temporal, multilayered and systems-based structure (Kerr & Phaal, 2020:1). This current form of a technology roadmap is described by Moehrle *et al*. (2013:4) as a graphical representation (Figure 2-5) encompassing all technology activities concerned with products, processes, functions, market agents, competencies, projects, and further aspects.

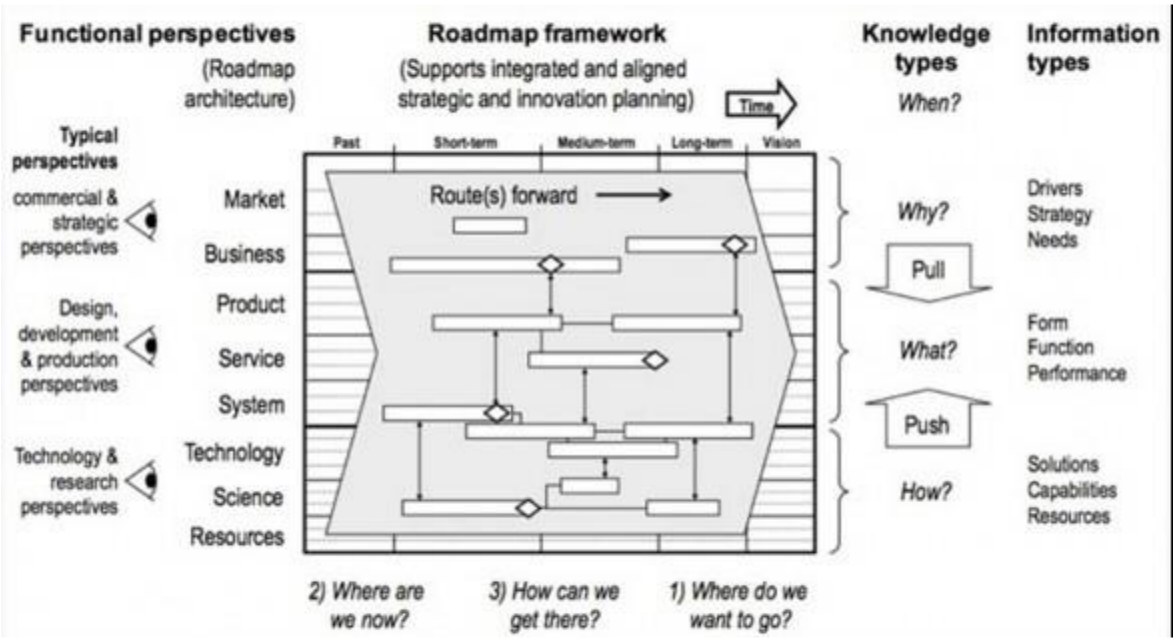


Figure 2-5: Technology Roadmap (CTM, 2021).

The technology roadmap (as illustrated in Figure 2-5 and Figure 2-6) consists of three horizontal layers that give the roadmap a market, product, and technology feature (Kerr & Phaal, 2020:1). The three layers represent the following strategic questions:

1. Market and business layer (top): why does the organisation need to act? That is, what are the market and business drivers?

2. Product layer (middle): What should the organisation do? That is, what is the value proposition the organisation provides to the market?
3. Technology layer (bottom): how will the organisation do it? That is, what solutions, capabilities and other resources will the organisation require to deliver the value proposition?

Technology roadmaps can integrate with other strategic planning and innovation processes and tools (Phaal *et al*., 2005:108). For example, the top layer of the roadmap (Figure 2-6) typically includes the market (external) and business (internal) drivers. These drivers can be assessed with strategic planning and innovation process tools such as Porter's five forces, SWOT analyses and assessments of the social, technological, economic, environmental, political and legal factors, also referred to as STEEPL.

Porter's five forces (Ungerer *et al*., 2016:99) are used to provide the strategic context of the roadmap relative to industry competitors, suppliers, buyers, new entrants and substitutes. A SWOT analysis (Ungerer *et al*., 2016:259) can be used to evaluate internal (strengths and weaknesses) attributes concerning external (opportunities and threats) factors. Both Porter's five forces and the SWOT analysis are means to establish a broader strategic context. Phaal *et al.* (2005:109) further emphasise that strategic planning is iterative and needs to be regularly revisited as the roadmap develops and matures.

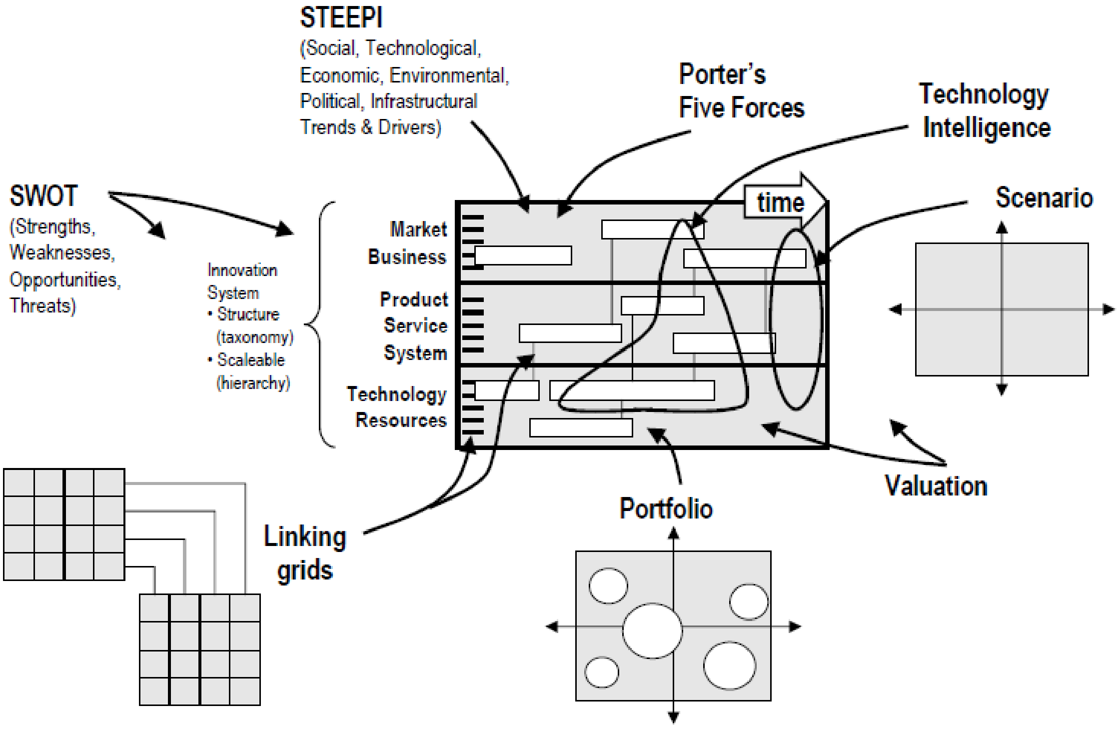


Figure 2-6: Technology Roadmap framework integrates with other strategic planning tools (Phaal *et al*., 2005:109).

The quality of a roadmap depends on the quality of the data, information and knowledge captured in the processes used to create the roadmap (Phaal *et al*., 2005:109). Therefore, technology intelligence systems need to be in place to identify, gather, interpret, and disseminate strategically important information. Moehrle *et al*. (2013:1) explain that those responsible for the digital transformation in an organisation face the tasks to acquire, preserve, protect, and apply the required technological competencies. These tasks translate into the need for managing technology and monitoring the constant flux of innovation, the multi-disciplinary connections and activities needed to improve the technology standing of the organisation. The goal of technology management in this context is to link the market and technology intelligence systems to identify, gather, interpret, and disseminate technology solutions that are strategically important to the organisation's value offering.

Roadmaps are divided into timeframes along the horizontal axis of the roadmap (Kerr & Phaal, 2020:1). These timeframes can be grouped into past, short-, medium- and long-term perspectives and the organisation's vision. The horizontal axis of the roadmap seeks to answer three fundamental, strategic questions:

- Where does the organisation want to go? That is, what is the vision of the organisation?

- Where is the organisation now? That is, what was done in the past and what needs to be done immediately or in the short term?
- How can the organisation get to the desired point? That is, what needs to be done in the medium to long term to achieve the vision?

An organisation needs to decide which possible options to pursue, such as projects, technologies, products, services, etc. These options will require action on project scope definition, scheduling, and resource allocation in the short term. Phaal *et al*. (2005:109) report that a wide range of portfolio methods was developed over the years to support the process of option selection and maintain a balanced portfolio of options. In this vein, Phaal and Mitchell (2009:4) summarise various portfolio selection tools into two orthogonal dimensions: Opportunity vs. Appropriability subsequently changed into Opportunity vs. Feasibility (Mitchell *et al*., 2018:5). Mitchell and colleagues (2018:5) explain Opportunity in this context as the estimated value that may results from a project, while Feasibility indicates the resources required to execute the Opportunity. In addition, various financial evaluation techniques can be used to support the valuation of the technologies in the portfolio, such as net-present value, internal rate of return, discounted cash flow, time to break even and payback (Phaal *et al*., 2005:109).

The primary purpose of linking grids, associated with technology and product layers in Figure 2-6, is to link technologies, products, and markets. The Quality Function Deployment (QFD), a well-known tool used in the product and design process (Cambridge Roadmapping, 2021), is considered a foundational tool as it links customer requirements with technical specifications (Heizer *et al*., 2017:204). Other linking grid tools to consider are the Hoshin Kanri X-matrix (Kanbanize, 2021) and Technology Income Statement developed by De Wet (1996:510). Although linking grids categorise products and technologies into timeframes, it is considered a weak link with time and narrative (Cambridge Roadmapping, 2021), while Technology Roadmaps often lack analysis capability. Therefore, these two tools complement each other well.

Phaal *et al.* (2003a:362) report that the attractiveness of technology roadmapping further lies in the flexible techniques in terms of:

- The wide range of aims roadmapping can contribute and support the strategic planning of an organisation.
- The timeframe is covered by the roadmapping process.
- The structure of the roadmap can be adapted to a particular application.
- The process followed to developed and maintain the roadmaps.
- The graphical format of the roadmap is used to present and communicate the result of the roadmapping.

- The range of tools, processes and information sources that can be integrated with a roadmap.

However, Phaal *et al*. (2003a:268) warn that there are inherent challenges associated with technology roadmapping due to the risk of dealing with a complex and uncertain future. Moehrle *et al*. (2016:6) also point out that since Technology Roadmaps primarily address the forecasting of technology developments and their interactions, the limitations of use lie in the uncertainty associated with technological development and innovations. Therefore, this process works best if the participants can manage uncertainty tolerance (Phaal *et al*., 2003a:268). Phaal and colleagues (2003a:269) further point out the flexibility of the technology roadmapping process is also a weakness as it must be customised to fit a particular application. Thus, it is not a rigid process that is ready-to-use for every strategy, product and technology development situation.

According to Moehrle *et al*. (2013:6), the purpose of technology roadmapping will vary depending on the various stakeholders involved in the process of creating the roadmap. Furthermore, roadmaps have a supervisory dimension; it facilitates coordination of different functional groups in the organisation, provides a competitive strategy, and coordinates intra- and extra-organisation technology activities where extensive co-operations or a high-level external procurement is required. Finally, technology roadmapping is an established tool for operational technology and innovation management (Moehrle *et al*., 2016:7) with aspects of documentation with a communicative purpose, institutionalisation, and instrumental linking functions.

2.5 The South African Context

The WEF report on the readiness for the future of production warned a few years ago that developing countries, such as South Africa, that relied on low-cost labour could lose their competitiveness to countries using emerging Industry 4.0 technologies to reshoring manufacturing back to advanced economies (WEF, 2018:2). This reshoring of manufacturing can lead to decreased production opportunities for developing countries.

The WEF Readiness Assessment of the future of production (WEF, 2018:19) indicated mixed results for South Africa. Although South Africa had the strongest structure for production in Africa, the contribution of manufacturing to the share of GDP has decreased significantly since the 1990s. However, the report highlights that South Africa's greatest strengths are its ability to innovate and that a sophisticated financial sector supports its entrepreneurial activity. However, the lack of engineers and scientists with digital skills was flagged as an area of concern. Interestingly, among the G20 countries, South Africa, Argentina and Brazil had the lowest readiness levels for the future of production (WEF, 2018:13).

One of the dilemmas at present is that the literature on the use and application of digital transformation leans towards being focused mainly on the need and conditions of the Global North. For example, Dewa *et al*. (2018:651), writing on Industry 4.0, states that South Africa has a gap in scholarly published empirical evidence on the use and application of Industry 4.0 technologies in the manufacturing industry. Ironically, given some of the constraints SMEs face in the developing world, Industry 4.0 may significantly benefit the pursuit of secured success. In this context, one should appreciate the statement by Schwab (2016:3) that decision-makers are too often caught up in traditional, linear and non-disruptive thinking or too absorbed by immediate concerns to think strategically about the forces of disruption and innovation shaping their future. Mittal *et al*. (2018:196) support this notion explaining that SMEs are overwhelmed by strategic and operational decision-making regardless of geographical location. Thus, companies are struggling to incorporate Industry 4.0 technologies into their business and operating models. Considering the context alluded to above, this may be particularly true for the African and South African contexts.

A survey performed by Dewa *et al*. (2018:659) indicated an interaction between departments in an organisation related to strategy and operations, but cross-functional collaboration scored relatively low. Investments in Industry 4.0 technologies scored the lowest in this category, and this was attributed to the lack of perceived business value in implementing Industry 4.0 implementing technologies. Dewa *et al*. (2018:662) conclude their study with the view that there is a lack of Industry 4.0 awareness in academia and the industry. The research has shown that South African companies possibly do not implement Industry 4.0 enabling technologies. Those companies that, in fact, do (i.e., implement Industry 4.0) are mainly entrepreneurs who used the enabling technologies to maximise business value.

Andreoni and Anzolin (2019:4) report that the effective adoption of Industry 4.0 technologies will not be equally distributed as companies in developing countries, such as South Africa, face different challenges in terms of (1) production capabilities supported by (2) enabling infrastructure. The infrastructures the authors refer to are reliable electricity and standardisation of connectivity. In addition to this statement, Dewa *et al*. (2018:658) modified existing Industry 4.0 readiness models by including a level 0 at the lower end of the scale, referred to as the Outsider level, and removed level 5 from the top end of the scale. To determine how prepared South African manufacturing companies are using Industry 4.0 enabling technologies, Dewa *et al*. (2018:659) showed that companies in their surveyed sample have basic machinery that does not allow a machine-to-machine connection. Yet, IT and data security have been invested in or partially implemented Dewa *et al*. (2018:659). This suggests that telecommunications and cybersecurity are important to the operations of manufacturing companies in South Africa.

Andreoni and Anzolin (2019:4) identified the following five challenges for developing countries, such as South Africa, when engaging in Industry 4.0 technologies:

1. Technology absorption, effective deployment, and capability thresholds.
2. Production system retrofitting and integration.
3. Basic and digital infrastructure.
4. Technology diffusion, Industry 4.0 islands and a digital capability gap.
5. Endogenous asymmetries in technology access and affordability.

In framing another challenge, Dewa *et al*. (2018:650) highlight the importance of connectivity as a requirement for Industry 4.0 technologies in South Africa. However, this requirement for connectivity is not always possible given infrastructure and other gaps, while advancements in Industry 4.0 technologies are offset by infrastructural bottlenecks (Andreoni & Anzolin, 2019:5). Digital production technologies require basic and digital infrastructure such as affordable and reliable electricity and decent connectivity to put Industry 4.0 technologies to sustainable use in production operations.

Although there are case studies in developing countries where Industry 4.0 technologies have been successfully implemented in companies, these are limited. Digital production technology showcases (success stories) are isolated to companies in what Andreoni and Anzolin (2019:6) refer to as '4IR islands'. They further state that the digital capability gap between these companies and the rest of their value chain is so extreme that it will be too costly to cross the gap, resulting in limited diffusion of Industry 4.0 technologies.

Dewa *et al*. (2018:656), in their research on what other developing countries are doing with regards to Industry 4.0, distinguish between advanced developing countries such as Singapore, Thailand, Malaysia and traditional developing countries like South Africa. Advanced developing countries such as Singapore, Thailand and Malaysia showed applications of Industry 4.0 going beyond the traditional manufacturing space. However, most of the observed Industry 4.0 innovation took place amongst multinational enterprises (MNEs) and Industry 4.0 was not, at least at the time, considered relevant to SMEs.

Dewa *et al*. (2018:656) further found that advanced developing countries had embraced Industry 4.0 with varying degrees of success. However, common obstacles to implementation were observed amongst these countries. The authors suggested that traditional developing countries such as South Africa can learn from these lessons. Countries like China and Thailand developed industrial development plans with parallel development plans supporting companies in implementing technologies associated with the 2nd, 3rd and 4th Industrial Revolutions. In China, it is convincingly argued that all industries cannot achieve an Industry 4.0 upgrade in the short term. In Thailand, for example, the aim is first to overcome middle income and inequality traps. Dewa *et al*. (2018:656) argue that these observations would possibly apply in other developing countries as well.

As far as it concerns South Africa, it can thus be concluded that South Africa still relies on its legacy production infrastructure. South Africa remains competitive with its dynamic innovation and development landscape, leveraged by an advanced financial sector. However, the lack of reliable electricity supply and affordable broadband internet are constraints to implementing digital production technologies.

2.6 Strategic Requirements for Successful Industry 4.0 Implementation

In South Africa and elsewhere, industrialisation is about the commitment of resources under uncertainty (Andreoni & Anzolin, 2018:58). The authors (2019:5) explain that establishing new plants is rare as it requires significant long-term investment, access to markets and a digital infrastructure to operate the plant. Therefore, companies with already committed capital in assets with pre-Industry 4.0 technologies need to find ways to retrofit and integrate the new digital production technologies into their existing operations.

However, the challenges associated with Industry 4 is also associated with business strategy, not just technology strategy. As indicated earlier in this study, Issa *et al*. (2018:973) made the valuable point that organisations struggle to implement Industry 4.0 enabling technologies as it is a concept rather than a ready-to-implement solution. These researchers argue that the primary challenge of manufacturing companies is to transform from a cost-based operation to a company with a high value-added competitive advantage.

Notably, Benetiz *et al*. (2018:197) observed that respondents to their research could not identify steps to implement Industry 4.0 beyond vertical integration. Therefore, developing an Industry 4.0 roadmap and the successful implementation thereof in South African SMEs will require the strategic decision-makers to have an overarching view and understanding of the topic. It is for this reason necessary to estimate whether there is a positive correlation between technology informed strategic decision-makers and the successful implementation of Industry 4.0 technologies in South African SMEs (this is addressed in Chapter 3). A further consideration is that one of the main challenges of Industry 4.0 implementation is the lack of awareness among businesses and those responsible for digital enabling technologies of the organisation's strategic and tactical levels and vision (Issa *et al*., 2018:974). This suggests that manufacturing companies (including SMEs) may fail to meet production needs by treating digital transformation as typical IT projects. This issue is attributed to manufacturing companies not (yet) grasping the full scope of the challenge of digital transformation.

Issa *et al*. (2018:975) state that traditionally, a business strategy was defined first, followed by IT strategy and then the alignment of the two strategies. The researchers convincingly argue that a paradigm shift is needed to harness the full potential of investment in digital enabling technologies. In the South African SME context, this will typically require a multi-level integration of business and IT management with the aim to incorporate the capabilities of digital technologies with business strategies and expectations. To this end, Issa *et al*. (2018:975) proposed that manufacturing organisations create a roadmap (see the discussion in Section 2.4 above) that defines a clear focus for digital technology implementation aligned with a specific organisation's maturity level. They further advised using such a roadmap to optimise business processes and operations rather than generate new business models.

In an empirical study, Issa *et al*. (2018:978) reported that organisations, especially SMEs, found that defining the areas where to focus on implementing digital technologies followed by idea generation (as discussed earlier) were of greater value than the preceding digital maturity assessment step. However, the latter was considered of little or no value to these companies. These insights raise the question of whether the importance of Industry 4.0 assessments may perhaps be overstated in the literature and whether or not, and if so, how manufacturing SMEs in South Africa may benefit from using it.

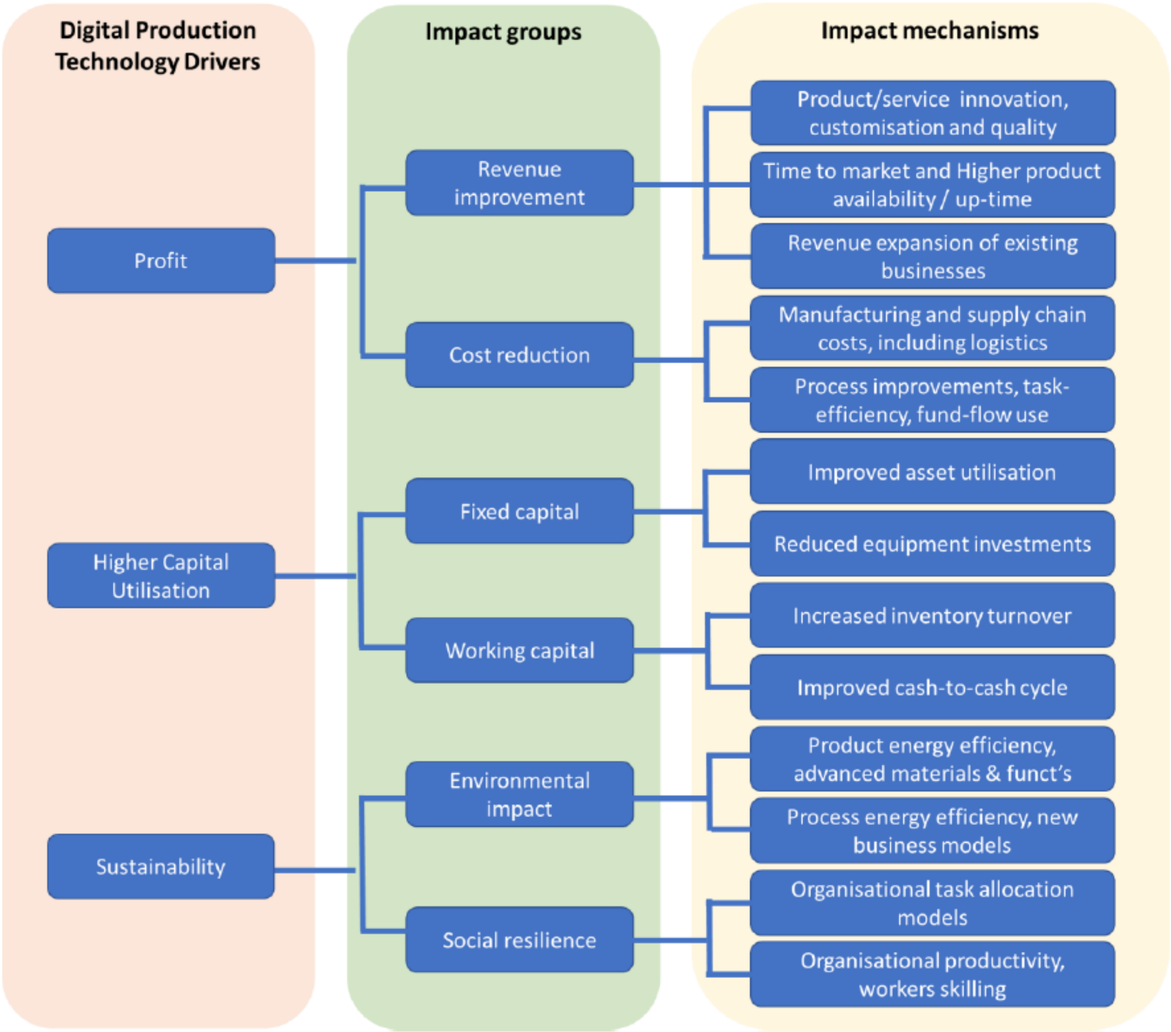
For SMEs in South Africa, it would be important to remember that the business and operational requirements for digital transformation are adaptable, digitalisation and demand-driven manufacturing processes (Issa *et al*., 2018:973). Issa *et al*. (2018:974) suggest in this regard that it is essential for companies to allocate resources and focus on the most critical aspects of digital transformation. The authors performed a literature review, and an empirical validation case study identified digital transformation maturity and business-IT alignment as two main aspects of the digital transformation process. Digital transformation maturity refers to the various levels that can be recognised for digital transformation in the organisation. Business-IT alignment refers to the fit between new enabling digital technologies and the business strategy and objectives.

As indicated earlier, Mitchell and Phaal (2009:4) proposed the Opportunity vs. Feasibility matrix as the core tool of the toolkit platform for evaluating projects in a portfolio. Project selection requires evaluation criteria that will depend on the SME situated in South Africa's strategy to achieve its vision, to name but a few aspects to consider. Further, the multifactor scoring methods introduced by Mitchell *et al*. (2018:2) focused on evaluating and selecting innovation projects within the technology and R&D environments. Mitchell *et al*. (2018:3) use an innovation funnel to explain the use of different multifactor scoring criteria to evaluate technology development at various stages of product development. It may be useful for SMEs in South Africa that the companies the authors looked at in their study used evaluation approaches using financial data alongside other factors known to be success pointers.

However, it should be borne in mind that the abovementioned multifactor scoring method is recommended for project selection. Nagarajah (2015:12) accordingly warns that these scoring methods need to be used with care when prioritising projects or balancing a portfolio of projects. Financial values have the potential to bias portfolios against projects where it is difficult to predict the outcomes or impacts in financial measures, such as innovation projects. Although Nagarajah (2015:12) warns against using financial value as a primary parameter in portfolio balancing, it can lead to profitability and cash flow problems if ignored.

With the abovementioned arguments kept in mind, the researcher recommends using profitability and capital utilisation financial measures (Andreoni & Anzolin, 2019:19) in conjunction with the Opportunity vs. Feasibility matrix (Phaal & Mitchell, 2009:6) to identify options for operations improvement in an SME manufacturing organisation in South Africa.

In this vein, Andreoni and Anzolin (2019:4) argue that companies in developing countries, such as South Africa, need to focus on incremental integration of the latest generation of technologies to execute several production tasks in existing production systems. Secondly, companies need to focus on how the integration of Industry 4.0 technologies will require a continuous process of retrofitting the same production systems and developing new capabilities to run them effectively. Therefore, strategic decision-makers in an organisation should refrain from futuristic technological discussions and focus incrementally on more targeted and grounded visions of what is feasible (Andreoni & Anzolin, 2019:4). This may be particularly valuable considering the typical features of manufacturing SMEs in South Africa. It is further important that the implementation of Industry 4.0 technologies and their impact can be evaluated in four main financial areas, as illustrated in Figure 2-7: (1) revenue improvement, (2) cost reduction, (3) fixed capital and (4) working capital. These impact areas are driven by two main sets of rationales for implementing Industry 4.0 digital production technologies: profit and higher capital utilisation (Andreoni & Anzolin, 201918). The authors also include sustainability as a driver for digital production technology through environmental impact and social resilience, another aspect of importance considering the socio-economic and environmental contexts in which SMEs in South Africa have to operate. Due to the limited scope of this study, this driver is, however, not extensively discussed in this study.



Source: Authors, based on the methodology proposed by King, 2015 (NIST)

Figure 2-7: The financial impact of digital production drivers (Andreoni & Anzolin, 2019:18).

Issa *et al*. (2018:974) argue that the large scope of changes associated with such an implementation project hinders the successful implementation of enabling digital technologies. This large scope of change may lead to management disappointment and failure. Issa *et al*. (2018:974) recommended a step-wise approach based on digital transformation maturity based on this argument. However, they emphasise that a manufacturing company will only achieve business success if both implementations of Industry 4.0 technologies and organisational changes are addressed.

Manufacturing SMEs in South Africa need to understand the impact of the choice of technology on its profit, as sustained profits are critical for investing in the firm's growth and competitiveness

(Andreoni & Anzolin, 2019:18). Digital production technologies can impact profit in two ways: (1) revenue improvement through product and service enhancement and (2) cost reductions through production improvements in the internal value chain. The authors further suggest the following impact mechanisms to improve revenue using digital production technology: (a) product/service innovation, customisation and quality, (b) time to market and higher product availability/up-time, and (c) revenue expansion of existing business. Following the thinking of Andreoni and Anzolin, it is suggested that manufacturing SMEs in South Africa identify market and business drivers within these three impact mechanisms.

Capital investment concerning fixed and working capital are essential to companies operating in countries like South Africa, where capital constraints can be a significant obstacle in implementing Industry 4.0 technologies (Andreoni & Anzolin, 2019:19). Two variables determine fixed capital investment in plant and equipment: (1) the extent to which digital production technologies can improve the scale-efficient utilisation of the fixed assets and (2) the ability to reduce the need for fixed investments that cannot be fully recovered. On working capital decisions and management, digital production technologies can significantly impact inventory turnover and the cash conversion cycle. In addition, digitisation of production and operations can help companies better manage existing production lines' life cycles to improve working capital management. In addition, the implementation of Industry 4.0 technologies to improve efficiency, effectiveness, speed, agility, full capacity utilisation, etc., will require a specific set of capabilities, knowledge and attitudes (Ungerer *et al*., 2016: 162) with the incentives to develop them (Andreoni & Anzolin, 2019:21). However, these are not equally distributed across sectors and countries.

2.7 Concluding Remarks

This chapter set out to review the literature relevant to understanding how existing Industry 4.0 roadmaps/models can be used for digital transformation in manufacturing SMEs in South Africa to help secure success potential. The literature review was conducted around the following questions:

- What is the generally accepted or dominating definition of Industry 4.0, also referred to as the Fourth Industrial Revolution?
- What are digital technologies in manufacturing?
- What does the concept of a technology roadmap mean?
- What is the dominating Industry 4.0 technology implementation perspectives in a developing country and, more specifically, South Africa?

- What seems to be the requirements for the strategic leadership of an organisation to improve the successful implementation of Industry 4.0-specific objectives?

Various definitions and characteristics of Industry 4.0 were identified in the literature. It was reported that the confusion created around these definitions make it difficult for companies to identify and implement Industry 4.0 technologies. Definitions are essential as it provides concept clarification. For this reason, the researcher defined Industry 4.0 for this study as the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies.

Implementing digital production technologies requires a paradigm shift from improving efficiency and scale of manufacturing towards flexible manufacturing. Therefore, various digital and autonomous technology solutions associated with Industry 4.0 were identified. For this study, three groups of digital production technologies were considered: (1) traditional production technologies that require retrofitting, (2) new digital production technologies and (3) products embedded with digital technologies. Furthermore, the generation of data and connectedness is at the core of digital production technologies. Thus, a clever combination of the emerging technologies implemented within the digital production environment can unfold the business success potential for SMEs.

