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Manufacturing in Australia – An explorative investigation of innovation capability enhancements using value stream thinking

Brogan Rylands
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Manufacturing in Australia – An explorative investigation of innovation capability enhancements using value stream thinking

Brogan Rylands
B Comm. (Int. Business), M. Strat Mgmt. (Dist.)

Supervisors:
Dr Tillmann Böhme, Dr Joshua Fan, and Professor Grace McCarthy

This thesis is presented as part of the requirement for the conferral of the degree:
Doctor of Philosophy

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The University of Wollongong
School of Management, Operations and Marketing
Faculty of Business

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Abstract

Supply chains and supply chain management continue to increase in importance, with research showing that it is supply chains that compete today, rather than individual businesses (Christopher, 2011). Supply chain management in the Australian manufacturing industry is of particular importance due to the challenges and changes being faced by manufacturing. This includes but is not limited to, declining employment figures and the decreasing percentage of gross domestic product (GDP) attributed to manufacturing, the recent closures, downsizing and offshoring of manufacturing, including the closure of automotive production plants, and downsizing of a major employer and steel manufacturer which is integral to its region as well as Australia, and the shift towards more advanced manufacturing methods with the introduction of Industry 4.0 in recent times. Manufacturing has been found to be of strategic and economic importance to the nation in which it is situated, attributed to higher standards of living, educational benefits, security, as well as being a source of competitive advantage, and foundation for innovation. The challenges faced by manufacturing have impacted on organisations large and small, including their immediate supply chains as well as those of their suppliers. Small to medium sized enterprises (SMEs) account for a large share of all businesses in Australia and provide a significant contribution to the nation through productivity, employment, and importantly, sources of innovation in which to compete. Innovation and innovative capability are imperative for businesses to compete today, and can be achieved through multiple ways such as through the introduction of innovative technology, products and processes. Also established in literature as being of importance is that of the state of supply chains, including their level of integration and maturity. Therefore, this research aimed to explore the state of supply chain maturity and innovation capability enhancement in Australian SMES in the manufacturing industry, through the adoption of innovative technology and processes.

This research begins by addressing a gap in literature through conducting an exploratory investigation into the state of supply chain maturity in Australian manufacturing SMEs. The Quick Scan Audit Methodology (QSAM), which uses mixed methods of data collection and multiple forms of triangulation, including data, researcher and method, was used in this research. Low supply chain maturity levels were discovered in the value streams of the SMEs included in this research, corresponding with international findings, revealing the need for strong supply chain management and the link between supply chain maturity levels, systems uncertainty and innovative capability. These findings provided context and a foundation for this research.

Next, innovation enhancement through the adoption of innovative technology (3D printing/additive manufacturing), and the impact that it has on value streams and manufacturing systems, is explored in cases of best practice from the United Kingdom. Case study research is used to establish pathways of adoption and business impact in SMEs that could be generalisable to other settings. Findings revealed that innovative technology adoption had multiple benefits, such as resulting in additional value streams, with the co-existence of traditional and advanced manufacturing methods, and additional value propositions for the customer. The SMEs were able to establish relationships with knowledge centres, increasing their access to technical assistance, machinery, and knowledge, increasing their competitive ability, and positively impacting on the region which had been facing similar manufacturing challenges to those in Australia.

Finally, a single longitudinal case study is presented, investigating the journey and pathways of growth and innovation in an agile, young organisation in the start-up space in Australia. This allowed for the researcher to take a step back and explore SMEs before they mature. Over the course of approximately 16 months, findings revealed multiple barriers to supply chain maturity and insight into the growth phases of start-ups. The turbulent environment and level of change also revealed the use of design thinking by the start-up in order to compete, including innovation through product, process, service and supply chain design.

Overall, by conducting this research early insight into the state of supply chain maturity in Australia and ways in which innovation capability can be improved through the adoption innovative technology and processes is provided.

Acknowledgments

I would like to thank my supervisors, Dr Tillmann Böhme, Dr Joshua Fan and Professor Grace McCarthy, for their guidance, patience and for all of their help (down to the final hours) of completing this thesis.

I would also like to thank the University of Wollongong for giving me the opportunity to pursue this educational endeavour, and my editor Dr Goodin.