SMEs are often overwhelmed with decisions and do not know how to transform their organisations: where to start, proceed, or go. Therefore, manufacturing SMEs will require a roadmap that is fit for purpose and size and guides them through viable phases of digital transformation and cross-linking with the purpose to a) show results that are both tangible and quantifiable; and b) help secure success potential. However, a review of 15 smart manufacturing and Industry 4.0 maturity models found that none were a good fit for the specific requirements of the digital transformation of manufacturing SMEs. Therefore, the technology roadmapping process in the format presented by the Institute for Manufacturing at the University of Cambridge is a possible roadmap suitable for manufacturing SMEs in South Africa.

Although South Africa has the strongest structure for production in Africa, the contribution of manufacturing to the share of the GDP has decreased significantly since the 1990s. Further to this, South African manufacturers face challenges in terms of production capabilities and enabling infrastructure. The latter refers to reliable electricity and connectivity. However, South African companies are innovative and entrepreneurial activities are supported by a sophisticated financial sector. Regardless, South African companies can learn from other developing countries, demonstrating progress with Industry 4.0 implementation. These lessons include realising that not all industries can achieve Industry 4.0 maturity in the short term, and developing countries also need to overcome the middle income and inequality traps.

From a strategic viewpoint, businesses require a multi-level integration of business and IT management to incorporate the capabilities of digital technologies with business strategies and expectations. To this end, businesses need a roadmap to optimise business processes and operations rather than generate new business models.

The following two chapters are devoted to the qualitative research approach taken to address the main research question. Chapter 3 explains the research methodology taken in terms of semi-structured interviews and the method used to analyse the data obtained through the interviews. Chapter 4 presents the results and findings from the interviews within the context of the literature review findings in this chapter.

CHAPTER 3 RESEARCH METHODS: QUALITATIVE STUDY

3.1 Introduction

This chapter and the next are devoted to a qualitative study to fortify and test the literature review findings in Chapter 2. A qualitative research approach was chosen to explore technologies' actual use (implementation) in manufacturing SMEs in South Africa. The qualitative study is scoped around traditional (conventional) production technologies and digital production technologies. The use of production technologies was considered within the context and definition of Industry 4.0: the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies (see section 2.2, Chapter 2).

This chapter discusses the data collection process and explains how the collected qualitative data was analysed. Chapter 4 is devoted to the findings of the data analysis.

3.2 Research Design

A cross-sectional research design was used to provide a framework for collecting and analysing data to further inform a response to the research question of this study (Bryman *et al*., 2017:100). Semi-structured interviews (preceded by self-completing questionnaires) with manufacturing SMEs were conducted to obtain qualitative data to triangulate the findings from the literature review in Chapter 2.

It merits to mention that the overall research design of this study consisted of eight steps based on the outline of the steps in the qualitative research approach presented by Bryman *et al*. (2017:41). The eight steps in the research design process that were used in the present study were earlier illustrated in Figure 1-1 in Chapter 1:

1. A preliminary literature survey identified the different aspects of the research topic. The information gathered through the literature survey helped to develop the main research question and the subsidiary research questions presented in this study.
2. The literature review collected information and gathered insights on the sub-topics that emanated from the main research question.
3. It was established that to answer the research question; the research design would have to include both a literature review and semi-structured interviews (qualitative research component).
4. For purposes of the qualitative study, a study population was identified, and a sample within the study population was selected through a purposive sampling method.

5. The identified study population is manufacturing SMEs in South Africa. The sample from the identified population consisted of contract manufacturers that specialise in subtractive manufacturing, additive manufacturing, and related processes. Engineering companies (SMEs) developing technology were considered as alternative units of analysis.
6. Data was collected through semi-structured interviews with senior management level staff in the targeted companies. The collected data were analysed to capture and present the findings. The semi-structured interviews were preceded by self-completing questionnaires, as further discussed below.
7. Next, the data analysis findings were compared with the findings of the literature review to identify relevant relations.
8. The results of the literature review and the data analysis were subsequently captured in this study/report.

This part of the research focuses on the implementation of Industry 4.0 technologies in South African manufacturing SMEs. The departure point, as informed by the literature review, is that a) these SMEs require a strategic framework that guides them through technology planning and implementation phases, and that b) technology supports the primary value activities in the organisation and the activities that support the primary value chain.

As stated in Chapter 2, the definition of Industry 4.0 for the context of this study is the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies. In layman's terms, Industry 4.0 speaks to the integration of operations technology with information and communications technology. As stated earlier, the VDMA (2016:9) reported that German companies struggle to implement Industry 4.0 technologies due to a dim view of the objectives, specific benefits, and solutions Industry 4.0 can provide. The VDMA's study showed that implementation of Industry 4.0 requires a digital transformation strategy (Issa *et al*., 2018:974). However, companies face various challenges with the implementation of Industry 4.0. This may be even more true for South African SMEs, as found in Chapter 2.

In line with the definition of Industry 4.0, the challenges companies face with the implementation of Industry 4.0 and the benefits of so-called roadmaps (see section 2.4, Chapter 2), it follows that research is needed to establish how roadmaps may potentially assist manufacturing SMEs in South Africa with the digital technologies associated with Industry 4.0.

Although a qualitative research approach is adopted in this study as part of the general orientation of the study, the idea is to better understand the theory of a selected technology roadmap rather than generate a new or novel theory (Bryman *et al*., 2017:31) for the implementation of Industry

4.0. For this reason, this study made use of a combination of a literature review and data analysis (i.e., mixed research method).

The literature review was conducted around five specific sub-questions (listed and discussed in Chapter 2) identified as important in answering the main research question. Three of the five questions as translated into themes were addressed in the semi-structured interviews:

- The concept of digital technologies in the manufacturing environment.
- Industry 4.0 in the South African context.
- The strategic requirements for successful Industry 4.0 implementation.

The literature review reflected on the definition of Industry 4.0 to assist with concept clarification and to help delineate the angle of analysis in the semi-structured interviews. It was accordingly not the objective with the semi-structured interviews to gauge the interviewees' understanding of the concept of Industry 4.0 nor their knowledge of technology roadmaps. The goal of the semi-structured interviews was instead to understand the problem (in the manufacturing SME context) and not to discuss a possible solution. Put differently: the issue explored through the interviews was the challenges manufacturing SMEs in South Africa face with technology implementation and management. The intention with the interviews and the data generated was to be able for the researcher to subsequently propose an appropriate roadmap for manufacturing SMEs in South Africa as an outcome of this study.

Though assessment tools are used to measure the technical capability of an organisation relative to known dimensions (Basl, 2018:4), it was only the organisation's current state that was measured quantitatively. It is acknowledged that to measure the impact of the implemented transformation projects, the end state of an organisation (such as an SME) will need to be measured to compare the results with the initial state and the target state. Such an assessment will require quantitative and longitudinal research (Bryman *et al*., 2018:109). However, this extended method was not possible in the limited time and scope of this research project.

3.3 Study Population

Mittal *et al.* state (2018:194) that SMEs and new product development are the driving force of growing manufacturing economies. Therefore, the impact of Industry 4.0 on SMEs needs to be understood, especially since SMEs requirements are different from that of large enterprises (Mittal *et al*., 2018:194), such as those in Germany that were considered in the VDMA study referred to earlier. The Manufacturing Indaba, for example, stated in a press release in 2018 (Manufacturing Indaba, 2018) that SMEs play a critical role in economic growth and represent one of the largest providers of employment in most countries. The press release further highlighted the challenges

SMEs face in that the survival rate of SMEs are low – more than half of start-ups do not make five years.

Therefore, the researcher supports the suggestion by Mittal *et al*. (2018:210) that SMEs develop their own (i.e., tailor-made) Industry 4.0 vision. Their research revealed that although they identified 40 papers on Industry 4.0 maturity models (including related terms such as 'assessments', 'readiness models', 'frameworks', and 'roadmaps') (2018:197), only fifteen of these papers were relevant to SMEs. However, Mittal *et al*. (2018:212) concluded that a significant limitation of their research was that it was based on a literature review only, without collecting primary research data.

The researcher chose to select manufacturing SMEs in South Africa as the units of analysis for the study. The reason for this was two-fold: 1) it is generally accepted that the Fourth Industrial Revolution has its origins in the manufacturing industry (Schwab, 2016:7); and 2) the researcher is employed with an engineering company (an SME) that provides consultancy services and is familiar with the manufacturing sector (in South Africa and internationally).

The definition of Industry 4.0 specified for this study is the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies. Therefore, the study population comprises of the stakeholders affected by or who affect the primary value chain and support activities in manufacturing SMEs in South Africa. The following listed population (individuals, organisations, and industries) were considered for participation in the study:

SMEs specialising in the following manufacturing methods:

- Contract manufacturing using conventional and subtractive methods focusing on manual machining and CNC Machining.
- Additive manufacturing methods for metals and polymers.

By limiting the population from the selected sample, the following influencing factors are limited: first, to review SMEs focusing on manufacturing with machining (subtractive manufacturing) or additive manufacturing. Secondly, the study targeted managers in the identified organisations who may be able to provide insight into the company's overall strategy, operation, and resources. Due to the diverse range of value-creating activities which gets integrated with Industry 4.0 technologies, the interviews should ideally not have been limited to a single person in an organisation. However, if limited I4.0 technology has been implemented and if it is a small company, then the relevant decision making will probably be with or be known to a single person.

An alternative unit of analysis, other than manufacturing SMEs, was possible, such as technology development and engineering product development SMEs who also rely on digitisation of their operations. In the overall context of SMEs, it was expected that these technology and product development organisations would face similar challenges to manufacturing SMEs. For this reason, the eventual unit of analysis was both manufacturing and engineering SMEs in South Africa.

Large or multinational enterprises were not considered an alternative unit of analysis as significant research has been done and published on the requirements of Industry 4.0 implementation within these types of organisations. In contrast, the requirements of SMEs, specifically, remain under-represented in research (Mittal *et al*., 2018:195).

3.4 Sampling Strategy

A non-probability, convenience sample strategy was followed. By virtue of its accessibility, the researcher included manufacturing and engineering companies within the researcher's existing network. The population was geographically limited to three areas: (1) Potchefstroom (North West), (2) Gauteng and (3) Western Cape. These three geographical regions were selected as the researcher are familiar with and had access to manufacturing and engineering SMEs in these locations.

The focus of the data collected was the viewpoint (inputs) of strategic decision-makers in the management of SMEs, who are considered responsible for the operation and possible digitisation strategies for those SMEs and who have already implemented some technology strategies to modernise their operations.

The initial aim was to interview a minimum of six manufacturing SMEs; ideally, ten organisations and not more than fourteen as the limited time and scope of the research did not allow for a more extensive research population. Only five interviews were conducted due to time limitations and the restrictions due to the COVID-19 pandemic.

3.4.1 Data Collection: Semi-structured Interviews

Although the research has a clear focus that would render it possible to have structured interviews, a *semi-structured* interview was selected as the interviewee's point of view was considered important in addressing the questions at hand. Therefore, rich, detailed answers were sought. Interviewees answered freely during the semi-structured interviews with the interviewer probing and exploring topics in-depth (Bryman *et al*., 2018:224) as per the interview guide presented in Appendix A.

The researcher made initial contact with the identified population via email, followed by a telephone call to introduce the research project. The people and organisations who participated in the research all provided written consent before the interview.

Five interviews were held out of seven companies that were contacted. There were no responses to the initial request via email. However, following up through telephonic calls and personal introductions, the companies welcomed the invitation to participate in the research. Only one company was hesitant due to concerns around the sharing of possible proprietary information. This concern confirms an observation made in the literature that SMEs fear the risk of disclosing essential information to potential competitors (Mittal *et al*., 2018:195).

The interviewees signed letters of consent before the interviews (see Appendix B for the template used for the Letter of Consent). The signed letters of consent are on file with the researcher and will be made available on request.

All interviews were performed remotely using videoconferencing software. Interviews were recorded with permission. Each interview was strictly limited to one hour.

The semi-structured interviews were designed to obtain information on the SMEs' strategic decision-making processes, operations management and resources to inform the research question and two subsidiary questions:

- What are the needs and requirements for the leadership of the organisation to successfully implement new technologies?

- What are the perceived and actual difficulties and barriers South African manufacturing SMEs face with implementing new technologies and the changes associated with the implementation?

The interview guide (see Appendix A) that the researcher developed in advance of the interviews centred around three perspectives identified from the literature review:

- Commercial and strategic perspective.
- Design, development, and production perspective.
- Technology, research and resource perspective.

The <u>commercial and strategic perspectives</u> focused on the SME's purpose: why does it exist as a company? Guiding questions were used to understand how external market factors and internal business drivers affect technology identification and implementation.

The design, development and production perspectives looked at the delivery of the SME's value proposition, that is, know what to do as a company? The questions mainly focused on operational aspects, such as the systems to realise the primary value chain and support activities.

The resource perspectives focused on the SME's technology resources to deliver the value proposition to the identified market. These resources are technologies, competencies and knowledge that forms the know-how in the company. Guiding questions were also used to look at skills development, technology information, academic partnerships, suppliers, facilities, infrastructure, financial resources, and ICT.

3.4.2 Data Collection: Self-completing Questionnaires

Self-completing questionnaires were not considered the chief method to address the research question as ordinarily, quantitative data collection methods are structured to answer a specified set of research questions and maximise reliability and validity (Bryman *et al*., 2018:224). In this study, a less structured, *qualitative* research approach was used due to the fluidity of the meaning and application of Industry 4.0.

This said self-completing questionnaires were used to gather company-specific background information before the interviews. Since the interviews were limited to one hour, time was efficiently used by focusing on the substantive questions from the interview guide (Appendix A). Company information was obtained using Google Forms, an online application for survey administration (Google, 2021). The information gathered via the self-completing questionnaire is captured in Appendix C. The self-completing questionnaires generated the following:

- Personal information: Name and contact email.
- Company details: Company name, industry or industries (sectors) in which the company operate, how long the company has been in existence, the type of manufacturing processes used, the number of people employed at the company and the company's annual turnover.

3.5 Data Analysis

After reviewing the three general qualitative data analysis strategies proposed in Bryman *et al*. (2018:342), the researcher identified 'thematic analysis' as a suitable framework to guide the qualitative data analysis process in the present study. Thematic analysis is considered a flexible method, not tied to a philosophical orientation, to identify, analyse, and describe themes across a collected data set (Bryman *et al*., 2018:350). The thematic analysis was subsequently performed using 'affinity diagrams' to identify patterns, create themes and help understand the data collected from the semi-structured interviews.

The so-called KJ method, also referred to as Affinity Diagramming, was used to analyse the qualitative data generated from the semi-structured interviews. The KJ method aims to reduce the 'trivial many' to the 'vital few', using image and language data processing techniques. Affinity diagrams allow the organisation of many ideas, opinions, issues, etc., into groupings based on natural relationships between each item, that is, their affinity (OU 2005:53).

In short, the KJ Method assures scientific treatment of qualitative data, which results in realistic, objective conclusions (Scupin 1997:236). Although it is recommended to perform an affinity diagram as part of a team (Scupin 1997:236; OU 2005:54; Plain 2007:88), the diagramming can be performed as an individual exercise. However, it is noted that performing an affinity diagram individually makes it more challenging to obtain the necessary creativity (OU 2005:54).

The interviews provided a lot of information in no particular order. The feedback of one interviewee contradicted or supported that of another interviewee on the same topic. Using the KJ Method, the author was enabled to create a summary of the interviewees' environment. Understanding the environment in which the interviewees manage technology was key to address the research question.

The statements made by the interviewees were narrowed down to a manageable data set through an iterative process of grouping statements that show affinity. This process was repeated till a manageable data set was created.

The data collected in the semi-structured interviews represent insights and opinions from the interviewees expressed verbally. Qualitative data can generally not be summarised quickly or concisely. Statistical analysis techniques cannot provide meaningful analysis of qualitative data. The KJ Method was particularly useful in this study to the extent that this method allows for creative thinking. The latter was needed because:

- The challenges that surround technology implementation in SMEs are large and complex.
- The information relevant to the said challenges appears as unorganised thoughts and ideas.
- A breakthrough in traditional concepts is needed.
- The data from semi-structured interviews are non-numeric and statistical techniques do not apply.

3.5.1 History of KJ Method

The KJ Method is named after the initials of its creator, Jiro Kawakita (Scupin, 1997:233). Kawakita was a Japanese ethnologist who developed an idea-generation methodology to gather qualitative data while facing challenges interpreting ethnographic data in Nepal (Scupin, 1997:233). The method was initially applied to organise complex, immeasurable, idiosyncratic, non-repetitive, behavioural, qualitative data collected in the field. Kawakita realised that masses of data could be spatially arranged to form new meaning and find ways to systemise the data (Scupin, 1997:234). This realisation led to the creation of what became known as the KJ Method.

3.5.2 How the KJ Method was used

This section explains how the KJ Method was used in the context of this study.

The method used to analyse the qualitative data generated through the semi-structured interviews was based on guidelines (Scupin, 1997:235; OU 2005:55 and Plain 2007:88) and the researcher's experience with the KJ Method and affinity diagrams. The steps in the execution of this method included the following:

Step 1 – Determination of the question that the KJ Method would address

Step 2 –Transferring of data from recorded interviews to sticky notes

Step 3 – Grouping of sticky notes

Step 4 – Labelling the resulting groups with descriptive titles (various levels)

Step 5 – Chart making

Step 6 – Written expansion

The purpose of the semi-structured interviews (as discussed earlier) formed the question that the KJ Method addressed (step 1): how does the strategic decision-making processes, operations management and resources affect digital production technologies implemented and managed by the manufacturing SME?

The recordings of the interviews were transcribed onto digital sticky notes (step 2). Only one issue or topic was written verbatim on each digital sticky note, in the language of the interviewee, that is, English or Afrikaans. A total of 1318 sticky notes were created from the recordings of the five semi-structured interviews. Based on a recommendation by Lucero (2017:238), different colour sticky notes were assigned to each interview to keep track of the source of the data presented on the sticky note.

The sticky notes were created and organised on a Miro whiteboard (Figure 3-1). Miro is an online collaborative whiteboard platform that enables users to work effectively with digital sticky notes (Miro, 2021). Although Kawakita suggested randomising the notes (Scupin, 1997:235) so that there is no logical order to the notes, the researcher preferred to keep the notes in the order it was created, as recommended by Lucero (2015:240), as the data depending on the context of the interview.

The sticky notes were arranged into related groupings (step 3); that is, the sticky notes in the group had an affinity to each other (Figure 3-2). The grouping was done quickly based on the immediate response or gut feeling of the researcher. According to Scupin (1997:235), Kawakita emphasised that one's choices for grouping in this phase of the KJ Method should not be motivated by preconceived biases. Still, 'feelings' should dominate the logic in grouping the sticky notes together. After the first round of grouping, the groups were reviewed and moved around as necessary. Ideally, no more than three sticky notes were grouped. Groups with more than three sticky notes were divided till there were no more than three sticky notes in a group. Sticky notes with similar wording or presenting the same statement were merged into one sticky note.

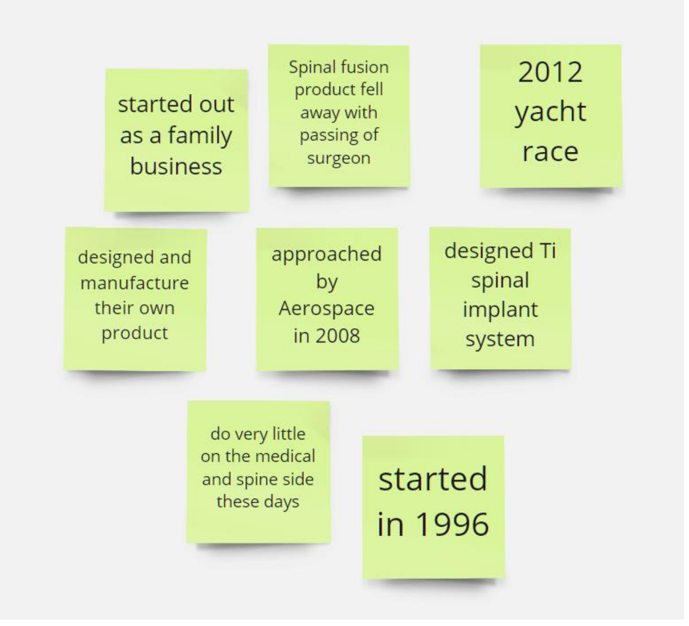


Figure 3-1: Transcribe recordings onto digital sticky notes: a sample.

Figure 3-2: Group digital sticky notes according to an affinity between the notes: a sample.

Once the groups evolved, a header title was created for each group (step 4). Identifying titles or more generalised concepts into groups helped classify the data (Scupin, 1997:236). Scupin further explained that grouping needs to be repeated to reduce the data to a manageable set.

This first level of header titles is referred to as 'red level' titles (Figure 3-3), with the sticky notes hidden behind the red titles. The red level titles were grouped using the same rules are before. A header title was created for each red level group. The 1318 sticky notes generated by this exercise were subsequently reduced to 538 red level titles. The first level grouping was performed in the context of each interview (Figure 3-4). Up to this point, the digital stick notes and the first level of header titles were grouped in the interview data set.

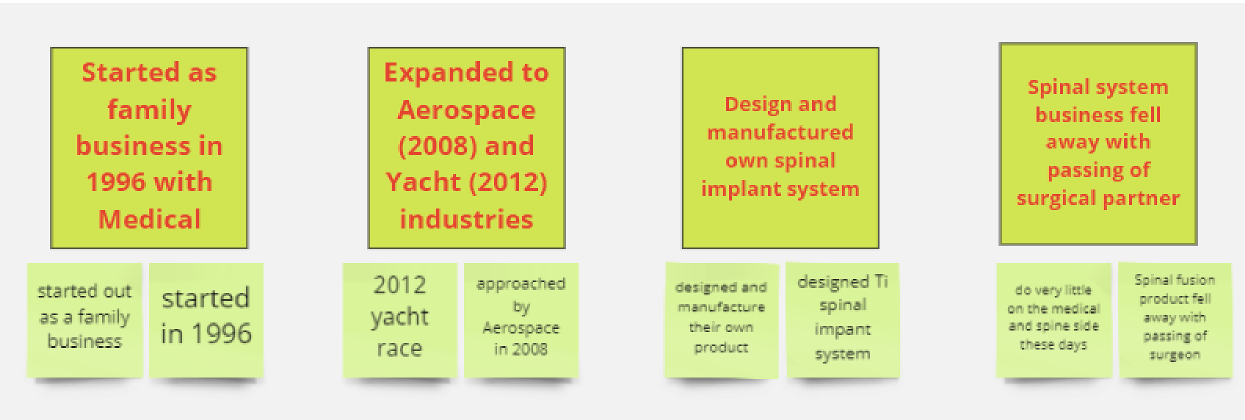


Figure 3-3: Give each group a title (red level): a sample.

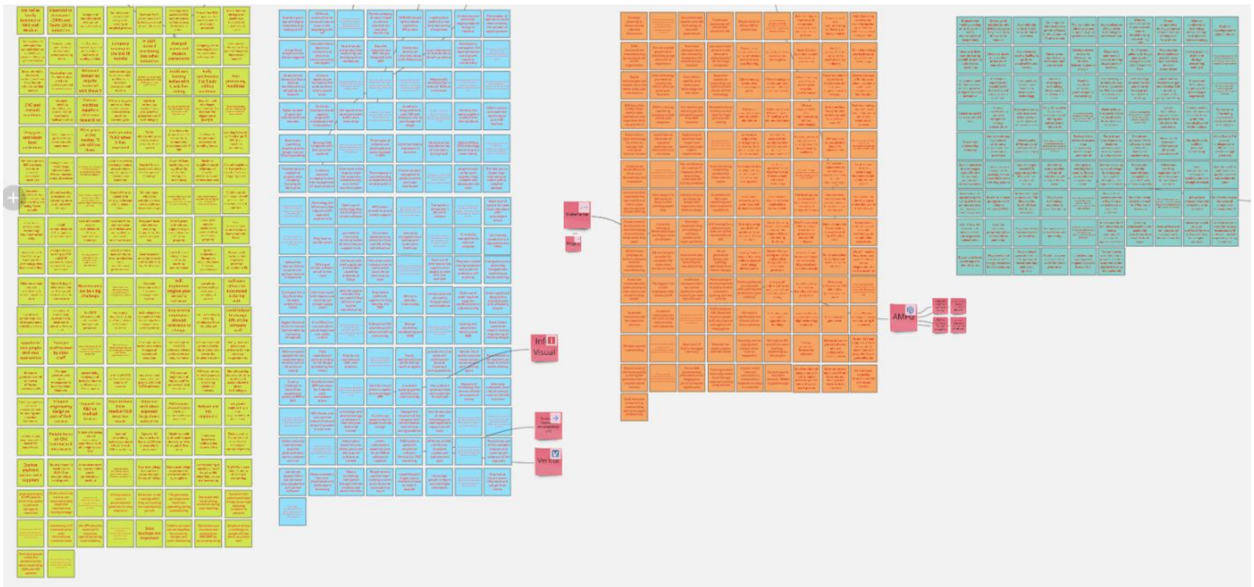


Figure 3-4: **First level grouping (red titles) was performed in the context of each interview: a sample.**

To manage the 539 first-level titles (red level titles), the titles were arranged according to the three high-level perspectives of a Technology Roadmap architecture (see Figure 2-5, Chapter 2). Due to the high number of interview data sets, the following guidelines were created for the management of the KJ Diagram headings (from the first-level titles and onwards) as distilled from the generalised architecture of a Technology Roadmap as described by Phaal *et al*. (2003b:365):

- Commercial and strategic perspectives explain 'why' the company exist in terms of external market and internal business drivers. Keywords associated with his perspective were: market, customers, competitors, environment, industry, business, trends, drivers, threats, objectives, milestones and strategy.
- Design, development, and production perspectives relevant to the company's value offering. This perspective collected the sticky notes about the form and function of the products and services offered by the company in response to the market and business needs. This perspective includes the systems the company employ to optimise production performance. Keywords associated with this perspective were: products, services, applications, capabilities, performance, features, components, processes, systems, platforms, opportunities, requirements and risks.
- Technology and research perspectives are the resources, solutions, capabilities, and enablers the company utilise to deliver its value offering. Keywords associated with this perspective were: technology, competencies, knowledge, skills, partnerships, suppliers, facilities, infrastructure, organisation, standards, science, finance and R&D projects.

Arranging the first level (red level) titles according to the three Technology Roadmap perspectives divided the 539 first level (red level) titles into three groups of 132, 142 (Figure 3-5) and 264 first-level titles (red level), which were manageable data sets to perform the second level (blue level) grouping. This grouping and re-grouping exercise was repeated twice to form second level titles (blue level) and third-level titles (green level). Figure 3-6 presents a sample of the resulting three grouping levels of the interview data set. The original interview data notes are tucked in behind the first level title (red level).

The 1318 digital sticky notes generated based on the five semi-structured interviews were eventually reduced to 107 header notes through three iterations of grouping notes with affinity (Table 3-1). The iterative process of grouping and re-grouping the notes were concluded after the third iteration (Appendix D)

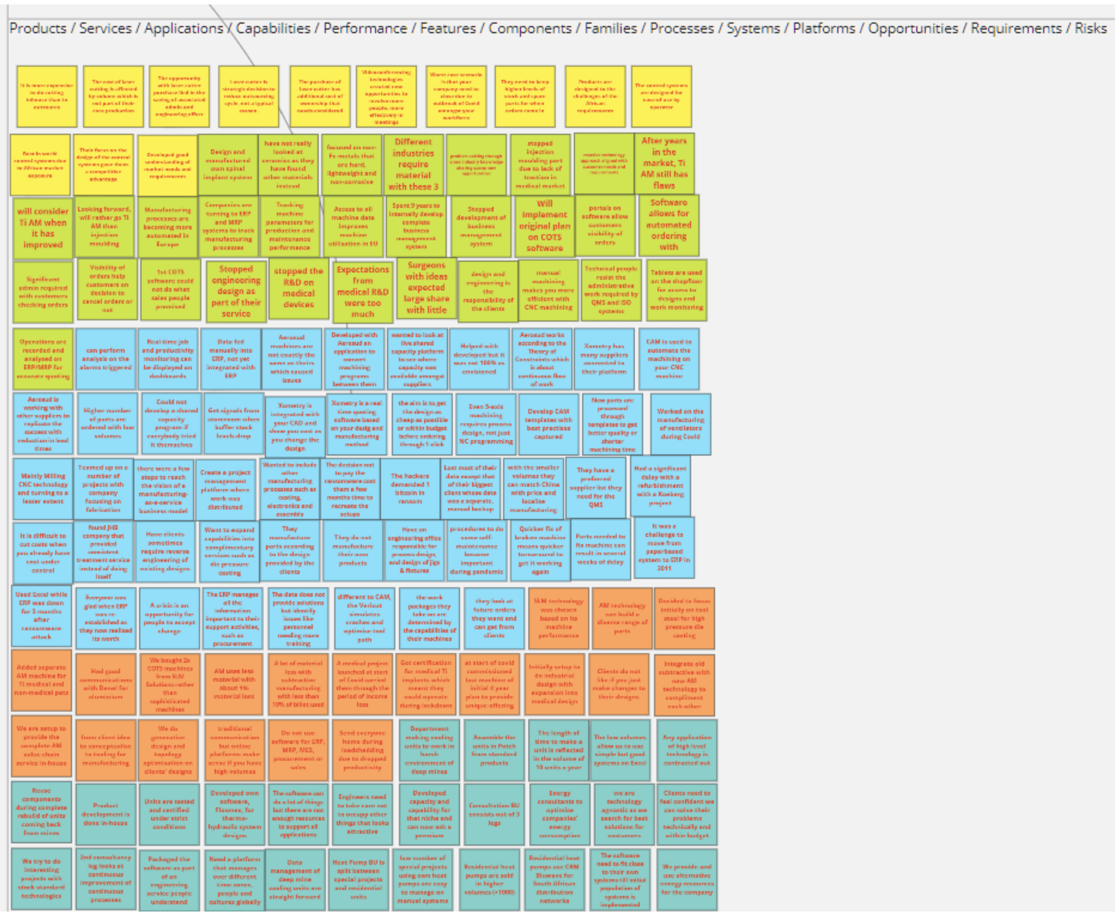


Figure 3-5: Red level titles arranged according to design, development and production perspectives of a Technology Roadmap: a sample.