Additionally, I would like to thank:

- ❖ The experienced QSAM team
- ❖ The Global Challenges Manufacturing Innovation team
- ❖ Dr Markus Gerschberger and the wonderful Logistikuum team at the University of Upper Austria – Steyr
- ❖ Dr Allan Rennie and the talented LPDU team at Lancaster University
- ❖ All of the organisations that allowed me to study them and the practitioners who took time out of their busy schedules to help further knowledge in the field (a shout out to Neil and the team, you know who you are...)
- ❖ My team at Svitzer Australia (including but not limited to Jason, Paul, Geoffrey, Angus, Dirk, Baher, James and crew) for allowing me the flexibility to pursue this research

Last, but not least, I would like to thank my truly wonderful family, including my brother Mitch, sister-in-law Kiralee, nephew/Godson Kylian, furbaby Patches Peanut Bubba, and my amazing parents, Narelle and Craig, who believed in me every step of the way. You always said “believe, achieve”. I couldn’t have done this without you, your love, support and help from God and the angels.

Certification

I, Brogan Carly Rylands, declare that this thesis submitted in fulfilment of the requirements for the conferral of the degree Doctor of Philosophy, from the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Brogan Carly Rylands

31st March 2019

List of Names or Abbreviations

| | |
|-------------|---|
| AM | Additive manufacturing |
| BPR | Business process reengineering |
| CE | Concurrent engineering |
| CI | Continuous improvement |
| DIFOT | Delivery in full on time |
| DIFOTIS | Delivery in full on time in specification |
| KET | Key enabling technology |
| KPI | Key performance indicator |
| QSAM | Quick Scan Audit Methodology |
| SC | Supply chain |
| SCM | Supply chain management |
| SME | Small - medium-sized enterprise |
| VS | Value stream |
| VSM | Value stream mapping |
| 3-DCE | Three-dimensional concurrent engineering |
| 3D Printing | Three-dimensional printing |

Peer-Reviewed Publications

Parts of this thesis have been published and presented elsewhere prior to submission for examination. Table 0.1 provides details of all papers which resulted from the work on this thesis.

Table 0.1: Publications resulting from this thesis

| Paper Title | Year | Authors | Outlet | Status | Relation to Thesis Chapter/s |
|--|------|---|---|-------------|------------------------------|
| "3D Printing: Fad, Fact or Fantasy – A supply chain /economics perspective" | 2014 | Böhme, T., Fan., J, Ordigoni, A., and *Rylands, B <i>*Percentage of contribution by the author: 40% (Including: literature review)</i> | White paper for the Global Challenges – Manufacturing Innovation Team at the University of Wollongong | Unpublished | Chapter 5 |
| "Supply chain integration in Australia: Benchmark comparisons with the UK automotive sector" | 2014 | Böhme, T., *Rylands, B., Reitner, K., and Ordigoni, A. <i>*Percentage of contribution by the author: 50% (Including: data collection, analysis, literature review, methodology)</i> | Proceedings of the 12th ANZAM Operations, Supply Chain and Service Management Symposium | Published | Chapter 4 |
| "Lean principles in the printing industry – a success story?" | 2014 | Reitner, K., Gerschberger, M., Böhme, T., and *Rylands, B. <i>*Percentage of contribution by the author: 40% (Including: data collection, data analysis, literature review, methodology)</i> | Operations Management in an Innovation Economy - Proceedings of the 21 Euroma Conference | Published | Chapter 4 |
| "3D printing – To print or not to print? Aspects to consider before adoption – A supply chain perspective" | 2015 | *Rylands, B., Böhme, T., Gorkin III, R., Fan, J., and Birtchnell, T. <i>*Percentage of contribution by the author: 80% (Including: data collection, data analysis,</i> | Proceedings of the 22nd Euroma Conference, Neuchâtel, Switzerland | Published | Chapter 5 |