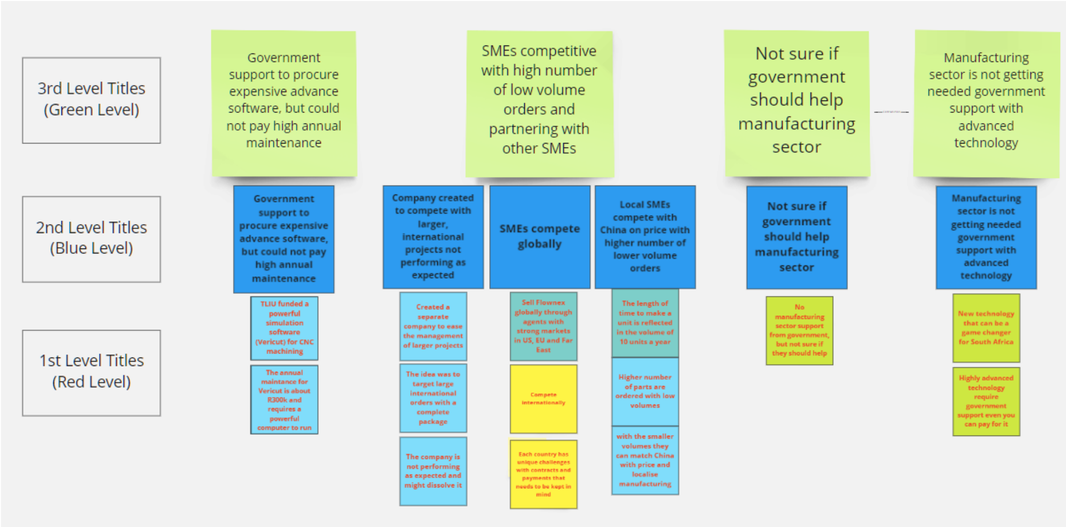


Figure 3-6: **3rd Level headers expanded to illustrate 2nd and 1st level groupings – a sample.**

Table 3-1: **Summary of reduction of data sets using the KJ Method.**

Data Level	**Number of Data Sets**
Digital Sticky Notes	1318
1st level grouping (red level)	539
2nd level grouping (blue level)	231
3rd level grouping (green level)	107

Instead of identifying cause and effect relations in the chart making step (step 5), as proposed by Scupin (1997:236), the third level groups (green level) were arranged according to the keywords (elements) of the three roadmap perspectives presented above. Each third level group were related to an element in one of the three Technology Roadmap perspectives. The results are discussed and presented in detail in Chapter 4, as part of the last step, written expansion (step 6).

3.6 Concluding Remarks

This chapter presented the methodology applied in the qualitative analysis part of this study. It was explained how the overall research design was based on a literature review and semi-structured interviews with senior management at South African manufacturing SMEs. This chapter paid specific attention to the KJ Method used to perform thematic analyses of the interview data generated. The results from the chart making and written expansion steps are presented in the next chapter. Still expanding on the KJ Method, chapter 4 focuses on the relations of the interview data with the three Technology Roadmap perspectives. The specific aim of the analysis is to determine: how does the strategic decision-making processes, operations management and resources affect digital production technologies implemented and managed by manufacturing SMEs in South Africa?

CHAPTER 4 FINDINGS

4.1 Introduction

This chapter presents the findings of the data analysis that followed the five semi-structured interviews. The objective is to better understand the environment in which South African manufacturing SMEs implement and manage technology. The interviews focused on the use of production technologies and digital productions technologies in the primary value chain and support activities of the participating SMEs. The findings in this chapter are categorically explained along the lines of the three perspectives of a technology roadmap. These perspectives were introduced in Chapter 2 (Section 2.4.4) and Chapter 3 (Section 3.4.1):

1. Commercial and strategic perspectives.
2. Design, development, and production perspectives.
3. Technology, research, and resource perspectives.

Notably, the data revealed a fourth possible variable (perspective) that did not transpire from the literature review (Chapter 2). This variable broadly relates to supply chain and logistics. Due to the scope and limits of this study, this variable is not discussed.

4.2 Demographic Information

The semi-structured interviews garnered insights from the participants on the three above mentioned perspectives. The demographic information obtained through the online survey form focused on the business itself and not on the participants. Each participant was given a code to distinguish between them. The participating SMEs ranged in size: two medium-sized, two small, and one micro-sized enterprise (Table 4-1).

Three of the five SMEs (SME1, SME2 and SME5) uses job-shop manufacturing while the other two SMEs (SME3 and SME4) use a range of manufacturing processes (Table 4-2). Job-shop manufacturing refers to process-focused manufacturing typical in high-variety, low-volume manufacturing and service organisations (Heizer *et al*., 2017:643). SME3 and SME4 have expanded their process-focused manufacturing services to provide a comprehensive yet unique offering in special metals. SME4, a metal additive manufacturing company, offers a complete value chain service, from design to finished product, to multiple industries. SME1 collaborates with other manufacturing and fabrication companies to compete with larger, international projects.

Table 4-1: Demographic information

Participant	Location	Years in operation	Number of people	Total turnover a year	Size of enterprise
SME1	Western Cape	> 20 years	11-50	< R50 million	Small
SME2	North West	Between 10 and 20 years	51-250	< R170 million	Medium
SME3	Western Cape	> 20 years	11-50	< R50 million	Small
SME4	Gauteng	< 5 years	1-10	< R10 million	Micro
SME5	North West	> 20 years	51-250	< R170 million	Medium

Table 4-2: Market sector and manufacturing processes.

Participant Code	Industries	Type of Manufacturing Processes
SME1	Aerospace & Defence, Automotive, Electronic and Digital Equipment Manufacturing, Food and Beverage Processing, Medical Equipment and supplies, Oil & Gas-related, Renewable Energy, Manufacturing-related Industries	Job Shop Manufacturing (Batch size <10), Job Shop Manufacturing (Batch size >10)
SME2	Machinery & Equipment	Job Shop Manufacturing (Batch size <10)
SME3	Aerospace & Defence, Machinery & Equipment, Medical Equipment and Supplies, Manufacturing-related Industries, Marine Manufacturing	Repetitive Manufacturing, Discrete Manufacturing, Job Shop Manufacturing (Batch size <10), Job Shop Manufacturing (Batch size >10), Process Manufacturing (Batch), Process Manufacturing

		(Continuous), Product Development, Engineering Design
SME4	Aerospace & Defence, Automotive, Machinery & Equipment, Medical Equipment and Supplies, Manufacturing-related Industries	Repetitive Manufacturing, Discrete Manufacturing, Job Shop Manufacturing (Batch size <10), Job Shop Manufacturing (Batch size >10), Process Manufacturing (Batch), Process Manufacturing (Continuous), Product Development, Engineering Design
SME5	Renewable Energy, Manufacturing-related Industries, Mining	Job Shop Manufacturing (Batch size <10), Service provider for the continuous process industry

4.3 The Three Perspectives of a Technology Roadmap

4.3.1 Commercial and Strategic Perspective

The commercial and strategic perspective represents the external market and internal business drivers. This perspective consists of 6 elements: markets, customers, competitors, business drivers, environment and strategy. The third level groups (green level) from the KJ Method were linked with each of the elements of a technology roadmap as shown in Figure 4-1. The discussion to follow considers each of the elements of the commercial and strategic perspective in terms of the interview data.

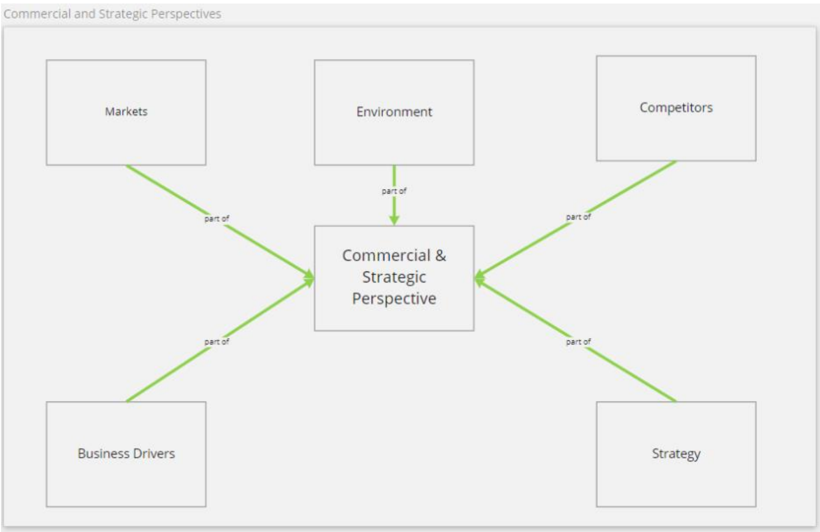


Figure 4-1: Elements of the Commercial and Strategic Perspectives.

4.3.1.1 Markets

Markets refer to the systems, institutions, procedures and social relations whereby businesses and customers engage in the exchange of products or services (Wikipedia, 2021).

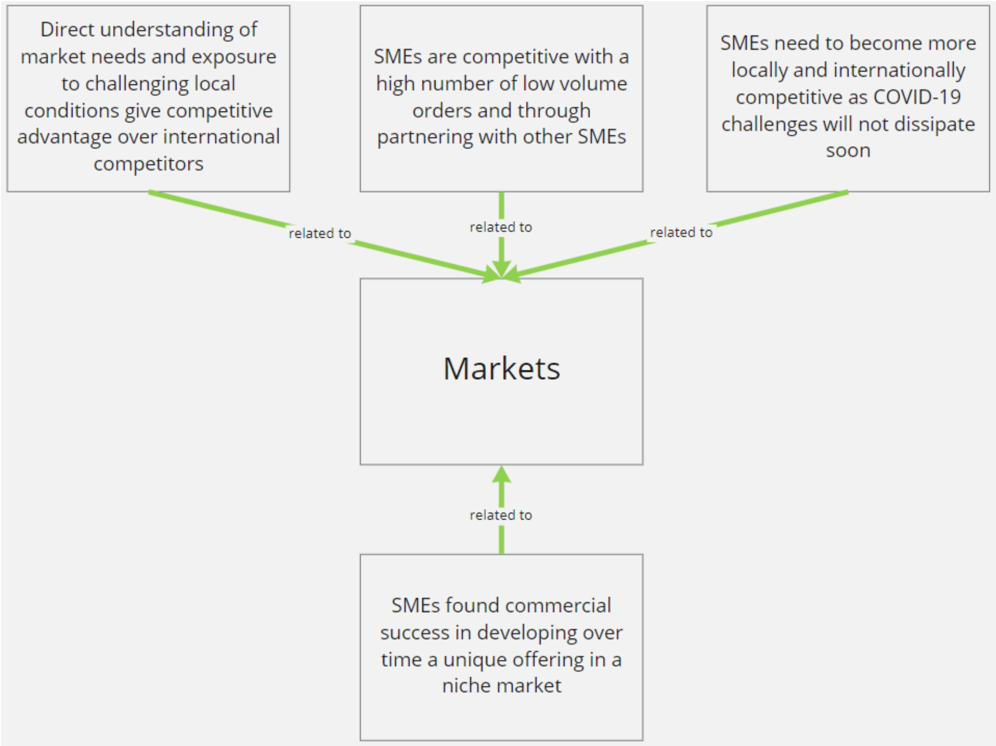


Figure 4-2: Market-related links.

<u>Direct understanding of market needs and exposure to challenging local conditions give competitive advantage over international competitors.</u> SME2 designs and manufactures food production equipment. Unlike its international competitors, exposure to the local and African markets led to the development of products suitable for local needs. They developed a good understanding of the market needs through a direct, hands-on approach to market research. The understanding of the local market enabled SME2 to make educated guesses about where the market is heading. Therefore, SME2's focus on developing advanced control systems for the challenging African market requirements gives it a competitive advantage over international competitors. SME5 extends this by additionally emphasising the need to create in-house capability and capacity to develop world-class products for the challenging African environment.

<u>SMEs are competitive with a high number of low volume orders and through partnering with other SMEs</u>. With low volume orders, SME1 is able to compete on price with a Chinese manufacturer. On a separate venture, SME1 partnered with other companies to create a separate company to

compete with larger, international orders. Three of the five interviewed SMEs sell and distribute their products to the international market. SME3 made the strategic decision to become an original equipment manufacturer (OEM) and stopped developing its own medical implant products

SMEs need to become more locally and internationally competitive as COVID-19 challenges will not dissipate soon. Four out of the five SMEs have developed a competitive advantage in providing job-shop manufacturing service for a high number of low volume orders. All the SMEs interviewed compete in the international market. SME1 managed to secure a contract with a local company that was struggling with its Chinese supplier.

SMEs found commercial success in developing over time a unique offering in a niche market. Four of the SMEs developed a unique service in a small niche market. The SMEs found success focusing on specific activities in a value chain of a narrow niche market. SME5 observed that companies need to avoid working in too many industries when working in a niche. Although SME4 provides a manufacturing service design, covering an extensive value chain, it initially focused on tool steel for the pressure die casting market. It since expanded into titanium for the medical market. Its service offering is unique to the South African market. SME5 commented that once a company finds a niche market, commit resources to that product or service, the company can create higher profit margins.

4.3.1.2 Competitors

Thompson *et al*. (2017:71) explain that the market is a competitive contest among competitors that is ongoing and dynamic. Competing organisations deploy significant effort to retain customers, strengthen its market position and yield good profits.

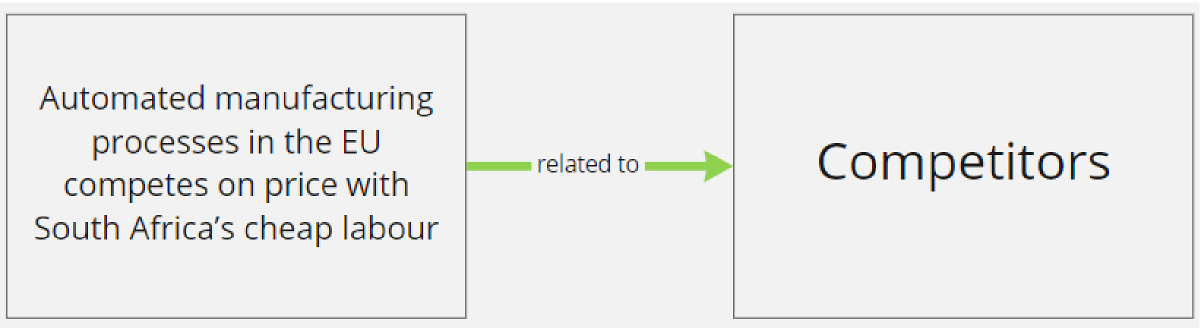


Figure 4-3: Competitor related links.

Automated manufacturing processes in the EU competes on price with South Africa's cheap labour. SME3 argued that although South African SMEs are competitive on price with lower labour costs, European manufacturing costs are coming down through automated processes, thus, using fewer people.

4.3.1.3 Environment

Macro environmental conditions consist of factors outside the sphere of influence of the SME, yet the factors have a significant impact on the opportunities available and the threats SMEs face (Ungerer *et al*. 2016:71).

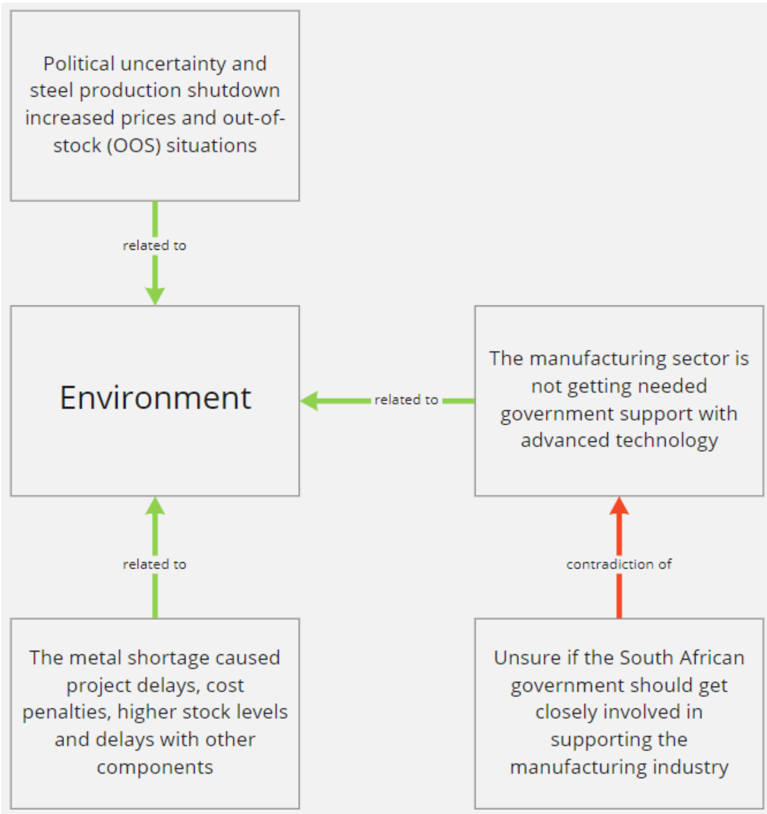


Figure 4-4: Environment-related links.

Political uncertainty and steel production shutdown increased prices and out-of-stock (OOS) situations. The shortage of steel has created significant challenges for South African SMEs which could not be mitigated. Both SME1 and SME2 stated that the shortage in steel supply was created when ArcelorMittal stopped producing steel due to the restrictions in the South African government placed on businesses at the start of the COVID-19 pandemic. SME1 claimed that ArcelorMittal was afraid that demand for steel will remain low. Therefore, according to SME1, ArcelorMittal kept vendors in the dark about the eventual start-up of steel production. This action worsened the steel shortage situation as the construction industry tried to recover project time lost during Level 5 lockdown. Both SME1 and SME2 mentioned that steel vendors were regularly out-of-stock as they did not keep high stock levels. SME2 reckoned that political uncertainty led to vendors not keeping high levels of stock. According to SME2, the OOS situation resulted in vendors asking exuberated prices due to the uncertainty of material supply. On top of this situation, the import of steel was made difficult by slow processing at harbours. SME2 further blamed high import duties on steel designed to protect the steel making industry in South Africa. The interviews with SME1 and SME2 showed that material shortage is an environmental issue for which the companies could not find an alternative solution during the pandemic. Without materials, these businesses cannot operate.

The metal shortage caused project delays, cost penalties, higher stock levels and delays with other components. In addition to manufacturing SMEs having been unable to operate due to a shortage in steel (see above) it also faced consequential project delays. Project delays, in turn, can lead to costly penalties. SME1 had a significant delay with a refurbishment with a Koeberg project due to the material shortage. SME2 claimed that there had been a shortage in supply of tool steel, stainless steel and aluminium. Although the COVID-19 pandemic can be viewed as a *force majeure* situation, as explained by SME2, the knock-on effects do not count as being part of it. Manufacturers of bolts and nuts also struggled to deliver due to the steel shortage. When materials were available, companies increased their stock and spare parts for when orders came in. Both SME1 and SME2 felt that the situation with material shortage was worsented by a lack of communication on the part of ArcelorMittal on the eventual and slow start of production at its steelworks. The interviews thus confirmed that communication between supplier and customer is a vital activity for business success.

SME3 felt that the manufacturing sector is not getting needed government support with advanced technology. This observation concerned a specific technology that can be a game-changer for the South African manufacturing industry. However, the supplier of this highly advanced technology needs government support. Contradicting this statement, SME3 was unsure if the South African government should get closely involved in supporting the manufacturing industry. Yet, examples were discussed in the interviews where government are supporting SMEs in various ways. For example, through the Technology Localisation Implementation Unit (TLIU), the government provided SME1 support with the procurement of expensive advanced software to perform simulations of its machining process. Other examples of government-sponsored support are presented elsewhere in this chapter.

4.3.1.4 Business Drivers

This section relates to the business drivers that govern the overall goals or 'purpose' of an organisation (Phaal *et al*., 2003a:362). The business drivers are internal to the organisation.

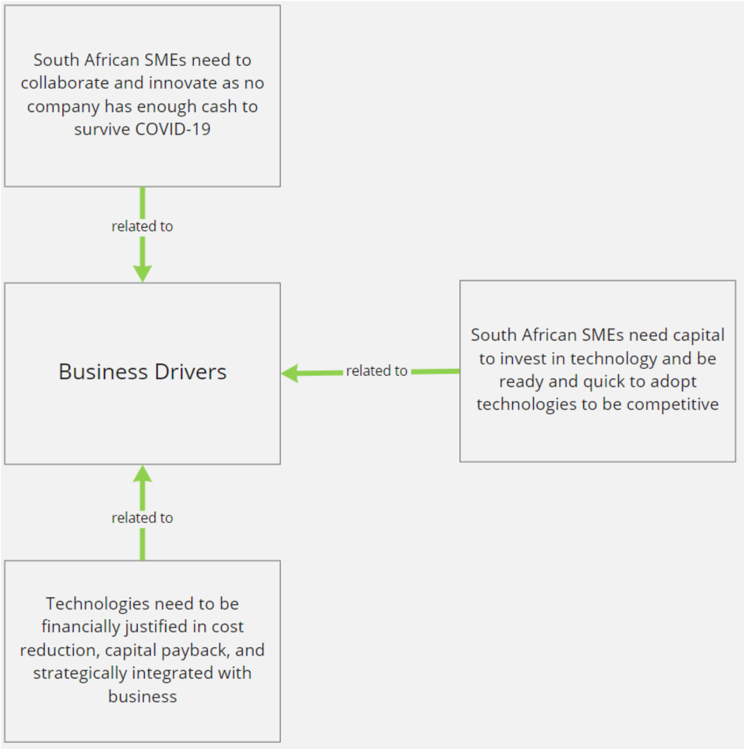


Figure 4-5: Business Driver links.

South African SMEs need to collaborate and innovate as no company has enough cash to survive COVID-19. South African SMEs need to collaborate and innovate, even more so with the challenges brought on by the COVID-19 pandemic. As SME4 pointed out, no company has sufficient financial resources to see them through during the COVID-19 pandemic. SME1 and SME2 believe that South African companies are dynamic and innovative and will be stronger (even more resilient) if they can overcome the impacts of the pandemic.

South African SMEs need capital to invest in technology and be ready and quick to adopt technologies to be competitive. According to SME3 and SME4, South African SMEs tend to be hesitant to adopt new technologies. This hesitancy affects companies' market competitiveness. SME4 expanded on this stating that companies need capital to implement new technologies and and should be ready to do so when the opportunity arises.

Technologies need to be financially justified in cost reduction, capital payback, and strategically integrated with business. The business drivers for technology management identified in the interviews were (a) revenue improvement by increasing throughput (SME1), (b) cost reduction (SME2) and (c) focusing on paying back capital (SME4). SME5 noted that technologies such as digital platforms are an integral part of its business. However, as pointed out by SME4, the requirement of a digital platform need to be evaluated against the benefits it provides. SME4 reckoned that in its case, the cost of a digital platform is close to the salary of a salesperson.

4.3.1.5 Strategy

The activities in the organisation that support business strategy.

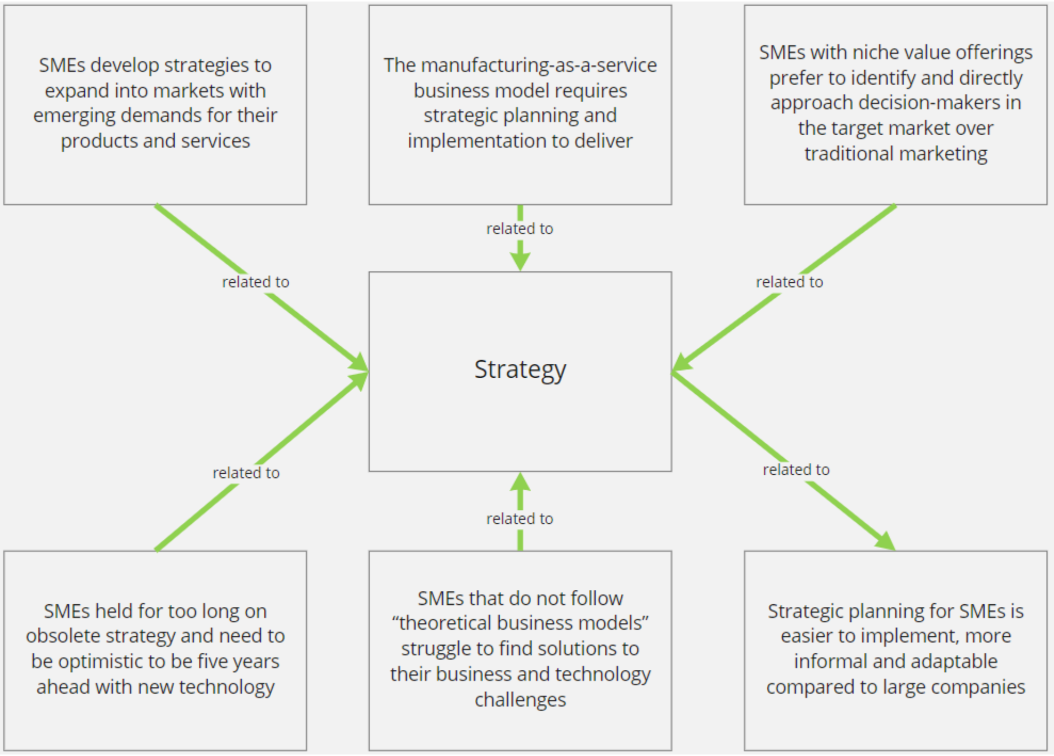


Figure 4-6: Strategy related links.

<u>SMEs develop strategies to expand into markets with emerging demands for their products and services.</u> SME3, established in 1996, initially focused on the development and manufacturing of a specific medical device. With the passing of its surgical partner and expert, this part of the business was closed. SME3 made the strategic decision to move into contract manufacturing for original equipment manufacturers (OEMs) in the aerospace, medical and other industries. This strategic move occurred on the back of an increase in demand for titanium-made parts in these industries. Thus, SME3 reacted to a market-pull situation. In reaction to the expansion into new industries, SMEs also developed technology implementation strategies. SME1 developed a roadmap for Industry 4.0 implementation, starting with machine connectivity using IoT devices. SME5 chose a strategy for technology development and regularly measured itself against the strategy.

The manufacturing-as-a-service business model requires strategic planning and implementation to deliver. SME1 is developing a strategy for a manufacturing-as-a-service business model. However, SME1 admitted that it still needs to "take a few steps" to reach its objective.

SMEs with niche value offerings prefer to identify and directly approach decision-makers in the target market over traditional marketing. Through direct marketing, SMEs identify the technical and business decision-makers in the target growth market. SME5 shared that individuals in each business unit are tasked to target and develop business-to-business marketing strategies instead of using third party marketing. SME4 decided on a similar marketing approach. Instead of using online marketing, SME4 identified possible clients and targeted its engineers and decision-makers. SME4 added that with advanced technologies, you need to identify the clients who can help grow your business. SME4 believes that traditional marketing will not attract clients to its additive manufacturing service. SME1 reported success when it changed its marketing effort using digital video-conferencing at the start of the COVID-19 pandemic.

SMEs held for too long on obsolete strategy and need to be optimistic to be five years ahead with new technology. SME3 recently changed its vision and mission statements. The company vision was long based on developing and manufacturing its medical device, an obsolete product. SME4's strategy is based on an optimistic view to be five years ahead with new technology compared to its competitors.

SMEs that do not follow “theoretical business models” struggle to find solutions to their business and technology challenges. SME3 stated that it is different to other manufacturing companies and does not follow the theoretical business models. This creates a challenge for the company as it does not always have business-related solutions or address business and technology challenges.

Strategic planning for SMEs is easier to implement, more informal and adaptable compared to large companies. SME4, a micro-sized enterprise, said that its strategic planning is based on informal discussions. The interviewee reckoned that strategic planning is easier for small businesses than larger enterprises as fewer people are involved. SME5, a medium-sized enterprise, admitted that strategies are initially clumsy, but it generates confidence when successes are achieved. Strategies will evolve as confidence grows and the strategies become optimised through waste elimination.

4.3.2 Design, Development and Production Perspective

The design, development and production perspective relates to the tangible systems that are developed to respond to the external market and internal business drivers idenifited in the commercial and strategy perspective (Phaal *et al.*, 2003b:365). The third level groups (green level) from the KJ Method were linked with each of the elements of design, development and production perspective in Figure 4-7. The discussion to follow considers each of the elements of the commercial and strategic perspective in terms of the interview data.

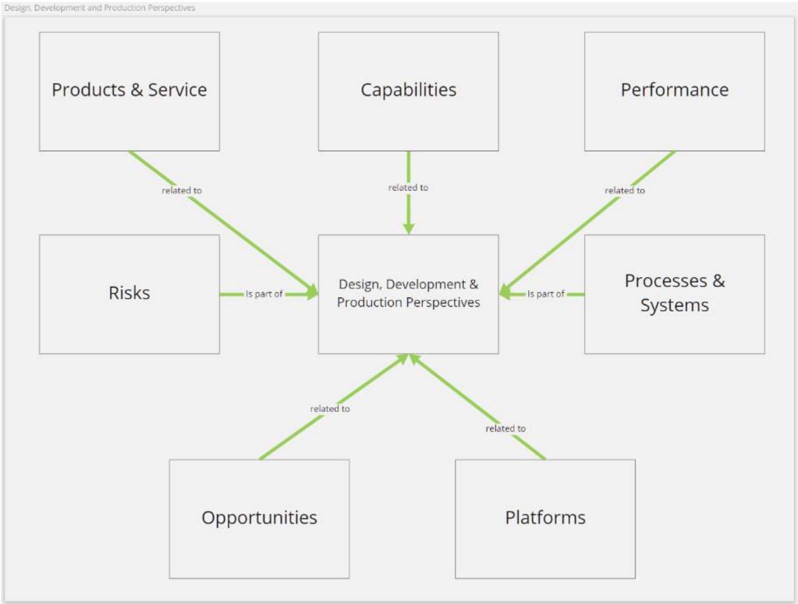


Figure 4-7: Elements of the Design, Development and Production Perspective.

4.3.2.1 Products and Service

The product and service element represents the development the value-offering that delivers benefits to customers and other stakeholders (Phaal *et al*., 2003b:365)..