| | | | | | |
|--|------|---|--|------------------------------------|-----------|
| | | <i>literature review, methodology, drafting for conference).</i> | | | |
| "Causes and Effects Impeding Efficient Patient Flow in Australian Emergency Departments: An Exploratory Investigation" | 2016 | Böhme, T., Williams, S., Deakins, E., Fan, J., and Rylands, B. <i>*Percentage of contribution by the author: 50% (Data collection, data analysis- led the study)</i> | 14th ANZAM Operations, Supply chain and Services Management Synopsium, Sydney, Australia | Published | Chapter 4 |
| "The adoption process and impact of additive manufacturing on manufacturing systems" <i>*Percentage of contribution to the chapter:</i> | 2016 | Rylands, B., Böhme, T., Gorkin III, R., Fan, J., and Birtchnell, T. <i>*Percentage of contribution by the author: 80% (Data collection, data analysis, literature review, methodology, drafted paper for journal).</i> | Journal of Manufacturing Technology Management | Published | Chapter 5 |
| "Causes and effects of ineffective patient flows: An exploratory investigation" | 2019 | Böhme, T., Rylands, B., Shukla, N., Fan, J., Williams, S., and Deakins, E. <i>*Percentage of contribution by the author: 50% (Data collection, data analysis – led the study).</i> | Journal of Production Planning and Control | *Submitted and subject to revision | Chapter 4 |

Source: Author

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Prologue: My Research Journey

The PhD journey has been a rollercoaster, which has been both challenging and rewarding. It began with compiling a list of potential research ideas and setting the research scope. Due to the changes in manufacturing that I have seen and experienced, it gave me the strong desire to study this area more closely, with the aim to add to knowledge that could potentially help both the region and other organisations Australia-wide. Throughout the journey, I was provided with opportunities to apply my experiences from practice, including knowledge within supply chain and operations in manufacturing, and learnings from academia, which was positive. I was fortunate to have access to many organisations, willing to open up and share their experiences. In total, I visited, interviewed, spoke with, presented to and studied over 15 organisations. These included Australian manufactures (both traditional and advanced), and a hospital (to lead a QSAM and gain further experience in research), and over 8 SMEs in the UK (including attending a Lloyds Innovation Day conference, where I met even more companies, gaining insight into interesting projects).

By conducting this research, it gave me the opportunity to become trained in an applied methodology (Quick Scan Audit Methodology), which I can take with me and apply to other scenarios. It also gave me the opportunity to work with great people, and experienced researchers. I was fortunate to begin my studies working with an experienced team of researchers during QSAMs in 2013 and become a part of the QSAM network. This included working with the talented team from the University of Applied Sciences Upper Austria – Logistikum, and learning about how they are applying this study to healthcare in Austria.

Within the University of Wollongong, I was fortunate to work as part of the Global Challenges team in the area of manufacturing innovation (which fitted perfectly with my research area). It brought a variety of disciplines together, such as Engineering, Social Sciences and Business, providing further opportunities to learn from the team, and take a holistic approach to the research. It also provided links to networks outside of the university, providing the opportunity for me to work with the knowledgeable LPDU Team at Lancaster University and businesses in the region.

Other opportunities such as publishing conference papers and journal articles, presenting at conferences including in Neuchatel (EurOMA and the EurOMA Doctoral Seminar, 2015), Sydney (ANZAM, 2016), student conferences within the Faculty, SMIG (Southern Manufacturing Innovation Group) in the Illawarra where I was able to present to practice and academia, and being involved in a

3D printing workshop, presenting to academia and working with a local start-up SME, all helped in creating valuable networks within practice and academia, building experience and gaining knowledge to be able to answer the research questions posed in this thesis. As my supervisor says, a PhD is an apprenticeship to becoming an academic, and all of the experiences have been significant in the journey, contributing greatly to this thesis.

1. Research Overview

There are strong arguments for Australia staying in manufacturing, and being prepared to pay a high price to do so. Manufacturing is the sector that contains and advances the skills and capabilities that prescribe membership in the ranks of the advanced nations of the world. For research and innovation, manufacturing provides the essential ground from which future streams of products and incomes can emerge. Whatever form the economy of the future may take, manufacturing will provide the enabling foundation for it (Milne, 2010, no pagination).

1.1 Introduction

1.1.1 Background to the research

Manufacturing in Australia has been changing, with employment and GDP for example declining (Milne, 2010). There has been a shift from traditional manufacturing, that peaked around the 1960s (Milne, 2010), to a focus on both advanced manufacturing (NSW Government – Department of Industry, 2018) and other industries such as services. Manufacturing efforts are changing, requiring a focus on “how” production takes place, rather than on what products are produced (NSW Government - Department), and an increased focus on education (both increasing employees’ education and partnering with educational facilities/research institutions) (NSW Government – Department of Industry, 2018). Although the industry has changed since, Australia has great potential to improve the current state of manufacturing and supply chains. Challenges in more recent times has seen manufacturing become more expensive and the landscape change, as well as the importance of supply chains and the value streams within them increase. As stated by Spinks (2014, no pagination), “Australia has the skills and capacity to be a global leader in highly specialised niche manufacturing, delivering high quality products and providing high quality jobs. We have done it before, and we can do it again”. Spinks (2014, no pagination) also added “...we can't simply rely on being the world's quarry”. Although there are benefits of other industries such as mining for example, there is more that Australia can offer, such as through developments in manufacturing (Spinks, 2014) and innovation within the area of supply chain. As highlighted by Milne (2010), manufacturing has been linked to an improved quality of life and has been considered the foundation for the advancement of research and

innovation. As such, manufacturing, innovation and the understanding and improvement of supply chains and the value streams within them are key to this research.

As Christopher (2011) and other researchers in the literature have noted, it is no longer business versus business, but supply chain versus supply chain. Supply chains can be defined in many different ways (Mentzer et al., 2001; Gibson, Mentzer and Cook, 2005), from more broadly as being; a flow of materials and information between the manufacturer and the final consumer, to more specifically as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer” (Mentzer et al., 2001, p. 4). As with the multitude of definitions, which exceeded 2,300 variants in 2005 (Gibson, Mentzer and Cook, 2005), supply chains and what they encompass vary from business to business. “Supply chains are not static – they evolve and change in size, shape and configuration, and in how they are coordinated, controlled and managed. New supply chains may emerge for many reasons” (MacCarthy et al., 2016, p. 1697). Reasons for change or emergence of new supply chains may be due to changes in the market, policies, technology and innovation for example (MacCarthy et al., 2016). There may also be impacts from man-made or natural disasters that result in change and increased levels of uncertainty (Choi et al., 2017). Uncertainty is faced by each process/activity within a supply chain (Choi, et al., 2017), and so investigating the state of the supply chain, whether it be through the level of supply chain integration or maturity (Stevens, 1989; Böhme et al., 2014b) for instance, to improve supply chain understanding and management is of importance. Organisations cannot afford to be complacent. They need to be cautious and wary of competitive advantages, whether they are temporary or sustainable (Fine, 1998), as well as the state of their supply chains and environment, including technological innovations and the ability to remain innovative. It has been said that an organisation or manufacturer is only as effective as its supply chain and that “A firm’s supply chain can thus make or break a firm” (Anekal, 2018, p. 54). The importance of supply chains cannot be overlooked or underestimated, which is as pertinent today as when it was highlighted by Christopher and Juttner (2000, p. 5);

“It is becoming apparent that a major re-appraisal of the way in which companies compete is now required and a new model of competitive strategy is emerging. It is based on the premise that increasingly a firm competes through its capabilities and competencies; in other words, by how well it manages the fundamental processes involved in satisfying customers. One of the most complex and therefore potentially critical processes in gaining competitive advantage is the supply chain process”.

Supply chains and their importance are not restricted to a certain industry or single organisation. Supply chains span large areas, including multiple industries. Due to this being a broad

research area, the focus for this research has been narrowed to concentrate largely on supply chains (including significant value streams) in Australian small to medium sized enterprises (SMEs), specifically those in the manufacturing sector. This is due to the current competitive environment which has seen the manufacturing industry change in Australia, impacting on many supply chains and the greater economy. It is also due to the importance of manufacturing as a foundation for future growth, research advancement and innovative capability at a country-level, as highlighted by Milne (2010), and the significant number of SMEs, which equate to over 95% of businesses in Australia (Ai Group, 2017; Gilfillan, 2015).