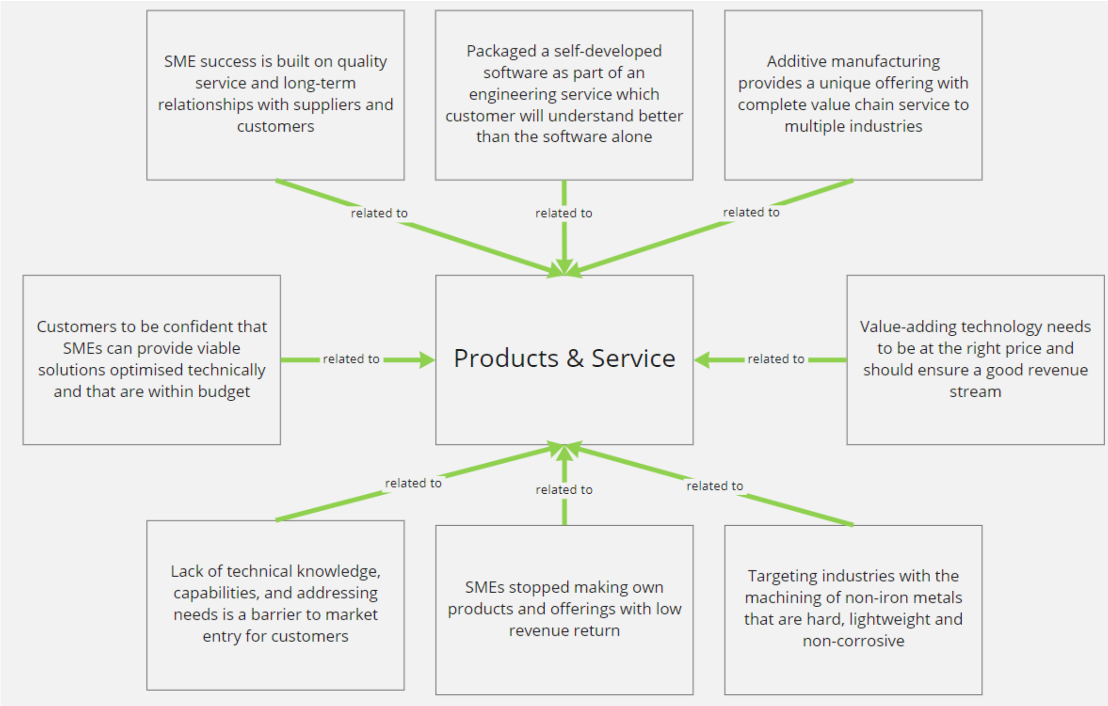


Figure 4-8: Product and Service-related links.

<u>SME success is built on quality service and long-term relationships with suppliers and customers.</u> Both SME1 and SME5 highlighted the importance of building a long-term relationship with suppliers and customers for commercial success. In the past, the SMEs interviewed, relied on customer referrals for new business. For this reason, SME1 said that quality of service is essential to gain and retain loyal customers.

<u>Packaged a self-developed software as part of an engineering service which customer will understand better than the software alone</u>.One business unit in SME5 developed software that, according to the interviewee, works brilliantly. However, the software is new, making it challenging to know and understand. Therefore, SME5 packaged the software as part of the engineering service, as clients will better understand a service than buying the software and trying it for themselves.

<u>Additive manufacturing provides a unique offering with complete value chain service to multiple industries.</u> SME4 offers a complete value chain service for additive manufacturing from concept product design to developing tooling for manufacturing. The company initially focused on industrial design and die casting products but expanded to design and products for the healthcare industry. It took SME4 approximately four years to acquire machines to implement the strategy to provide this unique additive manufacturing capability for various metals used in various industries. This included SME4 adding a separate machine with make parts from titanium for both medical

and non-medical industries. The commissioning of this machine and the certification to produce medical parts helped SME4 through the initial stages of the COVID-19 pandemic.

Targeting industries with the machining of non-iron metals that are hard, lightweight and non-corrosive. SME3 developed a niche in South Africa with the machining of titanium and exotic materials. Even though SME 3 have expanded into various industries since they were established in 1996, they have focused on non-iron based metals that are hard, lightweight, and non-corrosive metals.

A requirement for products and services is for customers to be confident that SMEs can provide viable solutions optimised technically and that are in budget. One of the business units in SME5 provides energy consulting services. This service aims to optimise clients' energy consumption, and SME5 provides alternative energy resources. SME5 felt that customers need to feel confident that their problems can be solved technically and in budget.

Value-adding technology needs to be at the right price and should ensure a good revenue stream. SMEs need to know and understand the value technology will bring to a client. SME5 stated that knowing the worth of a value-adding technology is a requirement to determine the price of the service. This is important to both company and the client. SME4 said it is important for the company to ensure that the technology is appropriate for the client. The technology also needs to provide a good revenue stream to manage commercial risks associated with that technology. SME4 highlighted the importance of identifying a target market where technology can add value. However, SME4 cautioned against the risk of expensive quotes as it put clients off the technology.

Lack of technical knowledge, capabilities, and addressing needs is a barrier to market entry for customers. Three of the five SMEs mentioned that a lack of technology knowledge, capabilities, and understanding of how technologies can address customers' needs are barriers to market entry. SME4 noted that an uninformed market views additive manufacturing technology as a low-level application; that is, customers think of additive manufacturing as “3D printing of plastic toys”. Therefore, the challenge SME4 face is to educate clients on how additive manufacturing technology can address their design and manufacturing needs. SME5 developed software which the market does not yet understand or know how to use. Therefore, SME5 developed a service that utilises the software it developed. Customers understand a package service better than a standalone software package. SME3 reckoned that the shortcomings of titanium additive manufacturing do not currently work for their market. Therefore, the capabilities of titanium additive manufacturing technology still need to developed to the point where it has properties comparable to that of machined titanium.

SMEs stopped making own products and offerings with low revenue return. SME3 ceased to design and manufacture its own medical implant devices, that is, a spinal fusion plate. As indicated earlier, this part of the business was closed with the passing of its surgical partner and expert. SME3 further stopped manufacturing injection moulding parts due to a lack of traction in the medical market. SME5 cautioned its engineers not to commit to projects outside its core service offering, even if it looks attractive. SME1's strategy was not to manufacture its own products but instead focused on contract manufacturing.

4.3.2.2 Capabilities

Capabilities represent the actions througt the use of assets to create, produce or offer products to the market (Ungerer, *et al.*, 2016:162)

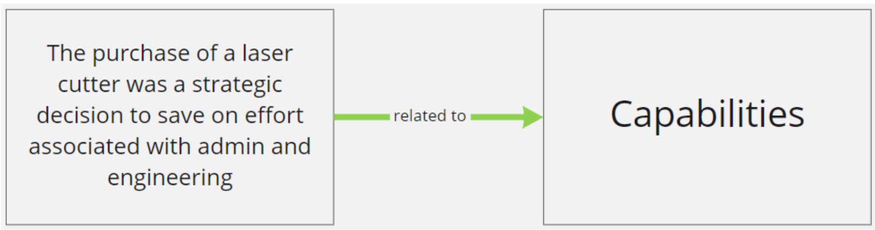


Figure 4-9: Capabilities related links.

The purchase of a laser cutter was a strategic decision to save on effort associated with admin and engineering. SME2's acquisition of a laser cutting machine is an example of technology implementation based on a strategic decision rather than a cost decision. SME2 acknowledged that while it is cheaper to outsource the laser cutting than performing it in-house, and while the machine came with an additional cost of ownership it had other benefits. These include savings associated with the administrative and engineering effort and a reduction of the costs associated with outsourcing. SME2 highligthed that these are not typical reasons for purchasing such production technology.

4.3.2.3 Performance

The element refers to business performance in accordance with the organisation's objectives (Phaal, *et al*. 2001:2).

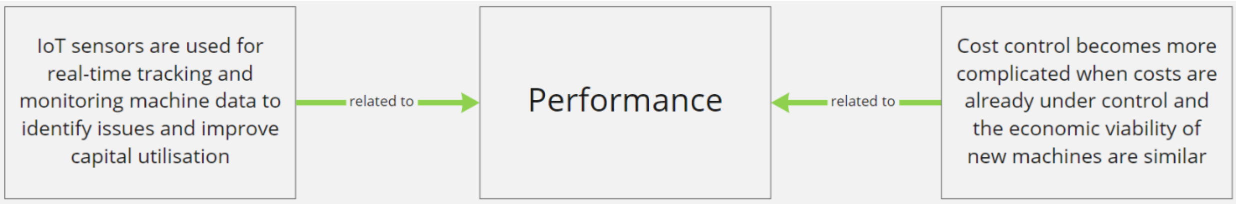


Figure 4-10: Capabilities related links.

IoT sensors are used for real-time tracking and monitoring machine data to identify issues and improve capital utilisation. Industry 4.0 technologies can increase capital utilisation using digital production technologies to improve scale-efficient utilisation of fixed assets. The analysis of machine data can identify issues and improve capital utilisation. As part of its technology roadmap, SME1 retrofitted its machining equipment with IoT devices to perform real-time tracking and monitoring of its manufacturing machines. SME1 admitted that the data generated from the machines do not provide solutions but assists to identify issues with production performance, maintenance scheduling or even personnel in need of training. SME3 believes that the availability and access to machine data help European-based manufacturers (SME3's competition) to improve on optimal use of their machines.

Cost control becomes more complicated when costs are already under control and the economic viability of new machines are similar. Once-off and operational costs needed to get full performance from a machine, make different machines' economic viability similar. SME4 commented that one needs to pay extra for a well-known brand of additive manufacturing machines to get full performance from the machine. Thus, the scope of quotations may differ, but the economic viability of the machines are like-for-like. SME1 echoed this sentiment, stating that the introduction of new technologies is challenged with significant once-off costs. SME1 further explained that cost reduction is difficult to achieve with introducing new technologies when the company already has costs under control. These statements point out that the impact of cost reduction through implementing Industry 4.0 technologies is made less significant due to hidden costs and the fact that companies may already have costs under control.

4.3.2.4 Risks

A risk is a an uncertain event or condition that, it it occurs, can cause significant negative (or positive) impact on an organisation (Ungerer, *et al.*, 2016:58).

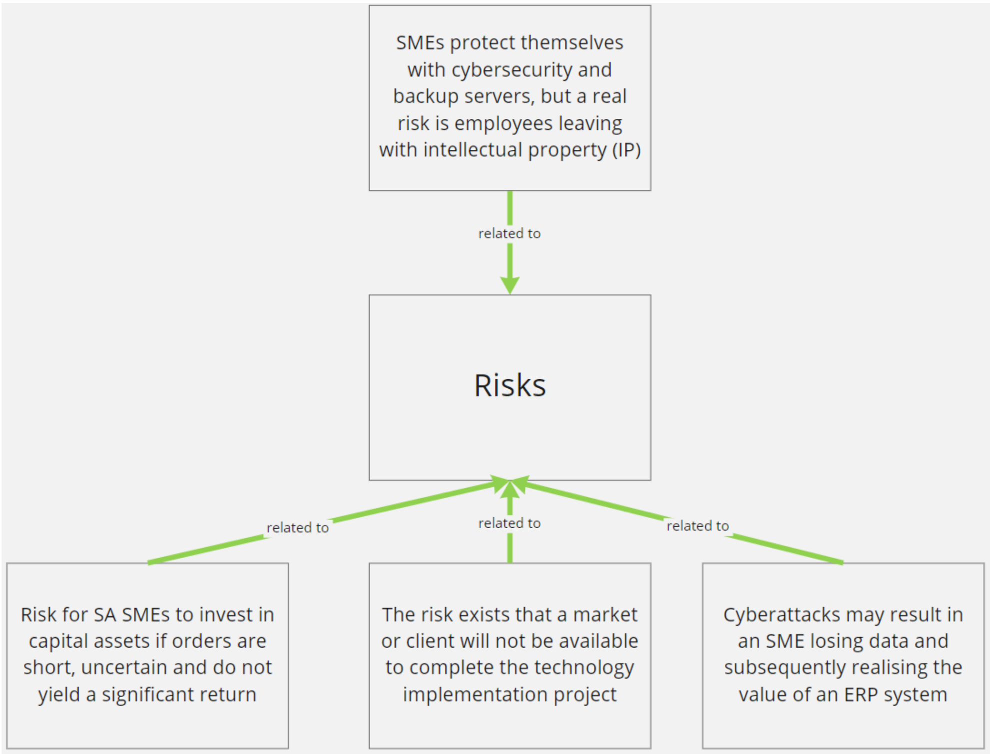


Figure 4-11: Risks related links.

SMEs protect themselves with cybersecurity and backup servers, but a real risk is employees leaving with intellectual property (IP). After a cyberattack, SME1 implemented advanced ICT security with more system redundancy and data backup. However, SME4 identified employees who knows the company's IP as a more significant risk than cyberattacks. SME2 and SME3 use backup servers to store data securely.

Risk for SA SMEs to invest in capital assets if orders are short, uncertain and do not yield a significant return. There is a risk for South African manufacturers to invest in expensive machines to match uncertain orders. SME3 stated that there is uncertainty with short term orders, which makes the implementation of production technologies risky. In the case of SME4, the Industrial Development Corporation (IDC), its funder, set an asset target (a strategic goal) which meant that the IDC did not mind the possible uncertainty of short term orders. SME4 further stated that a new technology mindset comes at a premium that will not always securely give a company a more significant return on its own or a funder's investment.

The risk exists that a market or client will not be available to complete the technology implementation project. There is a risk that a market will eventually be unavailable to complete technology implementation or project. SME1 has lost a significant source of income due to financial problems at a large South African parastatal. During the initial COVID-19 pandemic lockdown, SME4 took the risk of manufacturing products and being ready when the market opened again. For SME3, it is essential to know that a business will still be up and running between placing the order for a machine and the delivery thereof.

Cyberattacks may result in an SME losing data and subsequently realising the value of an ERP system. Cybersecurity was not one of the themes addressed in the literature review (Chapter 2). The interviews however highlighted that this is a significant issue for SMEs, and any company for that matter. SME1 fell victim to a cyberattack where its data was encrypted. The hackers demanded a ransom of 1 bitcoin from SME1 to decrypt its data which SME1 decided not to pay. The company lost most of its data. In the aftermath of this incident, SME1 used manual systems, like Microsoft Excel spreadsheets, to manage its operations. SME1 experienced significant resistance with the implementation of its ERP back in 2011. Ironically, everyone in the company was delighted when the ERP became operational again after three months.

4.3.2.5 Processes and Systems

An organisation requires effective processes and systems to ensure that technology resources in the organisation aligned with its strategy (Phaal, *et al*., 2001:1).

Figure 4-12: Capabilities related links.

Operation data can be recorded automatically into an ERP to allow for supply orders, materials for each job, quoting and note invoicing. SME1 uses a job card system linked with materials for each job. Through the company's ERP software, it can manage a job from quoting to delivery note invoicing. Although the ERP system allows for the automated recording of data, SME1 still feed the data manually into its ERP. SME3 uses a similar integrated ERP and MRP system for recording operational data for analysis and accurate quoting.

ERP capabilities need to match the initial data population process of an SME, which suggests that some do not need an ERP, MES or PLM system. SME1 and SME3 have voiced the importance of an ERP system to track their primary value chain activities and manage their support activities, such as procurement. SME1 mentioned that the company uses a smaller version of a well-known ERP software. Thus, it uses an ERP system that is more aligned with the company's needs and requirements. It was a challenge for SME1 to transfer the initial data population from a paper-based system to the ERP software. SME5 highlighted the need for the software to closely fit its systems until the initial population of systems is implemented. Not all of the BUs at SME5 use software to manage support activities due to the low number of units the company produces in a year. SME4 cited similar reasons for not employing digital technologies for support activities. The volume of work is still low enough for the company to manage support activities manually.

4.3.2.6 Opportunities

This elelement refers to the exploration of product opportunities (Phaal *et al*., 2001:11). The development of technology needs to be mapped and linked to market opportunities (Phaal, *et al*., 2003b:361).

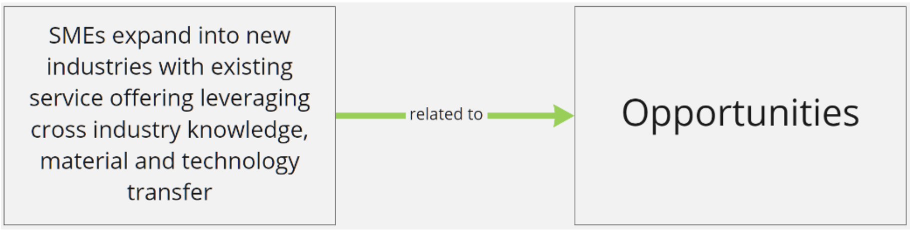


Figure 4-13: Opportunity related links.

<u>SMEs expand into new industries with existing service offering leveraging cross-industry knowledge, material and technology transfer.</u> Since 2008, clients in the aerospace and yacht industries have approached SME3 to manufacture exotic materials. With these opportunities, the company used its knowledge and experience to solve cross-industry problems. In 2021, SME3 revised its marketing strategy to expand into other industries actively. In 2020, along with the decision to expand into the automotive industry, SME1 also expanded its capabilities with complementary services such as casting, electronic assembly, and other manufacturing processes. At the start of the pandemic, both SME1 and SME4 were manufacturing healthcare products aimed at the pandemic response market. SME4 obtained certification to manufacture titanium medical implants towards the end of 2019. This certification allowed SME4 to operate during the initial stages of lockdown.

4.3.2.7 Platforms

A business platform allows for the facilitating exchanges between to or more independent groups.

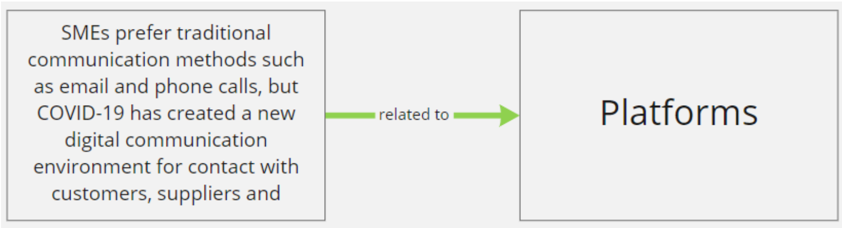


Figure 4-14: Platform related links.

SMEs prefer traditional communication methods such as email and phone calls, but COVID-19 has created a new digital communication environment for contact with customers, suppliers and internal meetings. Three SMEs indicated that they prefer to communicate with customers and suppliers by email or telephone. At this stage, they do not consider digital platforms that automate communications. Although digital communication platforms had been available for many years, the demand for such platforms skyrocketed with the advent of the COVID-19 pandemic. SME2 stated that videoconferencing technologies created new opportunities to involve more people, more effectively in meetings. SME5 highlighted the need for a stable communication platform affected the company's choice of a video teleconferencing platform.

4.3.3 Technology, Research and Resource Perspective

The technolog, research and resource perspective relates to the resources that needs to be organised and managed to respond to an organisation's strategy and value offering (Phaal, *et al*., 2003b:365).

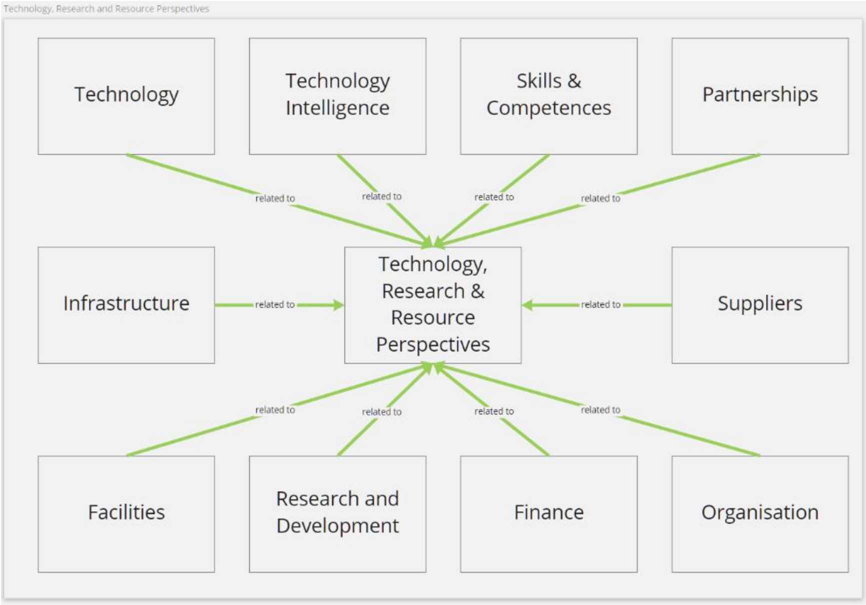


Figure 4-15: Elements of the Technology, Research and Resource Perspective.

4.3.3.1 Technology

Technology can not be explained in one single definition. Therefore, technology can be used as a term of reference: as a knowledge, as an artefact and as a process of enquiry and action (OU 2005b:19). Looking at the Greek origian of the word technology, it literally means the knowledge of a study of an art of craft (OU 2005b:19). As an artefact, technology transforms an input to technological knowledge and an output from it (OU 2005b:20). Technology as a process of enquiry and action is concerned with with the understanding, development, implementation and use of artefact systems(OU 2005b:23).

SMEs need to keep an open mind as technology is not industry bound, and suppliers and customers determine requirements. SME3 advised that companies need to keep an open mind towards technology with markets and customers in mind. In some cases, technology requirements are determined by suppliers. SME4 explained that additive manufacturing technology is not bound to a particular industry or market sector. Therefore, like SME3, SME4 takes a reactive technology approach by aligning the company and its technology with customer needs and requirements.

SMEs use various standalone software, but may have to expand looking at vendors with more extensive portfolios and necessary capabilities. SME1 and SME4 confirmed that they are using various standalone computer-aided engineering and manufacturing software packages. However, as their service capabilities and demand capacity increased, SME4 looked at software vendors with more extensive product portfolios.

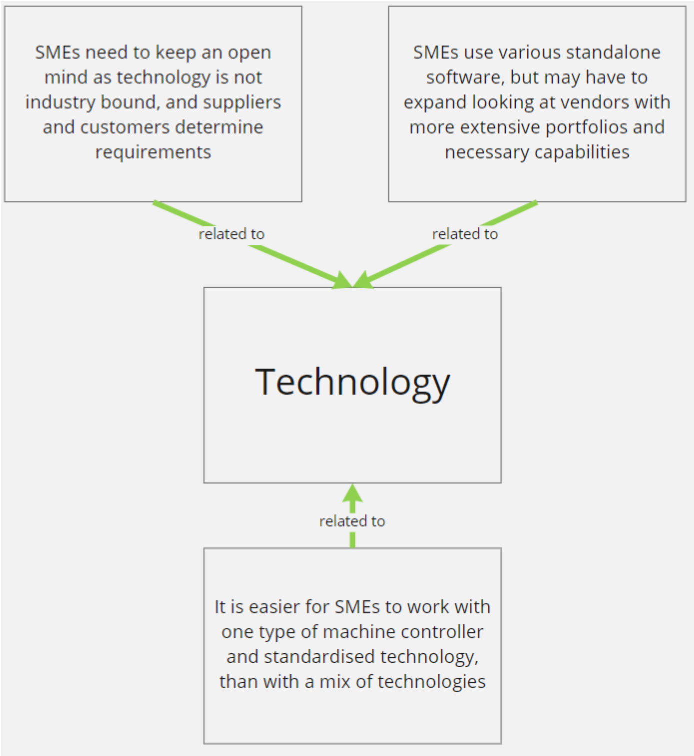


Figure 4-16: Technology related links.

It is easier for SMEs to work with one type of machine controller and standardised technology, than with a mix of technologies. Like most manufacturing companies, SME1 has a mix of machine controller technologies that are used on its CNC machines. This is a challenge for SME1, and the company would (with the wisdom of hindsight) only have chosen one machine control system from one brand. For SME1, it is also easier to work on standardised technology or with technologies from one vendor with an extensive product portfolio than with a mix of technologies.

4.3.3.2 Technology Intelligence

Technology intelligence systems need to be in place to identify, gather, interpret, and disseminate strategically important information

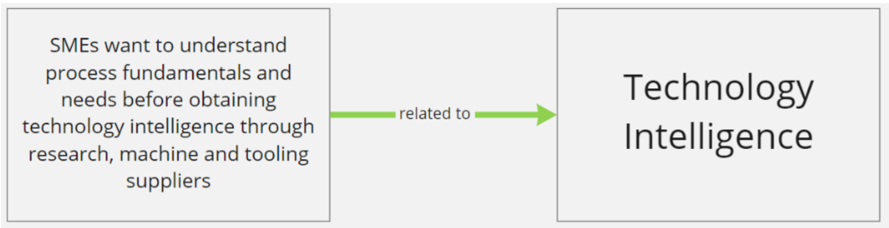


Figure 4-17: Technology Intelligence related links.

SMEs want to understand process fundamentals and needs before obtaining technology intelligence through research, machine and tooling suppliers. SME1 mentioned that it obtains technology intelligence through internal research and other initiatives. SME2 draws technology intelligence from the artisans who perform research on their machine technologies. SME4 drives the research and implementation of technologies to ensure the identified technologies will satisfy the company's needs. SME5 said that it is essential for the company to understand the fundamentals before implementing technologies. The risk with companies primarily relying on their own research into technology intelligence can constrain technology diffusion, leading to islands of Industry 4.0 technologies. However, this risk might be mitigated through cross-industry knowledge sharing as SME2 mentioned that machine and tooling suppliers are knowledgeable on production technologies.

4.3.3.3 Partnerships

Partnerships established via strategic alliances between two or more organisations to acquire technology resources and activities that would otherwise be unfeasible or ineffective to develop in-house (Ungerer, *et al*., 2016:255)

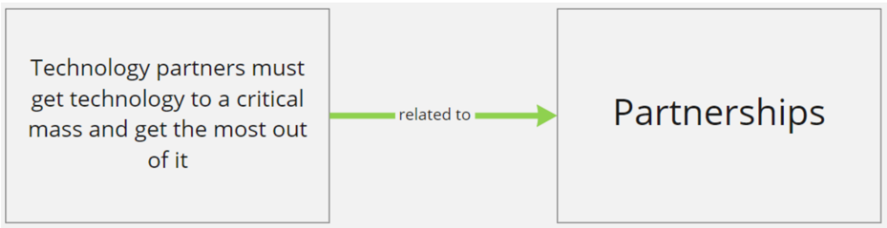


Figure 4-18: Partnership related links.

Technology partners must get technology to a critical mass and get the most out of it. SME5 believes companies need a technology partner to get the implementation and population of software to a critical mass to reach its potential. Both SME1 and SME3 partnered with the CSIR to get the most out of the technology they acquired.

4.3.3.4 Suppliers

The supplier element include activities associated with the procurement of equipment, services or suppliers.

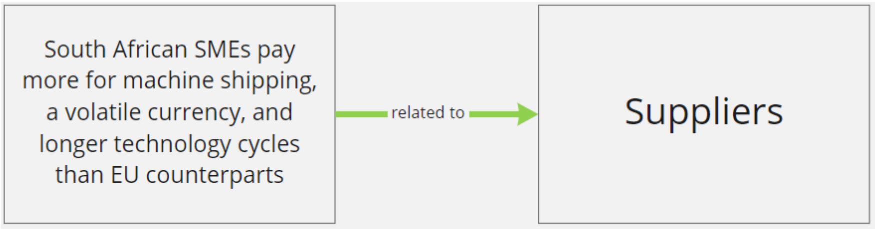


Figure 4-19: Supplier-related links.

South African SMEs pay more for machine shipping, a volatile currency, and longer technology cycles than EU counterparts. SME3 said that the high cost of shipping manufacturing equipment from Europe to South Africa adds to the already high price tag of equipment. Thus, South Africa's location relative to Europe poses a challenge. This challenge is made worse by the volatile South African currency.

4.3.3.5 Facilities

Facilities are the equipment, buildings and services provided to support the business.

SMEs rely on UPS to keep ICT functions going to perform essential admin and value-adding activities despite load shedding. Electricity looad shedding and unscheduled power outages are situations that South African companies came to live with. As a result, SME3 and SME4 plan their administration workload according to the load shedding schedule when it is available in advance. SME3 relies on uninterrupted power suppliers to keep essential ICT functions, such as computers and telephones, operative during load shedding.

Old or damaged UPS allows a short time to shut down machines and absorb electricity spikes. Both SME3 and SME4 indicated that their UPS were either old or damaged. SME3 still uses its UPS'; it allows the company approximately five minutes to safely shut down production equipment.

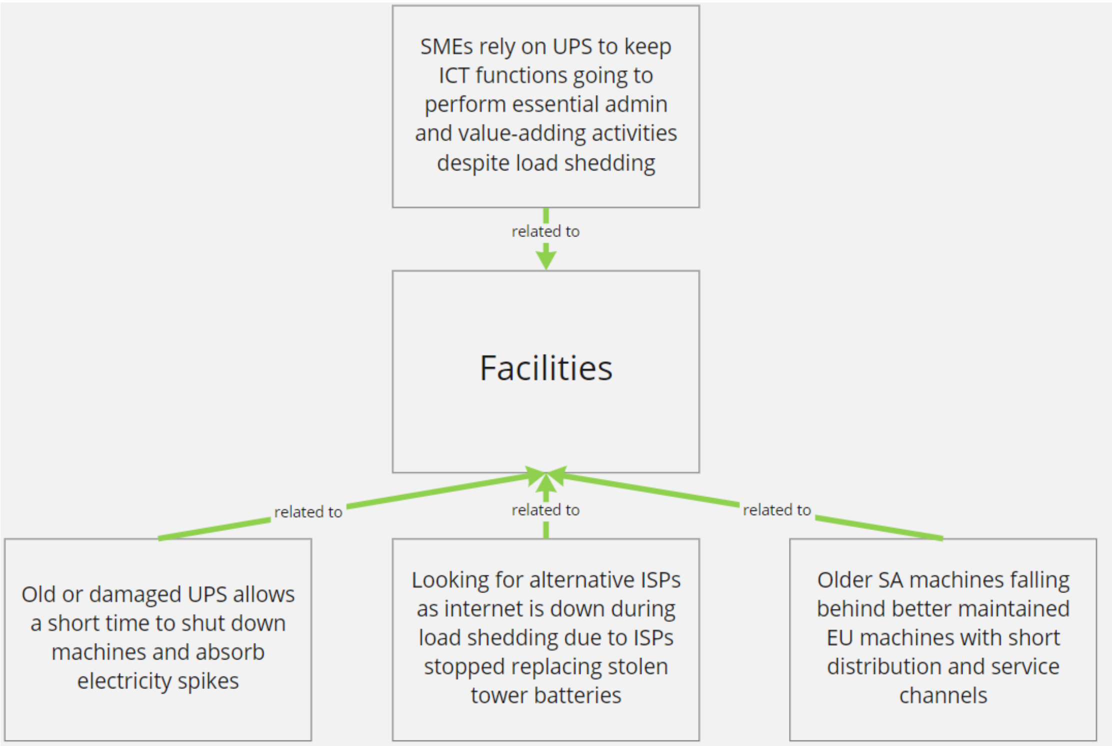


Figure 4-20: Facilities related links.

Older SA machines falling behind better maintained EU machines with short distribution and service channels. SME3 stated that manufacturing equipment used in South Africa tend to be older than those in Europe. In addition to this challenge, SME3 feels that South African companies are falling behind Europe to maintain manufacturing equipment. The benefit of better-maintained machines is that it leads to fewer machine breakdowns, thus, less downtime of equipment. SME3 stated that many machine suppliers are based in Europe, creating shorter service channels with European customers than with South African customers.

Looking for alternative ISPs as internet is down during load shedding due to ISPs stopped replacing stolen tower batteries. Both SME2 and SME4's internet is down during load shedding as their ISPs stopped replacing stolen batteries at their internet towers. SME1 cited the loss of internet connection as a big problem for the company. SME2 is looking at other ISPs as its current ISP is unreliable.

4.3.3.6 Research and Development

The activities an organisation undertake to innovate and introduce new technologies, new product and service to new or existing markets.

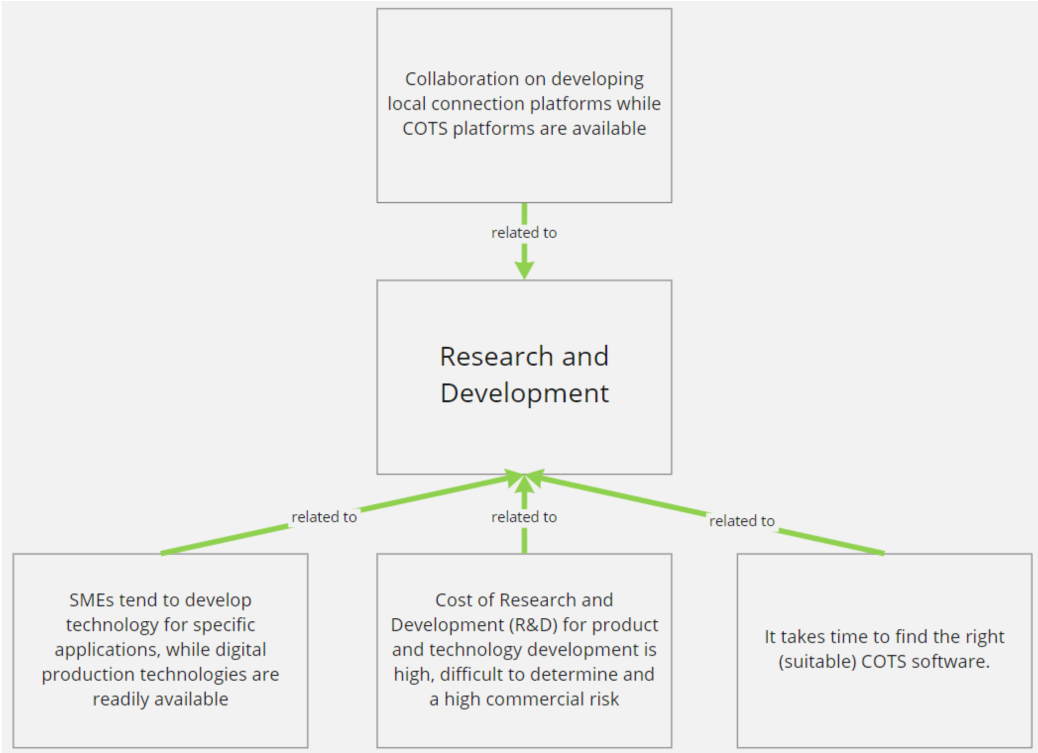


Figure 4-21: Research and Development related links.

<u>Collaboration on developing local connection platforms while COTS platforms are available.</u> Although the interviewed SMEs are not using online platforms to communicate with suppliers and customers, SME1 and SME4 have collaborated with commercial and research partners to develop a platform for shared manufacturing capacity and automatic quoting. SME1 has pointed out that COTS software embedded in a CAD package is available that provides real-time quoting of a design and manufacturing method. SME1 further stated that the company could not develop a shared capacity online platform if they tried independently.

<u>Cost of Research and Development (R&D) for product and technology development is high, difficult to determine and a high commercial risk</u>. SME3 stopped R&D on medical devices. The expectation and costs associated with R&D were skewed relative to the high commercial risks. SME3 felt that it was carrying all the risk while there was little commercial reward for the company. SME4 pointed out that doing a cost estimation of additive manufacturing has been difficult because of the indirect costs associated with the development of the technology.

<u>It takes time to find the right (suitable) COTS software.</u> SME3 tried to develop its business management system around "quoting to getting the product out of the door." However, this project was stopped after nine years as it did not meet the business' requirements. Turning to COTS software to implement the original plan, the first option failed because it could not do what the

salesperson claimed it could. During the interview, SME3 was confident that the second software option would be successfully implemented. In this case, more people in the organisation (SME3) were involved in the discussions with the vendor; thus, there were more inputs on the needs and requirements of the software. SME5 also mentioned the challenge of evaluating project management software that could not do exactly what the company wanted.

SMEs tend to develop technology for specific applications, while digital production technologies are readily available. SME1 noted that software for production technologies is usually developed in countries like the USA, which is also readily available to the local market. SME1 further explained how they co-developed an application for a customer that automatically converted machining programs between SME1 and their customer. This software application was specific to their project and could not be solved by commercially available software. SME5 developed internally products and software applications for the mining industry, which they then commercialised.

4.3.3.7 Finance

The activities associated with the finanincing of technologies and resources.

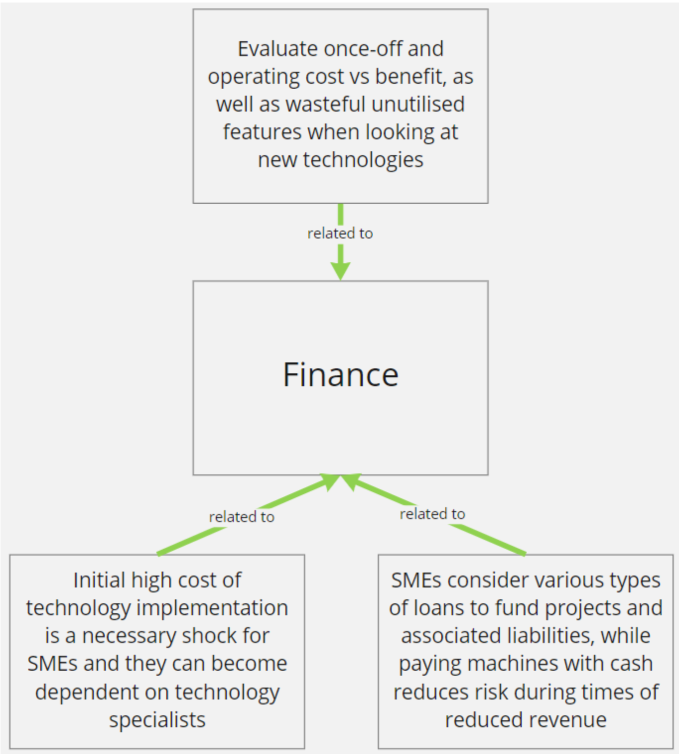


Figure 4-22: Finance related links.

Evaluate once-off and operating cost vs benefit, as well as wasteful unutilised features when looking at new technologies. SME5 mentioned one of the first questions they ask when evaluating new technology is: do you have the finance to develop or implement the technology? SME2 also stated that it looks at cost versus benefit with the implementation of technology. Three of the interviewees claimed that initial technology implementation is challenging, but the benefit of the technologies outweighs the initial effort. SME5 mentioned that software became more beneficial to the point where the benefit outweighs the effort to perform the tasks manually. In support of this, SME1 provided the example of the machining conversion program, which meant they could start machining without the need for running simulation first. Not only did this conversion program save significant time, but it also reduced possible errors associated with the manual conversion of the machining programs. SME2 provided the example of implementing a Product Data Management (PDM) system that had various issues, but it became more accessible with use. SME1 warned that companies need to consider the value of upgrades as unutilised technology features are a waste of money.

SMEs consider various types of loans to fund projects and associated liabilities, while paying machines with cash reduces risk during times of reduced revenue. Companies like SME3 carefully consider different financing options for the procurement of equipment. Loans are risky as they can become a liability during periods of low or reduced revenue. However, SME3 will likely convert IDC funding into bank loans as the IDC become impossible to work with. SME3 will try to pay for equipment with cash first. Equipment paid with cash helped them to survive through difficult times. However, depending on the project, SME4 will consider IDC or venture capital funding to finance equipment procurement.

The initial high cost of technology implementation is a necessary shock for SMEs, and they can become dependent on technology specialists. SME1 and SME5 stated that the companies could not afford the high initial costs to implement comprehensive technology solutions. Therefore, to keep the costs down, SME1 prefer to implement technology by itself – as far as this is possible. SME4 highlighted that companies could become dependent on technology specialists if they do not implement technologies themselves.

4.3.3.8 Organisation

The organisation elements refers to the involvement of stakeholders in the organisation with regards to technology identification and technology implementation.

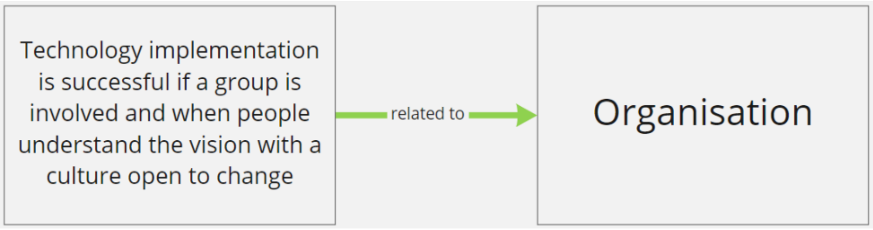


Figure 4-23: Organisation related links.

Technology implementation is successful if a group is involved and when people understand the vision with a culture open to change. According to SME1, successful technology implementation requires leadership to explain the vision behind the technology to the company. SME2 identified that a company culture open to change is required for the implementation of new technology. After two unsuccessful attempts to implement a business management system, SME3 involved a larger group of employees in its decision making process. As a group, they performed research and identified the needs and requirements for the software. This approach resulted in buy-in from the group and successful implementation of the technology.

4.4 Discussion on Findings

In the section to follow, the findings of this study (literature review and data analysis combined) are discussed along the lines of (1) the requirements and (2) the challenges the participating SMEs experience with their strategies, value offering to customers and the resources used to deliver on the latter.

4.4.1 Requirements

Manufacturing SMEs are required to implement technologies aligned with the main characteristics of Industry 4.0 (Deloitte, 2015:6) to address the need for vertical business processes and horizontal value chain integration. SMEs must attempt to improve resource efficiency with the use of vertical networking of intelligent production systems. The interviews showed an example of an SME collaborating with other companies and customers to develop an integrated and flexible value chain. These characteristics associated with horizontal integration (Deloitte, 2015:6) will optimise the value chain.

Manufacturing SMEs require operational data to optimise performance. The interviewed SMEs perform data analysis to improve the primary value activities; data is still fed manually into their ERP systems. Thus, there is a requirement for SMEs to implement a connected, end-to-end data thread that allows for automatic decision making (Singapore EDB, 2017:14). Although none of the SMEs interviewed is at the level of a connected, end-to-end data thread that allows for automatic decision making (Singapore EDB, 2017:14), the use of ERP systems by four of the five SMEs interviewed allow them to perform data analysis to improve their primary activities.

In order to provide a unique offering, manufacturing SMEs require through-engineering that integrates people, processes, and systems along the entire product lifecycle (Singapore EDB, 2017:12). For this purpose, SMEs may use various standalone engineering software to create digital products. These software applications allow an SME to optimise products and designs from customers for the manufacturing processes they utilise. To fully utilise the benefit of through-engineering, engineering and manufacturing processes need to be connected and integrated. This through-engineering will further require a data management system that allows process integration instead of relying on the manual transfer of engineering data.

It was indicated in the demographic information obtained that the interviewed SMEs mainly operate as job shop manufacturers, which are characterised by a high number of low volume orders. Therefore, business success is based on flexible manufacturing rather than the scale of manufacturing. It follows that Industry 4.0 technologies are crucial for South African manufacturing SMEs to survive challenging commercial conditions and remain internationally competitive.

The level of Industry 4.0 implementation in manufacturing SMEs need to match their capability and capacity to utilise these technologies. For example, there will be little benefit for an SME to implement advanced technologies to manage products' design, production, and distribution of low volume (less than ten annually). A similar situation is an SME that can manually manage support activities (procurement, sales, customer relations, etc.) due to the low volume manufacturing. However, the need for software to manage support activities may arise as the volume of manufacturing increases, and the benefit of these software outweighs the effort to operate processes manually.

All the interviewed SMEs highlighted the importance of strategy. The level of strategic planning and strategy implementation varied, as was evident from the micro-sized enterprise that based its strategy around informal discussions. Meanwhile, medium-sized enterprises tend to have more formal strategies characterised by vision and mission statements. Therefore, manufacturing SMEs are required to have flexible strategies; that is, the strategy can be changed quickly and is adaptable; that is, the organisation is able and willing to change its strategy.

Manufacturing SMEs need to implement technologies aligned with their strategic visions. From the interviews, it is difficult to conclude if the SMEs are overwhelmed by strategic and operational decision-making (Mittal et al., 2018:196). However, SMEs' challenges during the COVID-19 pandemic can distract them from thinking strategically about innovation to shape their future.

SMEs rely on their research, knowledge of machine equipment and tool suppliers as well as partnerships with academic and research institutions to gather technology intelligence. Manufacturing SMEs require technology intelligence to develop business strategies that are linked with the technology resources.

SMEs are required to automate tasks that can be routinised in their primary value chain and support activities. Automation of physical tasks was not mentioned as technology considered by the interviewed SMEs. However, there seems to be a need to automate processes in the secondary support activities. This finding supports Andreoni and Anzolin’s (2019:11) statement that the need for automation is not necessarily driven by the fact that the task is manual but rather depends on the degree of routinisation.

Manufacturing SMEs are required to evaluate the costs of technology against the benefit that technology will bring to the organisation. In support of this, the interviewed SMEs highlighted the importance of understanding the benefits of technology before implementing it. In some cases, this can lead to SMEs not implementing a specific technology as it becomes evident that it will not function as required. This finding resonates with Pessl et al. (2017:195), who stated that a lack of transparency and inability to quantify benefits contributes to companies' hesitancy to implement Industry 4.0 technologies. The requirement for cost evaluation against the benefits of technology also relates to Mitchell and Phall (2018), who presented the use of “Opportunity versus Feasibility” in project evaluation. The researcher agrees with Nagarajah (2015:12), who warns against financial analysis as it can bias project selection. Issa et al. (2018:973) argue in this regard that the focus of Industry 4.0 has moved from a technology problem to a business and added-value problem. The researcher's finding from the interview data is that SMEs tend to implement technologies that add quantifiable business value or strengthen a strategic position which is challenging to quantify. Further, the researcher observed that the SMEs carefully consider technologies they implement as they do not have the finances to implement technologies that add business value. These findings agree with Issa et al. (2018:973), who argue that the focus of Industry 4.0 has moved from a technology problem to a business and added-value problem.

The interviewed SMEs highlighted the importance of building a long-term relationship with suppliers and customers for commercial success. Good relationships with customers are essential to retain customers and lead to revenue improvements based on referrals from satisfied customers. This supports Andreoni and Anzolin’s (2019:26) suggestion that product and service quality are mechanisms for revenue improvement. Therefore, quality of service and long-term relationships with suppliers and customers are required for the commercial success of manufacturing SMEs.

Manufacturing SMEs are required to provide unique service offerings. This unique offering will vary from SME to SME. Overseas-based additive manufacturing service providers tend to focus on a specific part of the industrial value chain in the additive manufacturing industry, for example. However, in a developing country, like South Africa, where few additive manufacturing service providers exist, a unique additive manufacturing service offering can be a comprehensive value offering from concept to manufacturing a finished part. SMEs that provide subtractive manufacturing services tend to provide a unique service offering in a niche market.

Manufacturing SMEs are required to implement value-adding technologies at the right price and in a good revenue stream. To satisfy this requirement, SMEs need to know and understand the value technology will bring to a client. In addition, an SME needs to ensure that the technology is appropriate for the client and target market. However, SMEs need to beware of the risk of expensive quotes that may put clients off the technology. These observations from the interview data support the statement made by Issa et al. (2018:973) that the primary challenge of manufacturing companies is to transform from a cost-based operation to a company with a high value-added competitive advantage.

IoT devices are required for real-time tracking and monitoring machine data to analyse to identify issues and improve capital utilisation. As identified by Andreoni and Anzolin (2019:18), Industry 4.0 technologies can be used to increase capital utilisation using digital production technologies to improve scale-efficient utilisation of fixed assets. The analysis of machine data can be used to identify issues and improve capital utilisation, for example. The results from these analyses can help manufacturing SMEs to be more competitive.

The data from the interviews captured in this study do not suggest a lack of awareness of Industry 4.0 technologies, as was observed in the study by Issa *et al*. (2018:974). It is concluded from the interviews that manufacturing SMEs in South Africa are taking a cautious and incremental approach to technology implementation. It was observed that these SMEs try to understand the full scope of challenges with digital transformation before implementation. It is concluded that the management of a manufacturing SME is required to align both business and operation strategies for successful technology implementation.

It may be argued that the interviewed SMEs implement technologies that address each of the six application levels of Industry 4.0 as defined in the VDMA Industry 4.0 toolbox (VDMA 2016:15). The extent to which each application level is addressed varies between SMEs as they tend to implement technologies that address their more immediate business needs. Therefore, South African manufacturing SMEs require a technology roadmap that provides a framework for the sequential implementation and development of digital production technologies.

Based on the data from the interviews, the researcher supports the proposal by Issa et al. (2018:975) that manufacturing organisations use technology roadmaps, which defines a clear focus for digital technology implementation aligned with the organisation's business operation needs. Although the roadmap should not exclude the generation of new business models, the focus of the roadmap should be to optimise processes and operations in the organisation and along its value chain. The interview data support the statement made by Issa et al. (2018:974) that manufacturing SMEs in South Africa need to allocate resources and focus on the most critical aspects of technology implementation.

The requirements presented and discussed above are summarised in Table 4-3 below.

Table 4-3: Summary of requirements identified from the interview data.

Technologies must be implemented aligned with main characteristics of Industry 4.0 to address need for vertical business processes and horizontal value chain integration.
Operational data to optimise performance.
Through-engineering requires a data management system that allows for process integration instead of relying on manual transfer of engineering data.
Industry 4.0 technologies crucial to survive challenging commercial conditions and remain internationally competitive.
Level of Industry 4.0 implementation needs to match capability and capacity to utilise technologies.
Flexible strategies.
Technology intelligence to develop business strategies linked with technology resources.
Automation of tasks that can be routinised in primary value chain and support activities.
Evaluation of costs of technology against benefits.
Quality of service and long-term relationships with suppliers and customers.

A nique service offering.
A technology roadmap that provides a framework for sequential implementation and development of digital production technologies.
Implementation of technologies aligned with strategic vision.
To maximise capabilities of technology, partnerships with technology experts such as technology vendors, academic institutions, research institutions and or engineering consultants.
Implementation of value-adding technologies at right price and in a good revenue stream.
IoT devices required for real-time tracking and monitoring machine data to identify and analyse issues and improve capital utilisation.
Management should align business and operation strategies for successful technology implementation.
Allocation of resources and focus on most critical aspects of technology implementation.

4.4.2 Challenges

South African manufacturing SMEs face challenges with the high costs of comprehensive technology solutions, while affordable technology solutions have limited capability. ERP software connected with new generation manufacturing equipment will allow such SMEs to track manufacturing operations in near-real-time. Still, the high costs of enabling these features on new machining equipment can dissuade manufacturing SMEs from utilising these Industry 4.0 technologies.

Older manufacturing equipment requires retrofitting with IoT devices to extract operational data from the machines. This supports the observation by Andreoni and Anzolin (2019:17) that in developing countries like South Africa, production technologies require retrofitting with cyber-physical systems, such as IoT devices, to allow for integration on a technological and organisational level. To maximise the capabilities of technologies, manufacturing SMEs need to partner with technology experts such as technology vendors, academic institutions, research institutions (e.g. CSIR) and engineering consultants.

Manufacturing SMEs tend to use a mixture of standalone technologies, such as various standalone computer-aided engineering software packages. These software packages are not connected through a unified platform, thus, not allowing for an integrated through-engineering capability. SMEs can manage such disconnected systems when the level of complexity and the number of orders is relatively low. These disconnected systems become a challenge as businesses expand and product complexity increases. Comprehensive digital platforms that allow for the integration of ERP, PLM and MES are expensive, and manufacturing SMEs often cannot afford such platforms.

Andreoni and Anzolin's (2019:14) observed that unreliable electricity supply and internet connectivity are obstacles to utilising digital production technologies effectively. This observation was confirmed with all interviewed manufacturing SMEs that have highlighted a lack of reliable infrastructure in South Africa. Loadshedding and loss of internet connectivity harm business. The measures SMEs implement to mitigate these challenges are expensive.

The WEF (2018:2) report on the readiness for the future of production warned that countries, such as South Africa, which rely on low-cost labour, can lose competitiveness to countries that utilise emerging Industry 4.0 technologies. The interviews concluded that South African SMEs face various challenges that erode their competitive advantage based on the low cost of skilled labour. Therefore, South African manufacturing SMEs need to consider automating processes and workflows across all aspects of their operations to reduce and control costs.

Pessl et al. (2017:195) identified the high investment costs to implement Industry 4.0 technologies as the reason why organisations often do not implement Industry 4.0 technologies. Although certain technologies, such as IoT devices, became more affordable, the interviewed manufacturing SMEs cited the high initial cost of technology implementation as a significant challenge. The high costs were associated with retrofitting older machines with Industry 4.0 technologies as well as with the cost models OEMs force onto customers to gain access to advanced technology features on the machines.

It can take significant time and effort for manufacturing SMEs to expand their manufacturing capabilities and capacities. This is sometimes necessary when such SMEs make the strategic decision to enter new markets with existing value offerings or develop new value offerings for existing markets. Therefore, in support of the observation made by Andreoni and Anzolin (2019:58), manufacturing SMEs are challenged with the commitment of resources under uncertain conditions when making a strategic decision to invest in capital intensive production technologies.

Lack of technical knowledge, capabilities and how it addresses customer needs are challenges for customers utilising technologies. The interviewed manufacturing SMEs mentioned that a lack of technology knowledge, capabilities, and the manner in which technologies can address customers' needs are barriers to market entry. For example, as was stated earlier, customers view additive manufacturing as the "3D printing of plastic toys". Therefore, manufacturing SMEs face the challenge of educating clients on how production technologies could address their design and manufacturing needs. Another challenge is that customers do not know how to use new technology, like new engineering software.

The purchase of production technologies and digital production technologies have an additional cost of ownership not initially visible. A decision to perform manufacturing or fabrication in-house rather than outsourcing have additional costs such as technicians required to operate the equipment. The quotations for advanced digital production technologies, like additive manufacturing and CNC machining equipment, have hidden costs the vendor does not mention prior to the commissioning of the machines. These hidden costs can lead to profitability and cash flow problems for manufacturing SMEs if ignored in the financial evaluation of the technology.

The impact of cost reduction through the implementation of Industry 4.0 technologies are less significant when a manufacturing SME already has its costs under control. Room for cost reduction is further limited if there are hidden costs associated with implementing Industry 4.0 technologies. The interviews highlighted that high once-off costs associated with technology implementation could make the economic viability of technologies less attractive. In addition, manufacturing SMEs need to be aware of paying for technology features that are not utilised.

Manufacturing SMEs' strategic planning and strategy implementation are challenged by macro-environmental conditions outside their sphere of influence. Macro environmental conditions such as disrupted and constrained supply chains and load-shedding significantly impact manufacturing SMEs revenue streams and ability to control costs.

There is a lack of technology intelligence and technology implementation at academic, technical, and vocational education institutions in South Africa. Although not unanimous, some manufacturing SMEs believed they were further ahead with technology intelligence and technology implementation than (some) academic institutions. This finding supports Dewa et al. (2018:662) who observed that there is a lack of Industry 4.0 awareness in South African academia. However, the finding contradicts that of Dewa et al. (2018:662) that South African industry suffers from the same lack of Industry 4.0 awareness. Manufacturing SMEs tend to perform their own in-house technology research. Machining equipment and tooling suppliers, technology providers and industrial research organisations were identified as sources of technology intelligence for SMEs. In defence of Dewa et al. (2018:660), their research showed that small companies, such as the manufacturing SMEs interviewed as part of this research, tend to implement Industry 4.0 enabling technologies.

Unreliable and unstable internet connectivity is a challenge for the productivity and operations of manufacturing SMEs. This finding, based on the comments by the interviewed SMEs, supports the observation by Dewa et al. (2018:650) that internet connectivity is essential. The internet challenges manufacturing SMEs face is due to the lack of infrastructure and load-shedding.

The lack of local support and the inability of OEMs to set up machines for optimal performance of manufacturing SMEs are additional challenges to fixed capital utilisation, as observed by Andreoni and Anzolin (2019:19).

Table 4-4: Summary of challenges identified from the interview data.

High costs associated with comprehensive technology solutions, while affordable technology solutions have limited capability.
Legacy production technologies require retrofitting with cyber-physical systems to integrate technological and organisational levels.
Disconnected systems as SMEs expand and product complexity increases.
Loadshedding and loss of internet connectivity.
Low cost of skilled labour is an advantage in South Africa threated by the low cost of technology abroad.
High initial cost of technology implementation.
Commitment of resources under uncertain conditions when making a strategic decision to invest in capital intensive production technologies.
Lack of technical knowledge, capabilities and how it addresses customer needs among customers.
Production technologies and digital production technologies have an additional cost of ownership not initially visible.

High once-off costs associated with technology implementation can make economic viability of technologies less attractive.
Strategic planning and strategy implementation are challenged by macro-environmental conditions.
Lack of technology intelligence and technology implementation at academic, technical, and vocational education institutions in South Africa.
Lack of local support and inability of OEMs to set up machines for optimal performance.

4.5 Concluding Remarks

This chapter's objective was to better understand the environment in which South African manufacturing SMEs implement and manage technology. The findings in this chapter were categorically explained with reference to the three perspectives of a technology roadmap. The findings, as discussed above, were telling in terms of the requirements and challenges of these SMEs.

As far as the requirements are concerned, some of the outstanding insights include (1) the need to implement technologies aligned with the SMEs strategic vision, (2) the importance of the SMEs aligning their business and operations strategies and (3) the necessity for the SMEs to allocate resources and focus on the most critical aspects of technology implementation.

As far the challenges are concerned, it was revealing to see (1) the relevance of the macro-environmental conditions, (2) there is a lack of understanding under customers on how advanced production technologies can address their needs, and (3) the SMEs challenges with regard to the commitment of resources under uncertain conditions.

The next chapter draws this study to a close.

CHAPTER 5 CONCLUSION

5.1 Study Background

This study explored the use of production and digital production technologies specifically for manufacturing SMEs in South Africa. These digital technologies form part of the concept of Industry 4.0. The literature review revealed that manufacturing companies in developed and developing countries struggle to implement Industry 4.0 technologies successfully. However, Industry 4.0 is not neutral regarding its relevance for different industries and countries. Based on this challenge, Industry 4.0 was defined starting with the international context and was subsequently refined to fit the context of manufacturing SMEs in South Africa.

Industry 4.0 is a mere concept and not a ready-to-implement solution. The problem with the implementation of Industry 4.0 is multi-faceted in terms of horizontal value chain integration, vertical business process integration, organisational change management and the potential benefits these technologies can bring to an organisation. Therefore, companies struggle to implement Industry 4.0 technologies. This has led to the development of various maturity models, frameworks and strategic roadmaps used to implement Industry 4.0 technologies.

Against the backdrop of the available roadmaps and models, the main research question of this study was developed: how can existing Industry 4.0 roadmaps/models be used for digital transformation in manufacturing SMEs in South Africa to help secure success potential? This question translated into the main objective of this study: to focus on South African manufacturing SME's in exploring the way(s) in which existing Industry 4.0 roadmaps/models could be used for digital transformation towards unlocking these companies' success potential.

5.2 Findings Revisited

In Chapter 2, various definitions and characteristics of Industry 4.0 were identified from the literature. It was reported that the confusion created by this rich mix of definitions make it difficult for companies to identify and implement Industry 4.0 technologies. Definitions are nevertheless essential as it assists with concept clarification. For this reason, the researcher defined Industry 4.0 in this study as the integration and management of the primary and supporting activities in the production processes of an organisation and the industry value chain using autonomously communicating digital technologies.

The literature review identified that SMEs are often overwhelmed with decisions and do not know how to transform their organisations: where to start, proceed or go. Therefore, as identified throughout the literature review, various researchers concluded that manufacturing SMEs require a roadmap for Industry 4.0 implementation. These roadmaps need to be fit for purpose and must guide SMEs through viable phases of digital transformation. The roadmaps need cross-linking between technologies, products and markets with the purpose to a) show results that are both tangible and quantifiable; and b) help secure success potential. Four roadmaps from the literature review were considered in greater detail.

The Technology Roadmapping process was identified as a possible roadmap suitable for manufacturing SMEs in South Africa. Technology Roadmapping is an established tool for operational technology and innovation management. Technology Roadmapping involves the development of documentation with a communicative purpose, institutionalisation, and the identification of instrumental linking functions. Two outstanding and attractive features of Technology Roadmaps are:

- The wide range of aims Technology Roadmapping can contribute to and the manner in which it can support the strategic planning of an organisation.
- The range of tools, processes and information sources that can be integrated with a Technology Roadmap.

It was pointed out that the flexibility of the Technology Roadmapping process is also a weakness in the sense that it must be customised for a particular application. Thus, it is not a rigid process that is ready-to-use for every strategy, product and technology development situation. Technology Roadmaps have a long history with their origins in industrial engineering applications since the 1960s but became more prominent since the 1970s. Therefore, it is a tool that has an established track record across industries around the globe. The success of a Technology Roadmap as a tool lies in its supervisory role to facilitate the coordination of different functional groups in an organisation. Technology Roadmaps have the ability to provide organisations (such as manufacturing SMEs in South Africa) with a competitive strategy through coordination of technology activities where extensive co-operation and high-level investment is required. For these reasons, the researcher identified and discussed Technology Roadmaps suitable for manufacturing SMEs in South Africa and packaged it to serve as a strategic framework for technology implementation and management in these companies.

In Chapter 3, the methodology applied in the qualitative analysis part of the study was presented. Semi-structured interviews were conducted with five manufacturing SMEs to obtain qualitative data to identify the (1) needs and requirements for SMEs and (2) challenges SMEs face with the implementation of technologies. The interviews were conducted with questions structured around the three perspectives of Technology Roadmap:

- Commercial and strategic perspective.
- Design, development, and production perspective.
- Technology, research and resource perspective.

The qualitative data generated from the interviews were analysed using the KJ Method to reduce the statements made to a manageable data set. This was achieved through an iterative process of grouping statements that show affinity. Chapter 3 paid specific attention to how the KJ Method was used to perform thematic analyses of the interview data generated.

The findings from the analysis of the interview data were categorically explained with reference to the three perspectives listed above. These findings, presented in Chapter 4, provided a better understanding of the challenges faced by manufacturing SMEs in South Africa. A total of fourteen challenges were identified (Table 4-4, Chapter 4). Comparisons between the identified challenges from the interview data and the literature review were drawn. However, some of these challenges are specific to developing countries such as South Africa and were not evident in the preceding literature review that drew on research mainly from the Global North.

In addition, eighteen requirements (Table 4-3, Chapter 4) were identified that manufacturing SMEs should consider improving on the successful implementation of technologies. The analysis concluded that the interviewed South African SMEs have a good level of awareness of the strategic and resource requirements for successful technology implementation in their organisations.

5.3 Recommendations

Based on the research presented, the following are recommended:

- South African manufacturing SMEs face various macro-environmental conditions their counterparts in developed countries are not familiar with. The interviewed SMEs can mitigate the negative impacts associated with environmental factors outside their sphere of influence. However, the research indicated that some environmental factors do not have mitigating solutions. South African manufacturing SMEs are therefore recommended to evaluate the impact of external macro-environmental factors on their internal business drivers. This evaluation can be accomplished with analysis tools such as STEEPL, SWOT and Porter’s Five Forces. It is further recommended that SMEs use this kind of evaluation to consider possible commercial opportunities in challenging market conditions, such as the conditions brought on by the COVID-19 pandemic.
- It is recommended that South African manufacturing SMEs align their technology resources with their strategic direction / vision. This can be achieved using linking grid

tools such as QFD, Hoshin Kanri or Technology Income Statement to link customer requirements with technical specifications. In addition, these tools allow tracing the connections between technologies, products, and the markets.

- Technology intelligence forms the foundation on which decisions are made throughout a business. Therefore, it is recommended that South African manufacturing SMEs explore various avenues to gather and share technology intelligence.
- The importance of technology evaluation was highlighted in the literature reviewed and, in the interviews, conducted. Therefore, it is recommended that manufacturing SMEs identify and develop tools that can be used to evaluate the feasibility of a technology opportunity. It is further recommended that such a valuation not be done purely based on financial analysis and benefits, but also on the basis of non-financial parameters considered strategically important to the SME.

5.4 Contribution of this Study

The literature review identified research on the implementation of Industry 4.0 technologies in developing countries. However, the majority of published research and the dominant discourse on Industry 4.0 is still focused on the developed country context. Therefore, with the primary data collected through the semi-structured interviews, this study sought to contribute to knowledge of technology implementation and technology management in the South African manufacturing SME context, and to that of SMEs in developing countries, for that matter.

As identified in the literature review, research on the implementation of Industry 4.0 technologies tend to focus on large enterprises. Therefore, this study contributes to research on SMEs, specifically manufacturing SMEs. The study’s new contribution lies in its identification of requirements and challenges SMEs face and must consider in the technology management domain.

To conclude, the study presented and used the novel KJ Method to provide meaningful analysis of the qualitative data obtained through the semi-structured interviews. The KJ method has proven to be an effective and suitable tool for analysing unorganised thoughts and insights from a rich set of data. Although the KJ method was based on guidelines obtained from the literature, the researcher used the three perspectives of a Technology Roadmap to order a large amount of interview data to a manageable data set.

5.5 Remaining areas of research

As fortified by the data analysis in this study, the literature review resulted in a rich mix of new and relevant information. Not all of the latter has been directly relevant to the research question posed in this study. It is therefore pertinent that scholars and practitioners in future further explore the following:

- The suitability of Technology Roadmaps for different kinds of South African based SMEs (not only manufacturing).
- The use and application of Technology Roadmaps for supply chain management with a focus on logistics control.
- The real-life implementation and application of Technology Roadmaps in manufacturing SMEs with a specific focus on the three key perspectives identified in this study.

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APPENDIX A INTERVIEW GUIDE

Purpose
To obtain information on the manufacturing organisation's strategic decision-making, operations, and resources regarding technology. This is a semi-structured interview-based with open-ended questions. Therefore, it will be more of a discussion on how you get things done.

Objective
To obtain information that will provide context to the research question and the secondary objectives. • What are the needs and requirements for the leadership of the organisation to successfully implement new technologies? • To identify the perceived and actual difficulties and barriers South African manufacturing SMEs face with implementing new technologies and the changes associated with the implementation.

Theme – Organisation Demographics
• Organisation demographics were answered in a self-completing questionnaire sent to the participants before the interview.

Themes to be covered in the interview – commercial and strategic perspectives
I will ask you to expand on technology development in your organisation because I am trying to find a best practice and document it. The questions will mainly focus on strategic aspects that are considered when new technologies are to be implemented. Therefore, this section focuses on the 'purpose' of the organisation.

Would you mind answering the questions as you understand and interpret the question? I will only elaborate on the question if you request so. However, I want to avoid doing this as this can lead to the answers. If it is apparent that the interviewee does not understand the question, rephrase the question or break the question down

- Strategy
    - What tools or methods does your organisation use to analyse the internal and external context in which the organisation operates?
    - How are the insights developed from these analyses used to decide where improvement needs to be made through the implementation of technology?
    - When and for what reasons do you decide not to implement new technology within the organisation?
- What is your organisation's technology development strategy? (documented, formal, informal, how recent or how old?)
- When do you decide to implement new technologies? Who is responsible for the implementation?
- What do you consider your biggest challenges in technology implementation within your organisation?
- If we look at the requirements of the 21st century (before and after Covid-19), what would you think are the biggest challenges, opportunities, and issues to be addressed by technology?
- How do you suggest addressing these challenges, opportunities and issues?
- What technologies does your organisation implement to address the following two points?
    - What does your organisation do to improve profit?
    - What does your organisation do to improve capital utilisation?

Themes to be covered in the interview – Design, development and production perspectives
I will ask you more about your organisation's value offering to the market, that is, what product or service does your organisation offer. The questions mainly focus on operational aspects, such as the systems in place to realise the primary value chain and support activities. • Please explain to me what you consider are the primary value chain activities within your organisation? • What technologies are used in Primary value chain activities: ○ Supply chain (inbound logistics) - Tell me about your supply chain (suppliers and distributors) and their stance towards technology development. ○ Operations – what manufacturing technologies do you employ? Tell me more about your operations management? ○ Distribution – outbound logistics. How are you connected with your distributors and clients? ○ Marketing and sales – Describe the flow of information between marketing/sales and the rest of the organisation? ○ Service – how do you provide support services to your clients? • What technologies are used in Support activities: ○ Procurement ○ Technology and product development ○ Human resource management ○ Firm infrastructure • Performance management ○ How do you evaluate the performance of operations?

- What are the drivers for operations improvement?

Themes to be covered in the interview – resource perspectives

In this section, I will focus my questions:

- Is your IT managed internal or external to the organisation? Elaborate on the responsibilities of the IT function within the organisation.
- *Questions about resources*
  - What is your organisation's view on CAPEX, OPEX and Project Budget? Would your organisation prefer to fund technology implementation through CAPEX, OPEX or Project Budget? Would you mind providing insight?
  - Do you prefer to implement technology internally or get external sub-contractors.?
  - Staff skills and competencies
  - Do you have any partnerships, such as with an academic institution that provides research for technology implementation? What are the technology-related skills you look for with new appointments? How does this rate against other skills you look for in a new appointment?
  - How do you prepare your workforce for technologies implemented?
  - How good is your internet connection, and how important is an internet connection for your organisation? Is any of your operations equipment connected to the internet, and how important is it to your operations?
  - How does load-shedding affect your organisation? How do you manage the risks associated with load-shedding?

APPENDIX B LETTER OF CONSENT

Ethics informed consent form

MBA-STUDY: Exploring digital technology in manufacturing SMEs in South Africa

FIELD OF STUDY: Technology Roadmaps; Industry 4.0; Manufacturing

NORTH-WEST UNIVERSITY, SOUTH AFRICA

RESEARCHER: Marius Cronje

Dear Interviewee

This **Informed Consent Statement** serves to confirm the following information as it relates to the MBA mini-dissertation on exploring digital technology in manufacturing SMEs in South Africa.

1. The sole purpose of this study is to obtain information from experts (such as yourself) employed and/or operating in the manufacturing industry in an attempt to determine the nature of your everyday experience related to the research topic.

2. The procedure to be followed is a mixture between qualitative and quantitative research design, which includes structured, controlled and prescriptive questions but also open-ended questions where you will have the opportunity to communicate your views on the relevant topic during a virtual face-to-face interview. Basic background information related will be asked e.g. your name, academic qualifications and related experience to the topic.

3. The duration of the interview will take no longer than a maximum of 1.5 hours.

4. If at any point during the interview you should feel uncomfortable, you will be provided with the opportunity to make your discomfort known or immediately have the option to end your participation.

5. This interview takes place on a voluntary basis.

6. The confidentiality of the interview data is guaranteed. Fictitious names will be utilised when quoting statements in the dissertation.

7. Any confidential information that prohibits the researcher to publish it in the final dissertation should be communicated during the interview.

8. A list of questions to be asked in the interview will be made available to the interviewee prior to the interview. This is done to ensure a mutual understanding of what will be asked to avoid confusion during the interview.

9. A summarised copy of the final dissertation will be made available to the interviewee upon request.

10. The data gathered from the interview will only be used for research purposes.

I, ______________________ (name and surname), hereby declare that I have read and understand the contents of the Informed Consent Statement, and give my full consent to progress with the interview on _______________ (date) and use the information communicated by myself to him in his MBA dissertation.

Name and designation	**Signature**	**Date**
Interviewee		

APPENDIX C SELF-COMPLETING QUESTIONNAIRE

Exploring digital technology in manufacturing SMEs in South Africa

The scheduled interview will take an open discussion to obtain your viewpoint on the use of technology within your company.

This form, however, collects information about your company and will be used to characterise the population of companies interviewed broadly.

Name and Family Name

Contact Email

Company Name

Within which industries sector do your company operate? Multiple answers are allowed.

- Aerospace & Defense
- Agriculture & Aquaculture
- Automotive
- Chemicals
- Electronic and digital equipment manufacturing
- Food and beverage processing
- Logistics
- Machinery & Equipment
- Oil & Gas related
- Pharmaceuticals
- Renewable Energy
- Manufacturing related industries
- Other

How long has your company been in operation?

- Less than 5 years
- Between 5 and 10 years
- Between 10 to 20 years
- More than 20 years

What type of manufacturing processes are used in your company? Multiple answers are allowed.

- Repetitive manufacturing
- Discrete manufacturing
- Job shop manufacturing (batch size <10)
- Job shop manufacturing (batch size >10)
- Process manufacturing (batch)
- Process manufacturing (continuous)
- Product development and engineering design
- Other

How many people are employed at your company?

- Less than 10 people
- Between 10 and 50 people
- Between 50 and 250 people
- More than 250 people

How much is your company's total turnover a year?

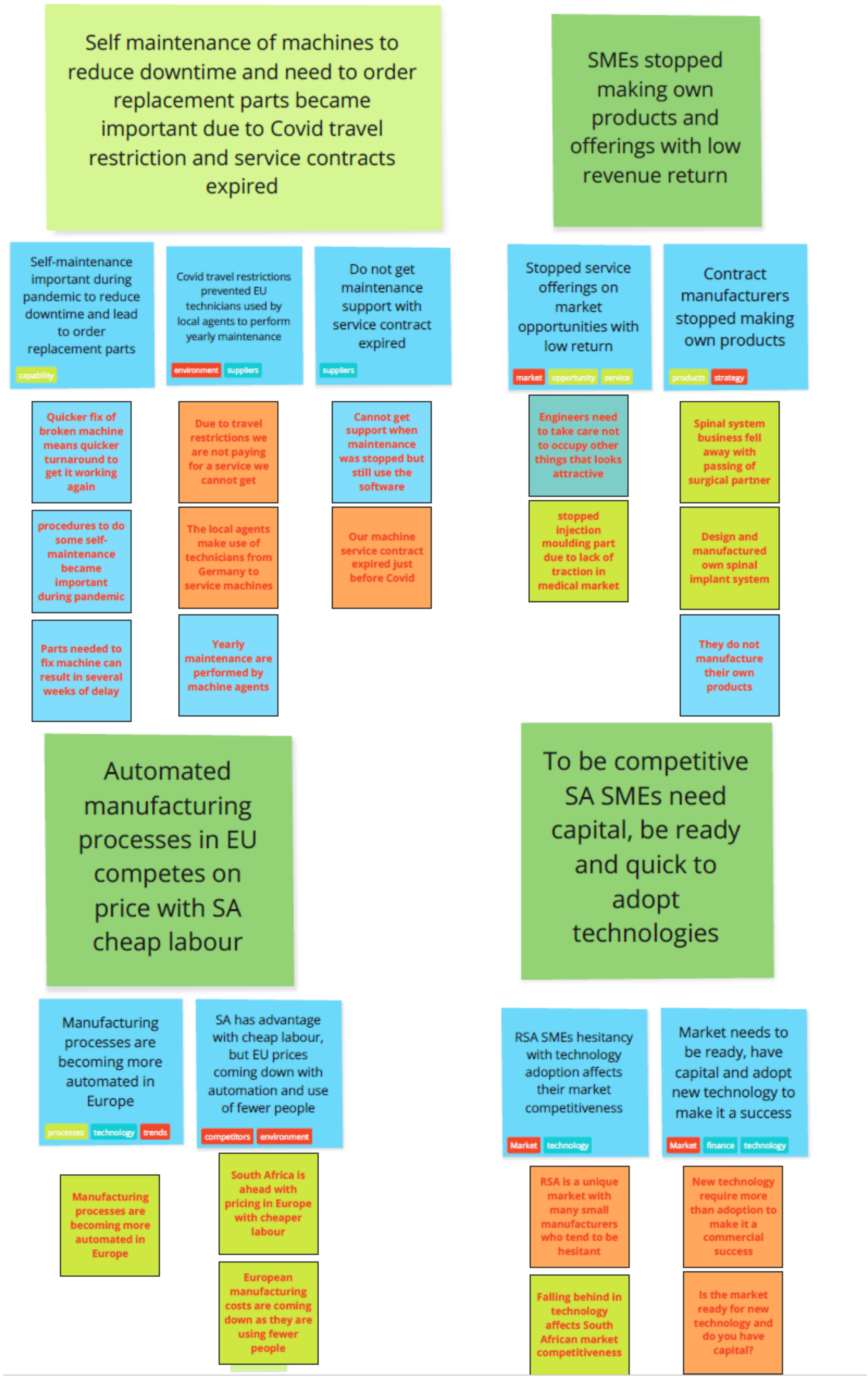
- Less than R10 million
- Between R10 million and R50 million

- Between R50 million and R170 million

- More than R170 million

The questionnaire is completed. Thank you very much for your patience and valuable feedback.

APPENDIX D QUALITATIVE ANALYSIS DATA (KJ METHOD)



SMEs prefer traditional communication methods such as emails and phone calls, but Covid has created the demand for digital communication platform to contact customers, suppliers and internal meetings

SMEs use traditional communication such as emails and phones
customer | suppliers

- email communication with suppliers and customers
- Communication with suppliers are via email and telephone
- communications are mainly through email and telephone

although available before, Covid created demand for stable digital communication platform & need to hold effective meetings
technology

- Digital communication was available but jumped years ahead with Covid outbreak
- Videoconferencing technologies created new opportunities to involve more people, more effectively in meetings
- Teams chosen over Zoom as it proofed a stable communication platform during the pandemic

SMEs competitive with high number of low volume orders and partnering with other SMEs

Company created to compete with larger, international projects not performing as expected
competitors | performance

- Created a separate company to ease the management of larger projects
- The idea was to target large international orders with a complete package
- The company is not performing as expected and might dissolve it

SMEs compete globally
competitors

- Sell Flownex globally through agents with strong markets in US, EU and Far East
- Compete internationally
- Each country has unique challenges with contracts and payments that needs to be kept in mind

Local SMEs compete with China on price with higher number of lower volume orders
competitors

- The length of time to make a unit is reflected in the volume of 10 units a year
- Higher number of parts are ordered with low volumes
- with the smaller volumes they can match China with price and localise manufacturing

COTS do not what SME wants and technology sales people do not address voiced requirements

Technology sales people do not address voiced requirements
requirements | technology

- Sales people of 1st COTS software did not address voiced requirements

COTS project management software can not do exactly what SME wants
technology

- Jira project manage does not do exactly what he wants

Government support to procure expensive advance software, but could not pay high annual maintenance

Government support to procure expensive advance software, but could not pay high annual maintenance
environment | finance

- TLIU funded a powerful simulation software (Vericut) for CNC machining
- The annual maintance for Vericut is about R300k and requires a powerful computer to run

SMEs need become more locally and internationally competitive as Covid challenges will not dissipate soon

Covid gave them client who had supply issues with Chinese manufacturer

opportunity suppliers competitors customer

Covid gave them a big client who normally ordered from China

client had issues with imports and could not get reliable supply chain

Covid challenges with business shut down & slow down will not dissipate soon

business environment

Covid had lead to slow down in business

They were closed during lockdown and could not produce or sell anything

The challenges brought on by Covid will not go away soon

Stopped 9 years of developing own business management system, but took couple of consultations to find the right COTS software

stopped 9 year on self development business management system which could not address requirements

RandD requirements systems

Spent 9 years to internally develop complete business management system

Stopped development of business management system

family member developed software did not address requirements

The 1st COTS software could not implement the original plan as promised by sales people

suppliers technology

1st COTS software could not do what sales people promised

Will implement original plan on COTS software

2nd COTS software has better chance of success as more people invested in decision

technology organisation systems

with 2nd COTS software better chance of success

input from and demo to more people with 2nd COTS software

Not sure if government should help manufacturing sector

Not sure if government should help manufacturing sector

environment

No manufacturing sector support from government, but not sure if they should help

Manufacturing sector is not getting needed government support with advanced technology

Manufacturing sector is not getting needed government support with advanced technology

environment technology

New technology that can be a game changer for South Africa

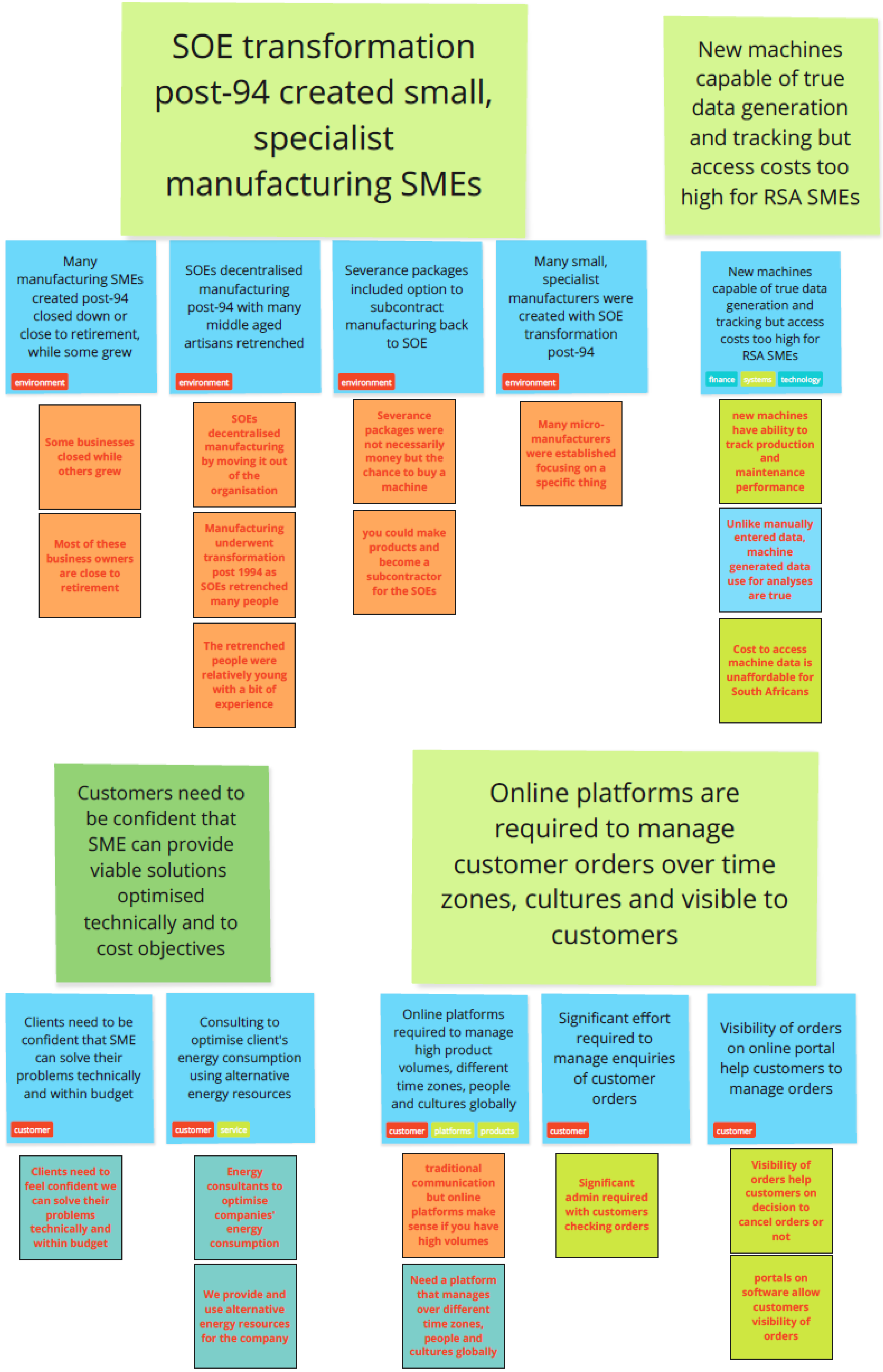
Highly advanced technology require government support even you can pay for it

Digital technologies are more tailored for white collar jobs than manufacturing sector

Digital technologies are more tailored for white collar jobs than manufacturing sector

technology

Digital technologies had moved more into white collar jobs and services



SOE transformation post-94 created small, specialist manufacturing SMEs
Many manufacturing SMEs created post-94 closed down or close to retirement, while some grew
environment
Some businesses closed while others grew
Most of these business owners are close to retirement
SOEs decentralised manufacturing post-94 with many middle aged artisans retrenched
environment
SOEs decentralised manufacturing by moving it out of the organisation
Manufacturing underwent transformation post 1994 as SOEs retrenched many people
The retrenched people were relatively young with a bit of experience
Severance packages included option to subcontract manufacturing back to SOE
environment
Severance packages were not necessarily money but the chance to buy a machine
you could make products and become a subcontractor for the SOEs
Many small, specialist manufacturers were created with SOE transformation post-94
environment
Many micro-manufacturers were established focusing on a specific thing
New machines capable of true data generation and tracking but access costs too high for RSA SMEs
New machines capable of true data generation and tracking but access costs too high for RSA SMEs
finance
systems
technology
new machines have ability to track production and maintenance performance
Unlike manually entered data, machine generated data use for analyses are true
Cost to access machine data is unaffordable for South Africans
Customers need to be confident that SME can provide viable solutions optimised technically and to cost objectives
Clients need to be confident that SME can solve their problems technically and within budget
customer
Clients need to feel confident we can solve their problems technically and within budget
Consulting to optimise client's energy consumption using alternative energy resources
customer
service
Energy consultants to optimise companies' energy consumption
We provide and use alternative energy resources for the company
Online platforms are required to manage customer orders over time zones, cultures and visible to customers
Online platforms required to manage high product volumes, different time zones, people and cultures globally
customer
platforms
products
traditional communication but online platforms make sense if you have high volumes
Need a platform that manages over different time zones, people and cultures globally
Significant effort required to manage enquiries of customer orders
customer
Significant admin required with customers checking orders
Visibility of orders on online portal help customers to manage orders
customer
Visibility of orders help customers on decision to cancel orders or not
portals on software allow customers visibility of orders

SA SMEs tend to develop own technology for specific applications while digital product technologies are easily available in developed countries

SME & client developed tech to automate machining process between them and extend tech to other subcontractors

RandD | customer | partnerships

- Helped with developed but it was not 100% as envisioned
- Developed with Aerosud an application to convert machining programs between them
- Aerosud is working with other suppliers to replicate the success with reduction in lead times
- Aerosud works according to the Theory of Constraints which is about continuous flow of work

digital product technologies are developed and easily available in developed countries

environment | technology

- These types of software are developed and easily available in USA

Have a few internally developed technologies such as heat pumps, Flownex, deep mine cooling units

RandD | technology

- Have a few internally developed technologies such as heat pumps, Flownex, deep mine cooling

Metal shortage caused project delays, cost penalties, higher stock levels and delays with other components

A shortage in various metals during Covid, leading to project delays, cost penalties & knock-on effect with other components

risk

- Project delays due to material shortage can lead to cost penalties
- There has been a shortage in supply of tool steel, stainless steel and aluminium
- There are cost and lead time implications if you order material from abroad
- Manufacturers of bolts and nuts struggle with supply due to steel shortages

Material shortage due to Covid caused project delays and required higher levels of stock kept

environment | risk

- They need to keep higher levels of stock and spare parts for when orders come in
- Had a significant delay with a refurbishment with a Koeberg project due to material shortage

manufacturing-as-a-service business model requires strategic planning & implementation to achieve

manufacturing-as-a-service business model requires strategic planning & implementation to achieve

business | service | strategy

- there were a few steps to reach the vision of a manufacturing-as-a-service business model

SMEs that do not follow theoretical models struggle to find solutions to their business and technology challenges

Do not know what the solutions are or how to address business and technology challenges

technology | business | challenges

- Do not know what the solutions are or how to address these challenges

SME acting differently do not follow theoretical models

business

- company is different as they do not follow the theoretical models

With Subtractive manufacturing, product engineering is responsibility of client while SME do process design, jigs and fixtures

Subtractive manufacturing make parts according to client's design requirements

service customer requirements

They manufacture parts according to the design provided by the clients

Clients require reverse engineering of existing designs, but do not like design changes made

customer service

Clients do not like if you just make changes to their designs

Have clients sometimes require reverse engineering of existing designs

Engineering is client's responsibilities, but use engineers for process design, jigs & fixtures

capability customer

Have an engineering office responsible for process design, and design of jigs & fixtures

Stopped engineering design as part of their service

design and engineering is the responsibility of the clients

AM have far less material loss than subtractive machining and CNC require process design not just software that automates or simulate machining

AM have far less material loss than subtractive machining during manufacturing process

processes technology

A lot of material loss with subtractive manufacturing with less than 10% of billet used

AM uses less material with about 1% material loss

CNC machining requires process design, not just software that automates or simulate machining

processes technology

different to CAM, the Vericut simulates crashes and optimise tool path

CAM is used to automate the machining on your CNC machine

Even 5-axis machining requires process design, not just NC programming

Initial high cost of technology implementation is a necessary shock for SMEs and they can become dependent on technology specialists

Initial high cost of technology implementation is a shock for SMEs but necessary

finance technology

the initial setup costs is a shock for SMEs but is necessary

SMEs cannot afford large initial costs to implement technology and become dependent on tech specialists

finance suppliers technology

You become dependent on technology specialists if you do not implement your self

Small businesses cannot afford to pay large supplier to implement comprehensive technology solutions

1x SME targeted industries with machining of non-FE metals that are hard, lightweight and non-corrosive

Have a niche in South Africa in machining of Ti and exotic materials

capability

One of few RSA companies that can machine Ti and exotic materials

focus on non-Fe metals that are hard, lightweight and non-corrosive

service

have not really looked at ceramics as they have found other materials instead

focused on non-Fe metals that are hard, lightweight and non-corrosive

Political uncertainty & steel production shutdown increased prices and OOS situations

OOS steel vendors charging high prices due to political & material uncertainty as stock become available
environment | suppliers

- political uncertainty leads to vendors not keep high levels of steel stock
- Stock out of steel meant that supplies were bought as soon as it was available
- Vendors are asking exuberated prices due to material supply uncertainty

Knock-on effects placed South Africa in bad situation with steel as industry could not catch up due to steel shortage
environment | industry

- The construction industry tried to catch up but could not as there was no steel
- South African manufacturers is currently in a bad situation regarding supply of steel
- Covid is a Force Majeure situation, but the knock-on effects are not proven force majeure situtations

Import of steel made difficult by processing at harbours and import duties
environment

- import protection of steel makes it difficult to import steel
- Harbours did not make effort to bring materials into the country

Mittal created steel supply shortage and uncertainty with slow start-up of production after covid shutdown
suppliers

- The Covid pandemic became an excuse for the AcelortMittal stopping production
- had issues with steel supply due to shortages caused by problems at Mittal
- By keeping vendors in the dark about eventual start-up of production, AcelorMittal created a shortage in steel supply
- Mittal was afraid demand will remain low and could not match demand after lockdown was relaxed

Subscription license option for own service will only make sense with high sales volume

Subscription license option for own service will only make sense with high sales volume
service

- Own software is still perpetual licenses due to the small market
- Subscription will only be profitable for the software if they have higher numbers

Strategic planning for SMEs easier to implement, more informal and adaptable compared to large companies

SME strategic planning easier, more informal and few people compared to larger businesses
strategy

- Strategic planning as a small business is easier than for a large coorporation due to number of people involved
- Strategic planning is based around informal discussions

Strategies will evolve as confidence grows and optimised with waste elimination
strategy

- The strategy is initially clumsy but will generate confidence when successes are achieved
- with strategy implementation you identify wastage and opimise the strategy

Took 4 years to acquire machines to implement strategy to provide unique AM capability for various materials used in various industries

took 4 years to acquire machines to implement strategy to provide unique offering
capability | strategy

- at start of covid commissioned last machine of initial 4 year plan to provide unique offering

Added separate AM machine for Ti capability for both medical and non-medical parts
capability | technology

- Added separate AM machine for Ti medical and non-medical parts

advanced CRM is indispensable for high value products sold internationally while low volume products for local market can be managed manually

Need a simpler CRM to manage for distribution of local heat pump BU (customer, systems)

- Residential heat pumps use CRM Bluwave for South African distribution networks
- looking to use a cheaper CRM package, not so powerful but has ticketing system
- Residential heat pumps are sold in higher volumes (>1000)

High cost CRM software is indispensable for high value business (technology, business, customer)

- the software BU uses an Indispensable CRM which is worth its high price tag

Benefit of company wide roll out of advanced CRM did not justify the costs (customer, technology)

- Benefit of company wide roll out of SalesForce did not justify the costs

CRM of low volume products can be managed manually (products, systems)

- Can use paper based CRM systems at other BUs with low number of clients
- The low volumes allow us to use simple but good systems on Excel
- low number of special projects using own heat pumps are easy to manage on manual systems

SME think market will respond well to locally produced CNC machine, even if inferior

SME think market will respond well to locally produced CNC machine, even if inferior (capability, market)

- Local wood machine manufacturer is looking into making CNC machines for metals
- Think market will respond well to local CNC machine even if inferior

Risk for SA SMEs to invest in capital assets if orders are short, uncertain and do not yield large return

Risk for SA business to invest in machines to achieve assets target that matches uncertain orders (business, risk)

- Am nervous as a RSA business owner to procure expensive machines
- Reached our assets targets with IDC funds

New technology is risky with short term orders and will not always yield large ROI (risk, technology)

- Short term orders make technology implementation risky
- A new technology mindset has a premium that will not always give you larger ROI

SMEs explore payment options with suppliers or partner with customer to purchase a machine

SMEs explore payment options with suppliers (finance, suppliers)

- Explore payment options with suppliers

some customers will partner with you in purchasing a machine (partnerships, capability, customer, finance)

- some customers will partner with you in purchasing a machine

The ERP capabilities need to match the initial data population, process of the SME, which means that some SMEs do not need an ERP, MES or PLM system

The ERP capabilities need to match the level of information, primary and support activities of manufacturing processes
processes | systems

- The ERP manages all the information important to their support activities, such as procurement
- Companies are turning to ERP and MRP systems to track manufacturing processes
- Use Infor Visual which is smaller version of bigger ERP

it is a challenge to transfer initial population and processes of manual systems to ERP
technology | processes | systems

- It was a challenge to move from paperbased system to ERP in 2011
- The software need to fit close to their own systems till initial population of systems is implemented

Some SMEs do not need the use software for ERP, MES, procurement, sales or PLM
systems

- Do not use software for ERP, MRP, MES, procurement or sales
- Data management of deep mine cooling units are straight forward

Cost of R&D for product and technology development are high, difficult to determine and for high commercial risk

Costing of AM is made difficult by indirect costs of technology development
RandD | finance | technology

- Costing of AM is made difficult by indirect costs of technology development

Stopped R&D on medical devices as costs did not justify the high commercial risks
RandD | service

- stopped the R&D on medical devices
- Expectations from medical R&D were too much
- Surgeons with ideas expected large share with little
- R&D costs are skewed relative the high commercial risks involved

Risk that market or client will not be there with completion of technology implementation project

Financial problems at large SA parastatal caused big loss of income
environment

- Lost a big source of income due to Denel's problems

there is risk that market will not be there with completion of technology implementation or project
Market | risk | technology

- Took the risk by completing products for when market opens
- need to be sure business is still there between placing machine order and machine delivery

Had good communication with SOE for AM of aluminium
customer | products

- Had good communications with Denel for aluminium

Costs hidden by suppliers negatively impact cashflow management and evaluation of capital investment critical to SMEs

Cashflow management is critical for SME while stringent capital is used for value creating investments
finance

- cashflow management is critical while you maintain capital for things that will make you money
- Operating budgets tend to have less strings attached than capital budgets

Suppliers do not tell you the hidden costs which makes operations very expensive
finance | suppliers

- EOS has a few hidden costs which make operations very expensive if do not plan for it
- There are hidden costs in the details that the machine suppliers do not tell you

SA SMEs need to collaborate and innovate as no-one has enough cash to survive Covid

No company has enough money in the bank to see through during Covid

finance

No company has enough money in the bank to see through during Covid

Dynamic innovation & collaboration will put SA SMEs that survive Covid in stronger position

environment opportunity

Covid forced South Africa to think more dynamically and innovative

You will be in a stronger position if your company can survive the effects of Covid

people should rather work together than compete and nobody gets the work

SME collaborated on the development local connection platforms, but COTS platforms are available e.g. real time quoting integrated of design and manufacturing method integrated with CAD

Participating in development of local automatic platforms, but online platform is available for production cycle visibility

RandD platforms

Participating in the development of platform with automatic quoting, but not priority

Online platforms are available with quoting and production cycle visibility

Xometry integrated with CAD allows for real time quoting of design and manufacturing method

features service

Xometry is a real time quoting software based on your desig and manufacturing method

the aim is to get the design as cheap as possible or within budget before ordering through 1-click

Xometry is integrated with your CAD and show you cost as you change the design

maintaining relationships and collaboration between SMEs are important while bad relationship with technology provider can make SME look for technology alternatives

Important for SMEs to maintain relationships

partnerships

We try to maintain relationships

Collaborate with other manufacturing SMEs who specialises on certain production activities

partnerships

Subcontract and work with other manufacturers who are experts on different aspects of machining

Teamed up on a number of projects with company focusing on fabrication

There is not a good relationship with CAD provider but rely on them for necessary support

partnerships suppliers

There is not a good relationship with CAD provider but rely on them for necessary upgrades

It is easier for SMEs to work with one type machine controller, standardised technology than with a mix of technologies

Manufacturing SMEs prefer to have one type of machine control rather than current mix of controls

technology

Will choose only one machine control from one brand if possible to start over

Like most companies, have mix of controls used on the CNC machines

It is easier to work with standardised technology or vendor with large portfolio than mix of technology

technology

Still looking for a software suite that can utilise the benefits of AM

It is easier to work on standardised technology than with a mix of different software

Rather look at COTS online platforms for integration of live shared capacity, project management and work distribution than to try and develop it on your own

- Looking at online platforms for integration of live shared capacity, project management and work distribution (platforms)
  - wanted to look at live shared capacity platform to see where capacity was available amongst suppliers
  - Create a project management platform where work was distributed
  - Xometry has many suppliers connected to their platform
- Connection shared capacity platforms are available, cannot develop one on your own (platforms)
  - Could not develop a shared capacity program if everybody tried it themselves

Older SA machines falling behind better maintained EU machines with short distribution and service channels

- SA falling behind with better maintained EU based machines due to shorter distribution and service channels (suppliers)
  - South Africa is falling behind Europe on machine maintenance
  - Better maintained European machines leads to fewer breakdowns
  - Machine suppliers based in Europe of shorter distribution and service channels
- South African machinery are significantly older than European machinery (facilities)
  - South African machinery are significantly older than European machinery

SMEs use various standalone software but as they expand looking at vendors with larger portfolios and needed capabilities

- As SME expand, they are looking at software vendors with larger portfolios (suppliers, technology)
  - With their expansion they are looking at software vendors with larger portfolios
- Advanced design software have needed capabilities but is very expensive (capability, finance, technology)
  - Materialise are strong on lattice and medical designs but are expensive packages
  - Currently looking at Materialise from the Magics suite of software
- SMEs are using various stand alone CAE software (technology)
  - Currently using stand alone products from various software vendors
  - Use various CAx tools for design, machining and lasercutting

SMEs need to keep an open mind as technology is not industry bound and requirements are determined by both suppliers and customers

- Technology requirements is determined by both suppliers and customers (suppliers, technology, customer, requirements)
  - Some technology requirements are determined by suppliers
  - reactive technology approach aligned with customer needs and requirements
- keep an open mind with market needs as technology is not industry bound (Market, industry, technology)
  - Keep an open mind to what market and customer bring them
  - AM technology is not bound to a certain industry or market sector

SA SMEs pay more for machine shipping, volatile currency and have longer technology cycles than EU counterparts

South Africa struggle to compete with Europe with short technology cycles, currency and distance to market

[technology] [Market] [competitors]

- South Africa struggle to compete with price against faster and shorter technology cycles in Europe
- There is very little manufacturing in RSA due to many exports
- South Africa's location relative to Europe is a challenge
- volatile currency exchange makes procurement and shipping of machinery a challenge

EU manufacturers pay less for shipping of machines

[finance] [suppliers]

- Cost of machines in Europe feels less due to lower shipping costs

Open source technology takes effort to implement but versatile to fit SMEs needs

Open source technology takes effort to implement but versatile to fit SMEs needs

[technology]

- Different communication protocols was an issue in the beginning with IoT
- Technology like MTconnect that requires a DIY approach requires time
- It takes time to figure out connection of devices to electrical wiring and signals
- Open source technology does not limit you to certain software
- through Access and SQL server can create own dashboards where software do not generate reports

An AM workshop requires less infrastructure than conventional workshop, but need people physically able to lift containers with heavy metal powder

Unlike polymer AM, Metal AM requires people with the physical strength to lift heavy goods

[skills]

- Unlike polymer AM, Metal AM requires people with the physical strength to lift heavy goods

An AM workshop requires significantly less infrastructure than traditional jobshop

[facilities] [infrastructure]

- We require significantly less infrastructure than a jobshop

Operation data can be recorded manually of automatically into ERP to allow for supply orders, materials for each job, quoting and note invoicing

ERP software allows for automation or supply orders, material for each job, quoting & note invoicing

suppliers | systems

- Software allows for automated ordering with suppliers
- Use a jobcard systems linked with materials for each job
- A scanned quoting system with delivery note invoicing

Operation data is recorded manually or automatically into ERP

processes | technology

- Data fed manually into ERP, not yet integrated with ERP
- Operations are recorded and analysed on ERP/MRP for accurate quoting

Lack of technology knowledge, capabilities and how it addresses needs is barrier to market entry for customers

Lack of knowledge and shortcomings is barrier to market entry for new technology offerings

Market | knowledge | technology

- An uninformed market view AM technology as low level applications
- People are unaware of the software which makes it a barrier to market entry
- Ti AM shortcomings do not currently work for their market

Clients need to be educated on how new technology capabilities are perceived and suit their needs

technology | capability | customer

- Clients need to be educated on new technology to ensure they know what they want
- People think of AM as 3DP of plastic toys

using IoT sensors for real time tracking and monitoring of machine data to analyse to identify issues and improve capital utilisation

Analysis of machine data can identify issues and improve capital utilisation

performance | technology

- The data does not provide solutions but identify issues like personnel needing more training
- Access to all machine data improves machine utilisation in EU

Signals from sensors provide data for operation management and analysis

performance | technology

- can perform analysis on the alarms triggered
- Get signals from storeroom when buffer stock levels drop

Real time tracking & monitoring of production and maintenance performance

performance | technology

- Tracking machine parameters for production and maintenance performance
- Real-time job and productivity monitoring can be displayed on dashboards

SME chooses when to connect digital enabled machines for remote service and software updates

Digital connected machines can be diagnosed remotely but still need a person present to provide feedback and perform tasks

suppliers | technology

- We still need to be present and give feedback when diagnostics run on the machine
- Most machine issues are digital which can be diagnosed and solved remotely

SME chooses when to connect internet enabled machines

facilities | technology

- We choose when to connect our machines to the internet

SMEs rely on UPS to keep ICT functions going to perform essential admin and value adding activities they plan around loadshedding

SMEs plan around loadshedding with admin or other value added activities (organisation)

- Can plan their admin workload if they know load shedding schedule in advance
- Team planned value adding activities during load shedding
- We plan around loadshedding

UPS are used to keep essential ICT functions operating during loadshedding (facilities)

- the UPS keep the essential IT functions operating during load shedding
- Computers and telephones keeping running during loadshedding to catch up on admin

Evaluate one-off and operating cost vs. benefit, as well as wasteful unutilised features when looking at new technologies

Look at financing, cost and benefit when looking at new technology (finance, technology)

- First question: do you have finance to develop the technology
- When they need something, they look at cost vs benefit

Initial technology implementation is challenging but outweighs effort to do it manually (challenges, technology)

- Software become more usable to the point where the benefit outweighs the effort to do it manually
- The implementation of PDM has challenges but gets easier with use
- This coversion program meant that they could start machining without the need for simulation first

Consider the value of upgrades as unutilised technology features are a waste of money (features, finance, technology)

- They did not use all the available features and could not get value out of the upgrades
- Features of technology that are not utilised are a waste of money

Cost control becomes more difficult when costs are already under control and economic viability of new machines are actually similar

One-off and operational costs for additional performance make economic viability of machines silimar (finance, performance)

- You need to pay extra to get the full performance from EOS machine
- Quotations may differ but the whole economic viability of machines are like-for-like
- the introduction of new technology are challenged with many once-off costs

Cost reduction becomes more difficult if you already have costs under control (performance)

- It is difficult to cut costs when you already have cost under control

Value adding technology needs to be at the right price and ensure good revenue stream

Ensure technology will add value for client and mitigate risk with good revenue stream (customer, risk, technology)

- Ensure this is right technology for client to manage risk with good revenue stream
- Start with a specific area where your technology can add value

need to know the value of technology for client as overpriced technology can put them off (technology, customer, products)

- Expensive quotes on something not suited can put clients off the technology
- Need to know the worth of the value added to determine cost of service

SMEs consider various types of loans to fund projects and associated liabilities while paying machines with cash reduces risk during times of reduced revenue

SMEs carefully consider various types of loans to fund projects as loans can become liability (finance, risk)

- Will look at IDC and VC for more funding, depending on the project
- Loans can become a liability when income is low
- Convert IDC loans to bank loans as IDC are impossible to work with

Paying machine with cash is 1st option as it reduces risk during times of reduced revenue (finance, risk)

- Paying cash is 1st option but recently also looking at capital financing
- Machines paid with cash helped them to survive through difficult times

Technologies need to be financially justified in terms of cost reduction, capital payback and strategically integrate with business

Revenue improvement, cost reduction and capital payback financial drivers with technology implementation (drivers, technology)

- biggest financial driver is revenue improvement by increasing throughput
- The implementation of technology is driver by a combination of revenue generation and cost reduction
- Focusing now on paying back capital rather than on expansion

The cost of digital platforms needs to be justified & form integral part of business (business, platforms)

- the cost of online platforms are close to that of a sales person salary
- Need to justify the cost vs. benefits of these platforms
- Digital platforms are integral to their business

While working together in offices are still preferred, engineers adopted easily to working remotely while support staff with family responsibilities found working from home more challenging

Engineers adopted easily to working remotely during Covid (organisation)

- Changed to working from home with ease, especially the engineering team
- Remote working allowed for the appointment of an retired design engineer based in PTA

Remote working was challenge for support staff with family commitments (organisation)

- Remote working was a challenge for those not having the discipline, like support services
- People with family commitment struggled to provide timely service remotely

Offices and working together is still advantageous for employee relations (facilities, organisation)

- Offices and working together is still advantageous for employee relations

Technology partners are necessary to get the technology to a critical mass and get the most out of it

Need a technology partner to get the software to a critical mass to reach its potential (partnerships, technology)

- Need a third party to get the software to a critical mass to reach its potential

Partnered with CSIR to get most out of technology acquired (partnerships, technology)

- partnered with the CSIR to get more out the technology they have on the floor
- CSIR/AISI helped with to better implement MTconnect

SME success if built on quality service and long-term relationship with both suppliers and customers

SMEs are built on long-term relationships with suppliers and customers
suppliers · customer · partnerships

- build long-term partnerships relations with customers
- they gain and retain loyal customers
- Our business is build on personal relationship

Customer referrals of success and quality service important marketing tools
customer · service

- in the past, marketing relied on customer referrals of quality service
- Make use of customer references to show our success record

Purchase of laser cutter was strategic decision to save on effort associated with admin and engineering

Purchase of laser cutting was a strategic decision to save on associated admin and engineering effort
capability · strategy

- The opportunity with laser cutter purchase lied in the saving of associated admin and engineering effort
- Laser cutter is strategic decision to reduce outsourcing cycle, not a typical reason.
- The cost of laser cutting is affected by volume which is not part of their core production

Laser-cutting has additional cost of ownership that makes it more expensive than outsourcing
capability · strategy

- It is more expensive to do cutting inhouse than to outsource
- The purchase of laser cutter has additional cost of ownership that needs considered

AM provide unique offering with complete value chain service to multiple industries

Offer complete value chain service for AM from concept design to tooling for manufacturing
service

- We are setup to provide the complete AM value chain service in-house
- from client idea to conceptualise to tooling for manufacturing

Additive manufacturer also do generative design and topology optimisation
service

- We do generative design and topology optimisation on clients' designs

Initially focused on industrial design and die casting products but expanded to medical
service

- Decided to focus initially on tool steel for high pressure die casting
- Initially setup to do industrial design with expansion into medical design

OEM force manufacturers to find backup with same capabilities to mitigate risk

OEM force manufacturers to find backup with same capabilities to mitigate risk
capability · risk

- Airbus forced Aerosud to find a backup manufacturer as mitigating risk measure
- Aerosud is a client who does there own manufacturing using 5-axis CNC machines like them

SMEs found commercial success in developing over time a unique offering within a niche market

SMEs with different origins that developed within a small market niche over 20 years or more
Market

- Their monopoly in quick porridge market started small when they saw a gap in the market
- Flownex was developed over past 25 years and have little market competition
- Started as family business in 1996 with Medical
- 20 year old engineering company

SMEs found success focusing on specific activity within value chain of narrow niche of market
Market

- Kept consultancy within narrow niche to avoid working in too many industries
- Consulting niche have best traction in gold mining and concentrator industries
- PostProcess uses CNC and heat treatments processes to service AM industry
- Only African Manufacturer of niche food and feed extrusion equipment
- Some companies focus on only one activity of the AM value chain
- Most players in AM wants to focus on the printing aspect only

Put everything into a world class niche service to get good margins
products

- Create good margins on this niche product as they are only in the world to make it
- Is very good in a niche and throw everything behind it

Engineering company (alternative unit of analysis) with no manufacturing capability have various BUs each focused with unique offerings in niche market

Engineering company have little manufacturing capability and no machining
capability

- Have very little manufacturing capability and no subtractive machining

Diversified technology company divided in BUs with own management and focus
technology

- Consultation BU consists out of 3 legs
- Diversified technology company with 6 BUs managed separately
- 2nd consultancy leg looks at continuous improvement of continuous processes
- Flownex is commercial success making largest part of business
- Heat Pump BU is split between special projects and residential units

SME prefers subscription to scale use as required and updates are included, while with Microsoft Office they had no choice

Have no choice with Office and similar software to go cloud based
technology

- With Office 365 they did not have a choice but to go with subscription
- Office and similar software are all on the cloud
- Used the previous perpetual Office licenses till we could not

SME prefers subscription to scale use as required and updates are included
capability suppliers

- Subscription based services allows you to use and stop the software as needed
- prefer subscription based services for an SME as software is updated

Packaged a self-developed software as part of an engineering service which customer will understand better than the software alone

Packaged the software as part of an engineering service people understand

service

- Packaged the software as part of an engineering service people understand

Need to back unknown software brand name with professional service

service

- There is no brand name to back the software, need to back it with our experience

SME developed good software product, but the market does not yet understand it

market products technology

- The software can do a lot of things but there are not enough resources to support all applications
- Developed a different set of software that works brilliantly
- This software is new to the market, making it challenging for people to know and understand the software

Capability and capacity to design and manufacture product for challenging African environment gave SME competitive advantage in international market

Focus on design of controls systems for challenging African requirements give them competitive advantage

products requirements

- The control systems are designed for ease of use by operator
- Products are designed to the challenges of the African requirements
- Their focus on the design of the control systems gave them a competitive advantage

SMEs created in-house capability & capacity to develop world class products for the challenging African environment

environment products capability challenges

- Developed own software, Flownex, for thermo-hydraulic system designs
- Best in world control systems due to African market exposure
- Product development is done in-house
- Department making cooling units to work in harsh environment of deep mines
- Developed capacity and capability for that niche and can now ask a premium

SMEs held for too long on obsolete strategy and need to have optimistic view to be 5 years ahead with new technology

Recently revamped strategy long based on obsolete product

products strategy

- changed vision and mission statements
- company vision was long based on own spinal system product
- Company revamp in the last 18 months

Strategy is based on optimistic view to be 5 years ahead with new technology

strategy technology

- with an optimistic view they want to be 5 years ahead with new technology

Unscheduled power cuts can be due to unannounced municipal work to power lines

Power outages can be due to unscheduled municipal work

challenges environment

- There are regular power outages due to loadshedding and municipal work

Direct understanding of market needs and exposure to challenging local conditions gave competitive advantage over international competitors

Developed good understanding of market needs with direct, hands-on market research
Market | research

- Developed a link with external market through conferences and training
- A hands-on approach to market research allows them to make educated guesses where the market is heading
- Developed good understanding of market needs and requirements

Unlike international competitors, exposure to the local market led to development of products for local challenges
competitors | Market | challenges

- About 80% of equipment sold to African market
- Their African footprint give them good understanding of the African market challenges
- Competitor products are designed for highly qualified and skilled users

Lead times are std machines are significant shorter and require less setup effort than advanced machines

Lead times are std machines are significant shorter and require less setup effort than advanced machines
suppliers

- Lead times on the order of standard machines are short and not a risk factor
- Sophisticated machines have longer lead teams and larger capital requirements
- Took 5 years with remote support to get new, advanced CNC setup properly

No AM supply issues as materials are air freighted and have short lead time

AM materials are airfreighted, short lead time and not affected by Covid material shortage issues
suppliers

- Material is shipped by airfreight only, which results in short lead times for materials

No issues with AM material supply during Covid, but need to be aware of admin restrictions
suppliers

- Need to be aware of the administrative restrictions with the use of certain materials
- Had not material supply issues during Covid as it was readily available

While electricity prices are increasing, unscheduled power cuts and loadshedding has negative impact on productive and can damage machines and tooling.

Power cut out can cause significant damage to CNC machines and work pieces
environment | risk

- Direct electricity cut out can cause extremely expensive machine and tooling damage

Covid and loadshedding causes drop in productivity
environment | performance

- Worst case scenario is that your company need to close due to outbreak of Covid amongst your workforce
- Send everyone home during loadshedding due to dropped productivity

Loadshedding has negative impact, causing a lot of issues while electricity prices are increasing
finance | performance

- Loadshedding has negative impact as power is essential
- Loadshedding is causing a lot of issues while electricity prices are increasing

SMEs with niche value offering prefer to identify and directly approach decision makers in target market over traditional marketing

through direct marketing, identify technical and business decision makers in target growth market

Market business

BU heads are responsible for marketing, sales, service and product management for targeted markets

Individuals are tasked to target and develop B2B marketing instead of 3rd party marketing

Instead of online marketing, identify possible clients and target their engineers & decision makers

with technology you need to identify the clients who can grow your business

Direct, digital contact within niche market more suited for selling technology than traditional marketing

market technology

Traditional marketing will not get you clients for AM

B2B strategy identify companies within our niche and spend effort to tell them about us

had good success when they changed their marketing to Teams meetings

Unscheduled power cuts are less of a risk for AM machines as every print layer gets recorded

Power cuts are less of a risk for AM machines as every print layer gets recorded

environment risk

Lower risk with machine issues due to loadshedding as every layer printed is recorded

SMEs develop strategies to expand into markets with emerging demands for their products and services

SMEs develop and evaluate strategies to move into new industries and technology implementation

industry strategy technology

Choose a strategy for technology development and keep a it alive

Need to regularly measure yourself against the strategy

Strategic move into contract OEM manufacturer for Aerospace, Medical and other

Developed a roadmap for I4.0 implementation starting with machine connectivity

Started 4 years ago with digital manufacturing looking at IoT

Emerging demand for Ti products increased in Aerospace and Marine industries

industry

storm damage during local yacht race turned that industry to Ti parts

Demand for Ti parts increased in Aerospace and other industries

The need for Ti components opened them to global high speed and luxury yacht industry

Change were more acceptable during Covid in SMEs where there is natural resistance to change, especially under long serving employees

There is a natural resistance to technology change

organisation | technology

- There is natural resistance to change
- Technical people resist the administrative work required by QMS and ISO systems
- The older artisan are hesitant to accept a new technology
- Some change was enforced to make it work
- long serving employees showed resistance to change

Technology has changed but some long serving employees have not adapted

organisation | technology

- Skill sets of long serving employees have not adapted
- technology has changed so their knowledge has changed to a certain extent

Change implementation and company restructuring were more acceptable during Covid

organisation

- A crisis is an opportunity for people to accept change
- Covid helped to change 40% of the company staff
- new employees better dealt with changes of revamped company
- New employees embraced new ideas as they were not involved with failed implementations
- Changed the structure of the company with retrenchments and rehiring during pandemic

Retrofitting of old machines with cheap IoT sensors using communication protocol developed by US company who provided local and remote support

Retrofitting of old machines to obtain data is relatively cheap by limited and depends on age of machine

technology | finance | performance

- Retrofitting of older machines with external devices provide limited data
- Older machines require retrofitting to obtain machine data
- Connection and automatic tagging depends on age of machine
- Connection devices are relatively cheap at R1,700 per box

Found US based company which provided local and remote support to digitally connect old machines

suppliers | technology

- MTConnect provide local and remote support
- Found an US based protocol, MTconnect, which converted all communication to internet based language
- Parent company, Vimana, helped to connect machines for real time monitoring

SME have diesel generator but still waiting for municipal permit to use it

Lack of permit stop them from operating the generator

environment

- Generator is not running while they are waiting for municipality permit

SMEs want to understand process fundamentals and their needs before they obtain technology intelligence through own research, machine and tooling suppliers

Technology intelligence through own research, machine and tooling suppliers
RandD | suppliers | technology

- Artisans suggest new machines based on own research into machine technologies
- Obtain technology intelligence through internet research and other initiatives
- Contact machine suppliers after own research on machines
- Tooling suppliers are very knowledgeable on tooling and machine technoloy

Technology implementation done internally to understand fundamentals, adapt to SME needs
RandD | technology

- Want to understand the fundamentals before implementing new tech, e.g. CRM
- we drive and ensure technology implementation is right for our needs
- Want to understand technology before change and adapt to new technology
- We are responsible for the implementation of new technologies

depending on the size of the SME, fast, reliable, yet affordable internet and local area network is required for communication, machine connection and cloud services

Good local area network is needed for communication between machines and buildings
infrastructure | technology

- local area network is needed for communication between machines and programming
- Good local area network between building is important

Fast & reliable internet is essential for international communication & cloud service, but expensive
technology | finance | infrastructure

- Good internet is essential to stay in contact with international market, especially during pandemic
- A good, stable internet connection is essential but depends on what it is used for
- Work productivity requires good, reliable internet
- rely heavily in IT communication with international customer base
- need a fast internet line for cloud service, but fast internet is expensive

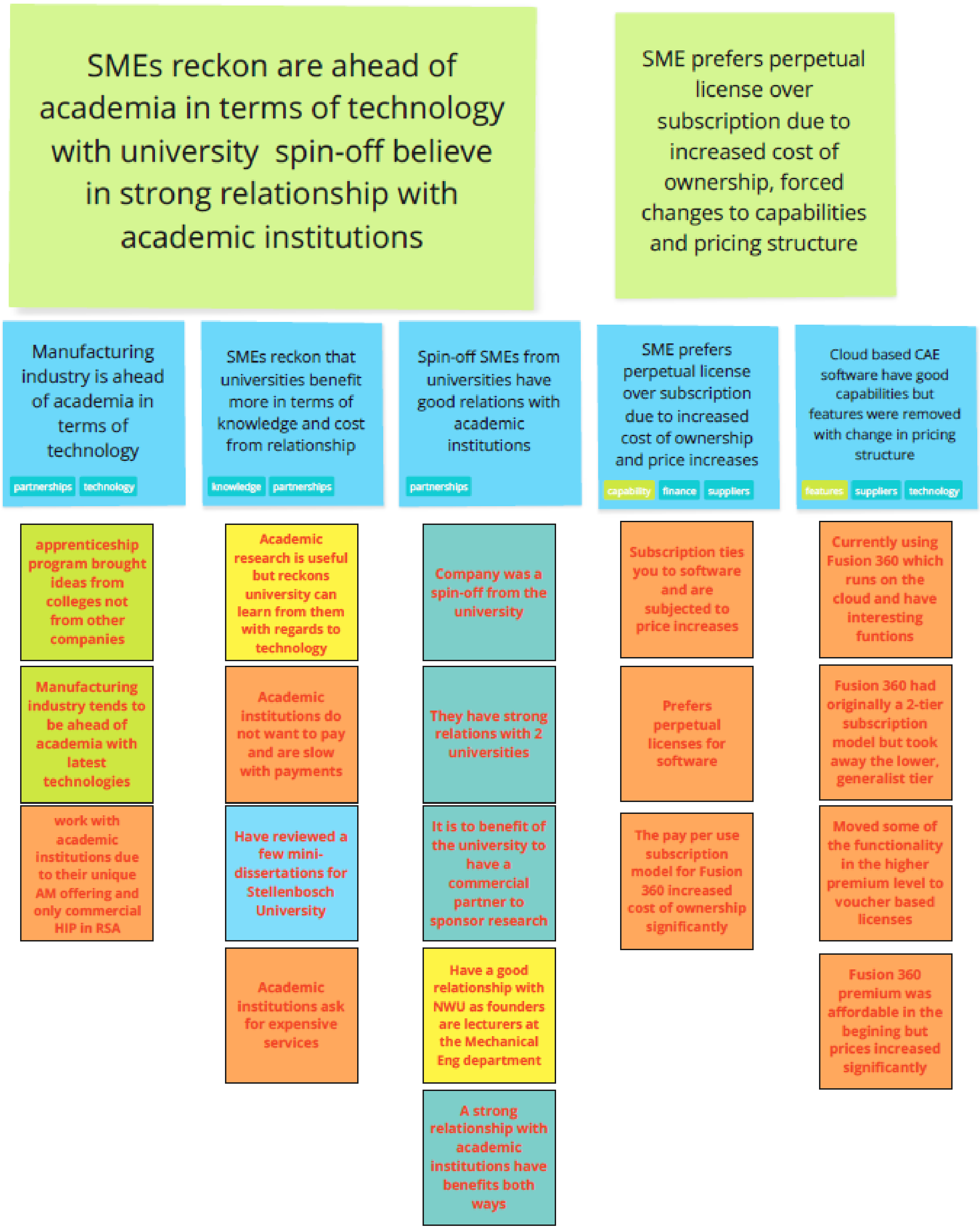
Do not require very high speed internet with small number of people in SME
infrastructure | organisation

- Small number of people but will look at higher internet speeds when they are more people
- Do not require fast fibre internet, 10MB/s is good enough

MD does not have a technical qualification and relies on staff technical expertise

MD does not have a technical qualification and relies on staff technical expertise
organisation | skills

- MD does not try to be the person that know best regarding technical matters
- MD is not an engineer and rely on staff to make technical decisions


SMEs reckon are ahead of academia in terms of technology with university spin-off believe in strong relationship with academic institutions
SME prefers perpetual license over subscription due to increased cost of ownership, forced changes to capabilities and pricing structure
Manufacturing industry is ahead of academia in terms of technology
partnerships
technology
apprenticeship program brought ideas from colleges not from other companies
Manufacturing industry tends to be ahead of academia with latest technologies
work with academic institutions due to their unique AM offering and only commercial HIP in RSA
SMEs reckon that universities benefit more in terms of knowledge and cost from relationship
knowledge
partnerships
Academic research is useful but reckons university can learn from them with regards to technology
Academic institutions do not want to pay and are slow with payments
Have reviewed a few mini-dissertations for Stellenbosch University
Academic institutions ask for expensive services
Spin-off SMEs from universities have good relations with academic institutions
partnerships
Company was a spin-off from the university
They have strong relations with 2 universities
It is to benefit of the university to have a commercial partner to sponsor research
Have a good relationship with NWU as founders are lecturers at the Mechanical Eng department
A strong relationship with academic institutions have benefits both ways
SME prefers perpetual license over subscription due to increased cost of ownership and price increases
capability
finance
suppliers
Subscription ties you to software and are subjected to price increases
Prefers perpetual licenses for software
The pay per use subscription model for Fusion 360 increased cost of ownership significantly
Cloud based CAE software have good capabilities but features were removed with change in pricing structure
features
suppliers
technology
Currently using Fusion 360 which runs on the cloud and have interesting funtions
Fusion 360 had originally a 2-tier subscription model but took away the lower, generalist tier
Moved some of the functionality in the higher premium level to voucher based licenses
Fusion 360 premium was affordable in the begining but prices increased significantly

Technology implementation is successful if group is involved in decision making, people understand the vision and there is a culture open to change

Technology implementation successful if group involved in decision making
organisation technology

the more people get involved in the decision the better the implementation

As a group they identify their technology needs, requirements and specifications

perform technology research as a group before procurement of technologies

success of integrating IT technology increase if people understand the reason for it
technology facilities organisation

success of integrating IT technology increase if people understand the reason for it

Successful technology implementation require good communication of vision and a culture open to change
organisation technology

successful implementation of technology require to explain your vision to other people

A culture open to change has lead to solid model adoption in assembly and fabrication, but not in machining

looking for altenative ISPs as internet is down during loadshedding due to ISPs stopped replacing stolen tower batteries

Internet is down during loadshedding as ISPs stopped replacing stolen tower batteries
environment facilities

ISPs stopped replacing batteries stolen at internet towers

Internet towers only have 30 min batteries and then you are stuck with no internet

Loadshedding causes issues wit internet as not all ISPs use backup batteries

Looking at other ISPs as lost internet connection is a big problem
facilities

Looking at other ISPs as current ISP is not reliable

lost internet connection is a big problem for them

Engineering SME uses standard technology to design a product and advanced technology for factory acceptance testing

Develop and maintain products with reusable component, standard and agnostic technologies
products technology

Reuse components during complete rebuild of units coming back from mines

We try to do interesting projects with stock standard technologies

we are technology agnostic as we search for best solutions for costumers

Advanced technology used to locally assemble, test and certify products for use
products technology

Units are tested and certified under strict conditions

Assemble the units in Potch from standard products

Use advanced testing facility to perform required factory testing

SME invest in machines with increased capacity and performance capability to match current and expected work

SME invest in machines to increase capacity and demand for capability

performance | capability | finance

they will look into bigger machines as the demand for bigger parts justify it

Bought about 10 machines in 2015-16 to accommodate rapid growth

current and future work is based on machine capabilities and performance

performance | capability | opportunity

the work packages they take on are determined by the capabilities of their machines

SLM technology was chosen based on its machine performance

We bought 2x COTS machines from SLM Solutions rather than sophisticated machines

they look at future orders they want and can get from clients

SMEs uses tablets on workshop floor for manufacturing design and recording of operator activities

The number of operators can be determined by the number of signals present

performance | technology

The number of operators can be determined by the number of signals present

SMEs used tablets in workshop to go digital design and real time monitoring, but adoption was challenging

technology | performance | systems

Tablets are used on the shopfloor for access to designs and work monitoring

implemented tablets for real time monitoring of machines

Adoption of was a challenge as people did not see tablets as a work tool

There was resistance in the use of iPads to move away from the use of drawings on the shopfloor

Want to move to use of solid models throughout shopfloor to reduce errors

old or damaged UPS allows short time to shut down machines and absorb electricity spikes

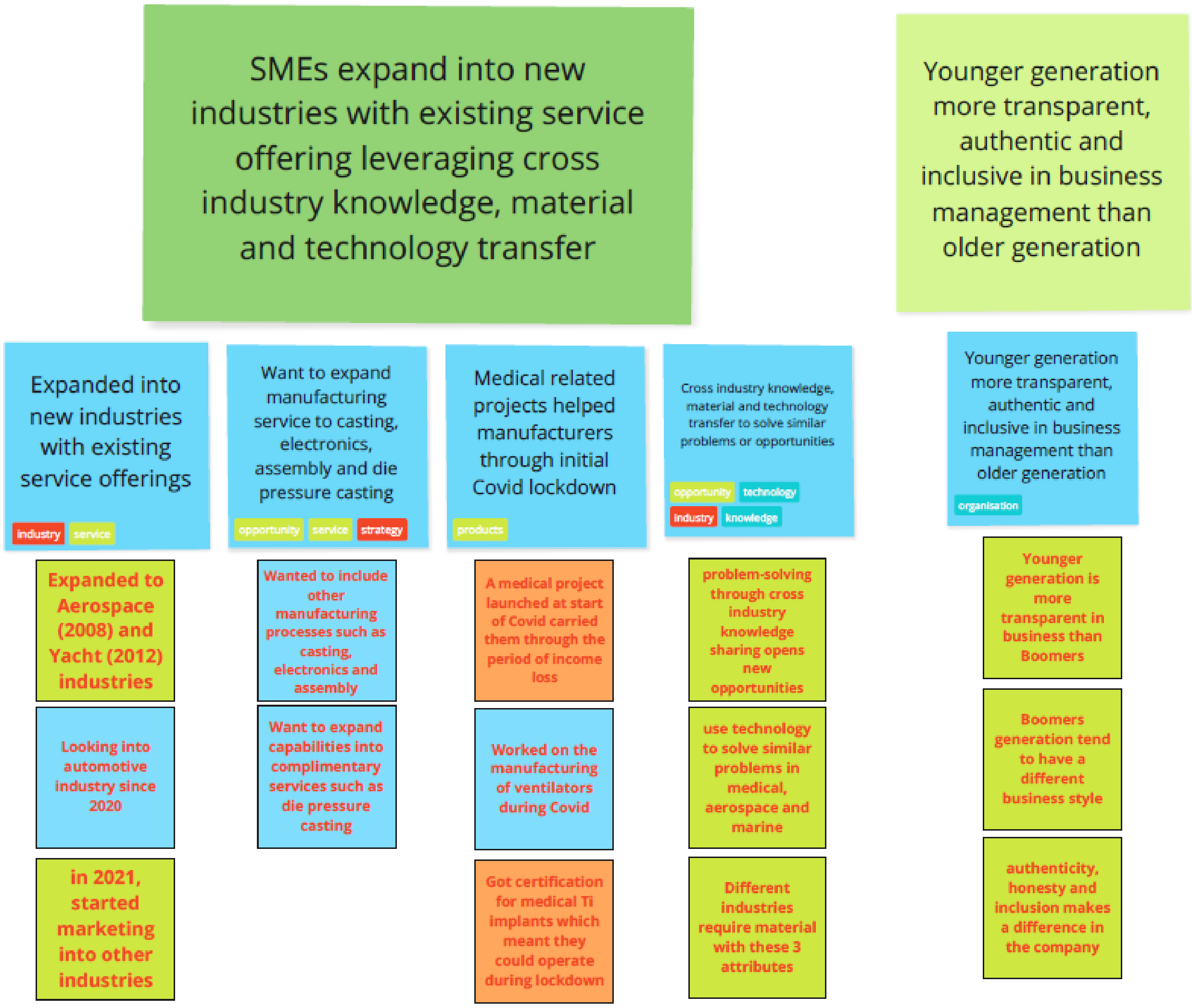
old or damaged UPS allows short time to shut down machines and absorb electricity spikes

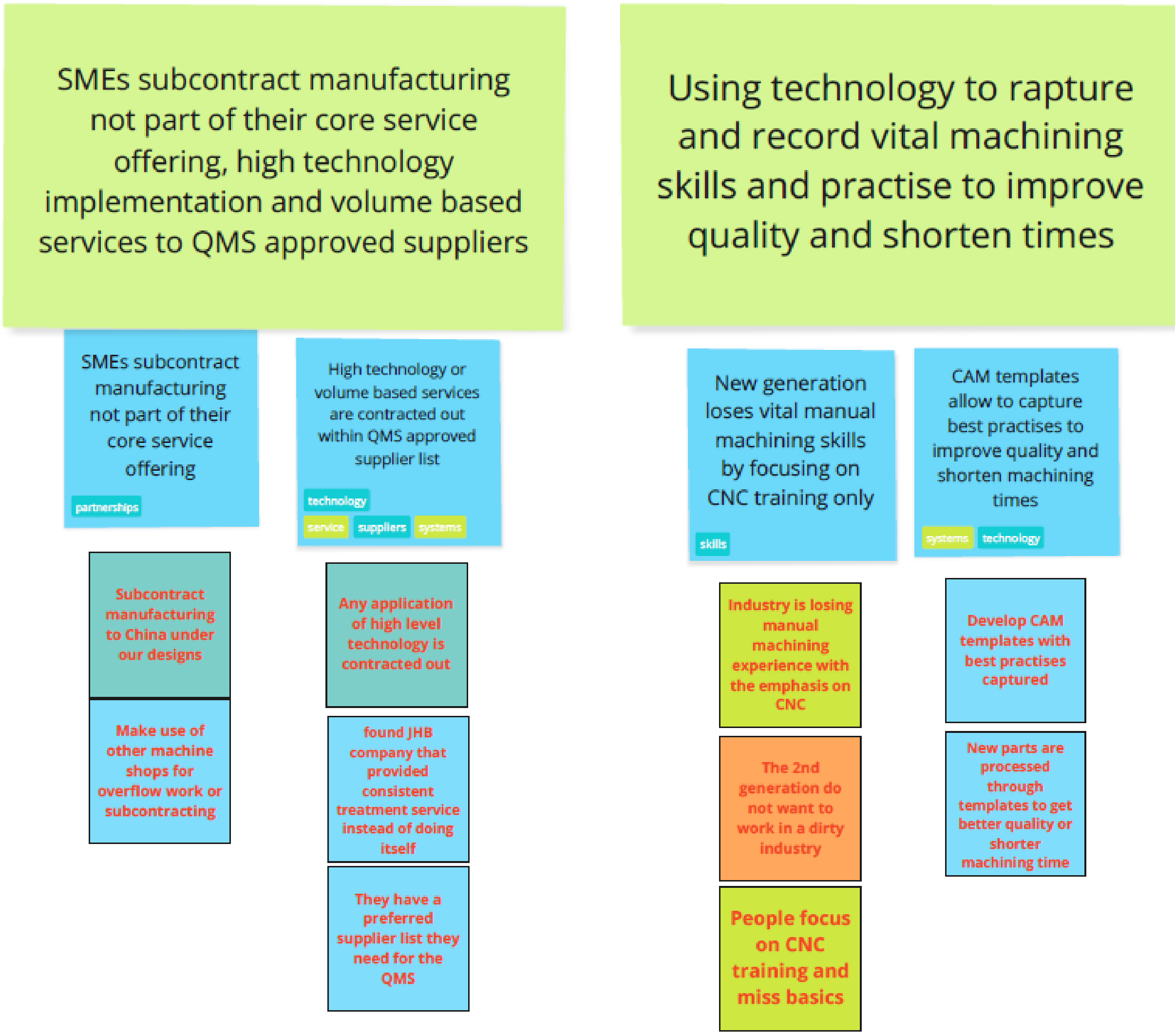
facilities | risk

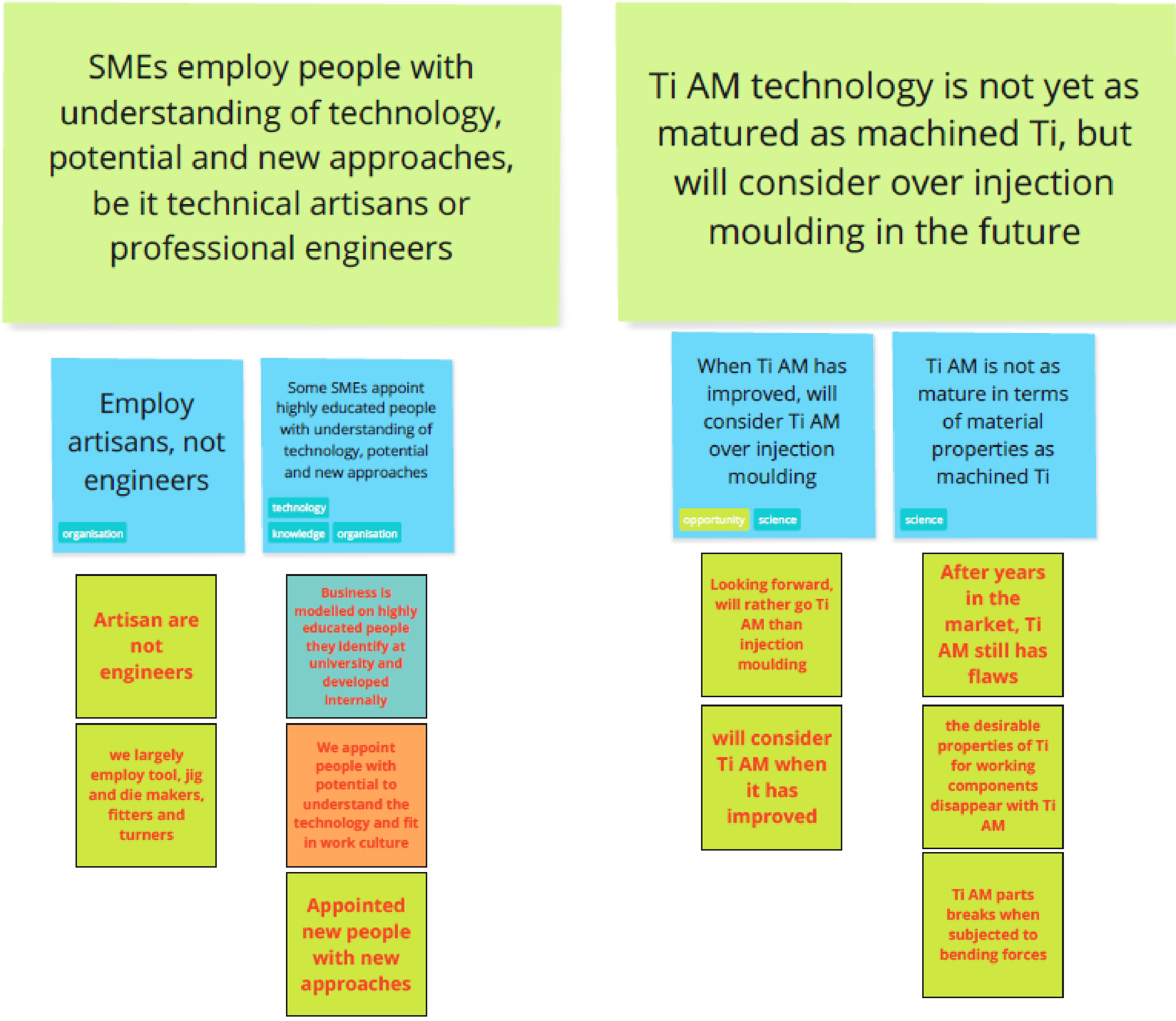
Old UPSs allows them 5 min to shut down everything

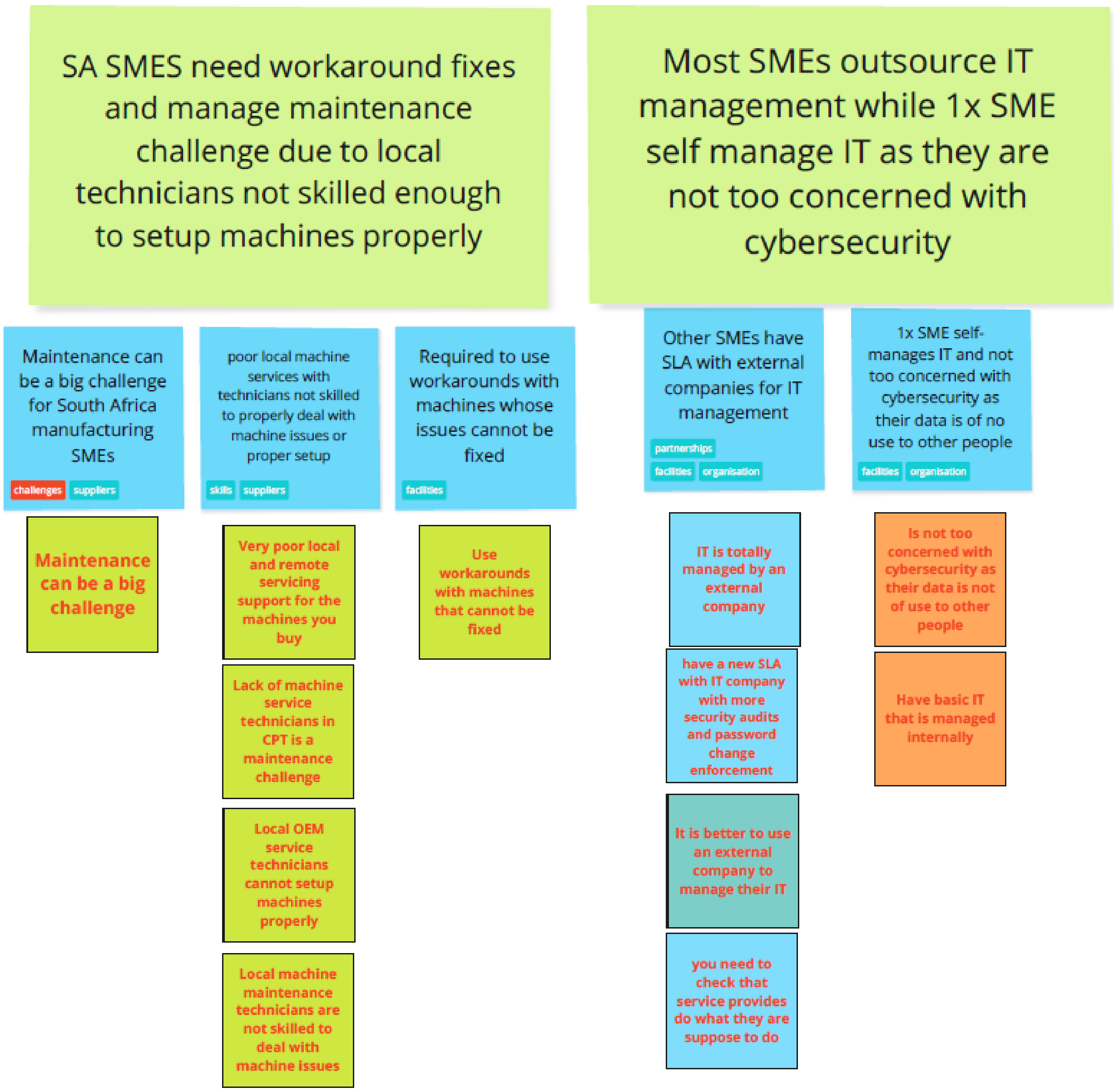
large investment in UPS absorb electricity spikes to prevent damage to machines

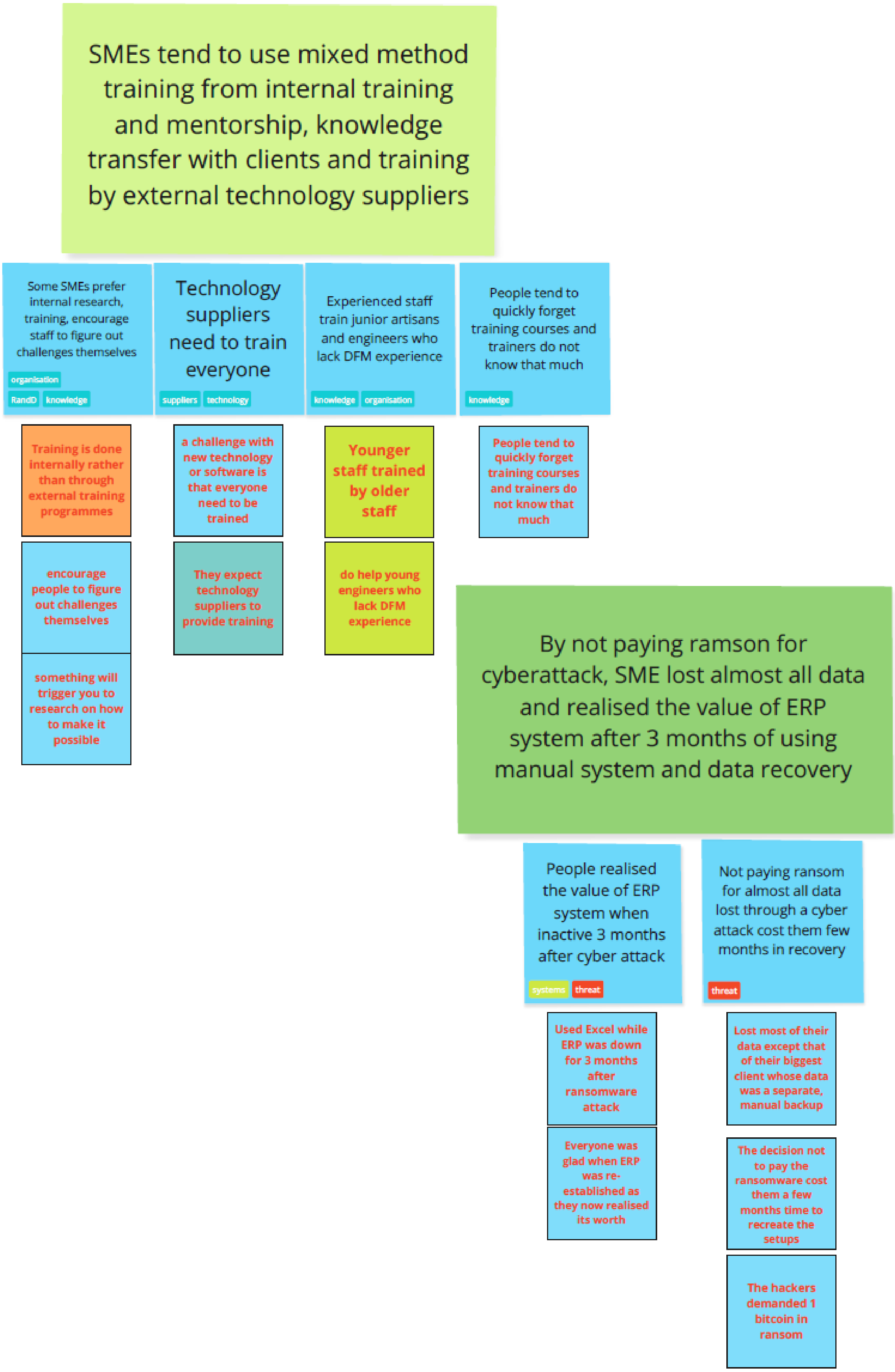
our UPS was damaged and we are not using it anymore


SMEs expand into new industries with existing service offering leveraging cross industry knowledge, material and technology transfer
Younger generation more transparent, authentic and inclusive in business management than older generation
Expanded into new industries with existing service offerings
industry
service
Want to expand manufacturing service to casting, electronics, assembly and die pressure casting
opportunity
service
strategy
Medical related projects helped manufacturers through initial Covid lockdown
products
Cross industry knowledge, material and technology transfer to solve similar problems or opportunities
opportunity
technology
industry
knowledge
Younger generation more transparent, authentic and inclusive in business management than older generation
organisation
Expanded to Aerospace (2008) and Yacht (2012) industries
Looking into automotive industry since 2020
in 2021, started marketing into other industries
Wanted to include other manufacturing processes such as casting, electronics and assembly
Want to expand capabilities into complimentary services such as die pressure casting
A medical project launched at start of Covid carried them through the period of income loss
Worked on the manufacturing of ventilators during Covid
Got certification for medical Ti implants which meant they could operate during lockdown
problem-solving through cross industry knowledge sharing opens new opportunities
use technology to solve similar problems in medical, aerospace and marine
Different industries require material with these 3 attributes
Younger generation is more transparent in business than Boomers
Boomers generation tend to have a different business style
authenticity, honesty and inclusion makes a difference in the company


SMEs subcontract manufacturing not part of their core service offering, high technology implementation and volume based services to QMS approved suppliers
SMEs subcontract manufacturing not part of their core service offering
partnerships
Subcontract manufacturing to China under our designs
Make use of other machine shops for overflow work or subcontracting
High technology or volume based services are contracted out within QMS approved supplier list
technology
service
suppliers
systems
Any application of high level technology is contracted out
found JHB company that provided consistent treatment service instead of doing itself
They have a preferred supplier list they need for the QMS
Using technology to rapture and record vital machining skills and practise to improve quality and shorten times
New generation loses vital manual machining skills by focusing on CNC training only
skills
Industry is losing manual machining experience with the emphasis on CNC
The 2nd generation do not want to work in a dirty industry
People focus on CNC training and miss basics
CAM templates allow to capture best practises to improve quality and shorten machining times
systems
technology
Develop CAM templates with best practises captured
New parts are processed through templates to get better quality or shorter machining time


SMEs employ people with understanding of technology, potential and new approaches, be it technical artisans or professional engineers
Employ artisans, not engineers
organisation
Some SMEs appoint highly educated people with understanding of technology, potential and new approaches
technology
knowledge
organisation
Artisan are not engineers
we largely employ tool, jig and die makers, fitters and turners
Business is modelled on highly educated people they identify at university and developed internally
We appoint people with potential to understand the technology and fit in work culture
Appointed new people with new approaches
Ti AM technology is not yet as matured as machined Ti, but will consider over injection moulding in the future
When Ti AM has improved, will consider Ti AM over injection moulding
opportunity
science
Ti AM is not as mature in terms of material properties as machined Ti
science
Looking forward, will rather go Ti AM than injection moulding
will consider Ti AM when it has improved
After years in the market, Ti AM still has flaws
the desirable properties of Ti for working components disappear with Ti AM
Ti AM parts breaks when subjected to bending forces


SA SMES need workaround fixes and manage maintenance challenge due to local technicians not skilled enough to setup machines properly
Most SMEs outsource IT management while 1x SME self manage IT as they are not too concerned with cybersecurity
Maintenance can be a big challenge for South Africa manufacturing SMEs
challenges
suppliers
poor local machine services with technicians not skilled to properly deal with machine issues or proper setup
skills
suppliers
Required to use workarounds with machines whose issues cannot be fixed
facilities
Other SMEs have SLA with external companies for IT management
partnerships
facilities
organisation
1x SME self-manages IT and not too concerned with cybersecurity as their data is of no use to other people
facilities
organisation
Maintenance can be a big challenge
Very poor local and remote servicing support for the machines you buy
Lack of machine service technicians in CPT is a maintenance challenge
Local OEM service technicians cannot setup machines properly
Local machine maintenance technicians are not skilled to deal with machine issues
Use workarounds with machines that cannot be fixed
IT is totally managed by an external company
have a new SLA with IT company with more security audits and password change enforcement
It is better to use an external company to manage their IT
you need to check that service provides do what they are suppose to do
Is not too concerned with cybersecurity as their data is not of use to other people
Have basic IT that is managed internally


SMEs tend to use mixed method training from internal training and mentorship, knowledge transfer with clients and training by external technology suppliers
Some SMEs prefer internal research, training, encourage staff to figure out challenges themselves
organisation
RandD
knowledge
Technology suppliers need to train everyone
suppliers
technology
Experienced staff train junior artisans and engineers who lack DFM experience
knowledge
organisation
People tend to quickly forget training courses and trainers do not know that much
knowledge
Training is done internally rather than through external training programmes
a challenge with new technology or software is that everyone need to be trained
Younger staff trained by older staff
People tend to quickly forget training courses and trainers do not know that much
encourage people to figure out challenges themselves
They expect technology suppliers to provide training
do help young engineers who lack DFM experience
something will trigger you to research on how to make it possible
By not paying ramson for cyberattack, SME lost almost all data and realised the value of ERP system after 3 months of using manual system and data recovery
People realised the value of ERP system when inactive 3 months after cyber attack
systems
threat
Not paying ransom for almost all data lost through a cyber attack cost them few months in recovery
threat
Used Excel while ERP was down for 3 months after ransomware attack
Lost most of their data except that of their biggest client whose data was a separate, manual backup
Everyone was glad when ERP was re-established as they now realised its worth
The decision not to pay the ransomware cost them a few months time to recreate the setups
The hackers demanded 1 bitcoin in ransom

Diverse AM technology complement, not replace, subtractive machining to be more efficient and diverse

Integration of AM, CNC and manual machining technologies are complimentary and more efficient

technology

- Integrate old subtractive with new AM technology to compliment each other
- manual machining makes you more efficient with CNC machining
- Aerosud machines are not exactly the same as theirs which caused issues

Additive Manufacturing will not replace subtractive manufacturing

competitors

- AM will not close jobshops as there is always a need for subtractive manufacturing

AM technology can build a diverse range of parts

products technology

- AM technology can build a diverse range of parts

Large capital investment in diesel generators, high fuel costs for operating and infrastructure costs to accommodate generator or solar panels

SMEs invested large capital in diesel generators, high fuel costs by paid back quickly

facilities finance

- Have a diesel generator which is large capital investment but paid back quickly
- Procured a diesel generator that have high fuel costs during loadshedding
- Have a backup generator
- The generator can keep some machines operating during loadshedding

Significant infrastructure costs required to accommodate generator and solar panels

infrastructure facilities finance

- Infrastructure costs to accommodate generator is very expensive
- Had to do some infrastructure work for diesel generator
- Investigation identified construction changes to roof structure as obstacle to solar panels

New location required upgrading to make it presentable as a high tech company

facilities

- with the move we had to upgrade the building
- you need to be presentable as a high technology company

SMEs protect themselves with cybersecurity and back-up servers but big risk is employees taking IP with them

implemented advanced IT security after cyberattack with more redundancy for data backup

risk | technology

- now using encrypted cloud backup and some users OneDrive
- Made their IT system 3x times more redundant after ransomware attack
- Got a more advanced virus protection that uses ML to flag odd behaviour
- more complicated security is required as more technology exposes you more

SMEs uses on-premise servers for backups

facilities | technology

- All engineering data are on servers
- Data backups are important
- They have on site file server

SME consider employee taking IP a bigger risk than cyber attack

organisation | risk

- The biggest risk is with employees who knows the IP

Manufacturing SMEs have advanced production technologies complemented with conventional and post-processing machines

SMEs have manual machines

capability

- Manual workshop, sandblasting and CMM
- CNC and manual machines

Manufacturing SMEs have advanced multi-axis CNC machines

capability

- Mainly Milling CNC technology and turning to a lesser extent
- multi-axis turning lathes with C-axis live tooling
- Subtractive CNC machining with advanced milling and turning
- Fully synchronise 3 to 5 axis milling machines

SMEs have various forming and post-processing machines

capability

- Post processing machines
- Already have bending and forming machines
- In addition to AM, have machining and heat treatment capabilities
- Have a hot isostatic press commissioned during lockdown