Organisations in regional and wider Australia have been experiencing financial hardship in more recent times (Valadkhani and Smyth, 2016; Stanwick et al., 2015; Cydonee, 2015; ABC Regional News, 2013), due to factors such as the exchange rate, international competition, and the rising cost of manufacturing in Australia. The Australian automotive industry in particular has experienced significant adversity with major companies ceasing manufacturing in recent times, resulting in the loss of thousands of jobs within the companies (Galloway and Zervos, 2017), as well as the wider Australian based automotive supply chain. A major employer and steel manufacturer have also undergone significant changes, including downsizing and restructuring due to the competitive environment that is challenging their ability to keep steel manufacturing in Australia. They too were impacted by the spill over effects of the automotive industry (Galloway and Zervos, 2017), including ceasing manufacturing in Australia, among other challenges, displacing the Australian steel that would have been used in the automotive production process. The effects have not been restricted to steel and automotive however, with many manufacturers facing challenging times across Australia, including countless SMEs. Whilst services have reportedly increased, other industries such as manufacturing have not. Output declined by nearly 3% and employment by almost 4% according to a 2015-2016 Australian Government industry report (Australian Government, 2016b). Historically, during the late 1950s “manufacturing accounted for 29% of Australian GDP” (Milne, 2010, no pagination). This dropped to less than 10% approximately 40 plus years later (Milne, 2010). In New South Wales alone, employment in manufacturing decreased by over 26,000 jobs within a 5-year period from mid-1995 to mid-2000 (Australian Bureau of Statistics, 2001). Between 2008 and 2012, Australia saw the loss of approximately 100,000 manufacturing jobs (Commonwealth of Australia, 2012), which is cause for concern.

The cause for concern regarding such changes is due to the importance of manufacturing on multiple fronts. Manufacturing has been linked to an improved quality of life and the advancement of

innovative opportunities (Milne, 2010). As such, assisting organisations through applied research could potentially benefit manufacturers Australia-wide. This area of improvement is also in the interest of the Australian Government (Australian Government, 2015; 2016) and educational institutions (Monash University, 2017; UOW, 2017; The University of Queensland Australia, 2014). In order to assist academia and practice, developing an understanding of the current business landscape, including supply chain maturity and being able to benchmark Australian organisations would be beneficial to improving the current state of supply chains. This is due to being able to provide insight into the current state and possible improvements going forward. Identifying levels of supply chain maturity, which has been successfully performed in other countries (Childerhouse et al., 2011d; Towill et al., 2002), has been linked to assisting in the assessment and comparison of supply chain performance, identification of areas for improvement, and implementing continuous improvement initiatives to name a few (Aryee, Naim and Lalwani, 2008; Trkman et al., 2007; Lockamy III and McCormack, 2004). This research provides early insights into the Australian landscape through exploring supply chains and multiple value streams in two mature SMEs in-depth, as well as the exploration of best practice in two additional SMEs where innovative technology was adopted for manufacturing, and taking a step back to investigate the journey of less mature start-up SME and their journey of supply chain evolution and growth.

1.1.2 Research contribution

Applied research of supply chains in practice in this thesis resulted in contributions to both academia and practice, as summarised in Table 8.1 in Chapter 8. The contributions ranged from the further generalisability and application of Quick Scan Audit methodology (QSAM) in the Australian context to determine supply chain maturity, adding to the international database of knowledge (contributing to academia), and the ability to benchmark performance (potentially assisting academia and practice), to the extension and testing of a conceptual model in the start-up SME space in Australia, to investigate the journey of growth and supply chain evolution in a longitudinal case study as per Chapter 6. According to Christopher and Juttner (2000, p. 6) “managerial guidelines are often conceptual and derived exclusively from literature reviews”. This research offers insight into practice, which is anchored in theory/literature that can assist practice and academia.

1.1.3 Thesis overview

This thesis comprises of eight chapters. The structure of this thesis is as follows; it begins with an introduction and overview of the research in Chapter 1, targeting the importance of supply chains and SMEs within manufacturing in the Australian context that have motivated this study. Next, Chapter 2 provides a broad literature review for this thesis, and contains the key themes of supply chain (SC) and supply chain management (SCM), assessment tools and techniques to diagnose supply chains

(specifically SC maturity) and benchmark performance, followed by barriers to this and the impact of innovation, including key enabling technologies, on the supply chain. This review provides the theoretical and conceptual justification for this study. Chapter 2 also presents the overall research question and sub-questions, which are summarised in Figure 2.6, to address gaps identified in literature. Gaps, such as insight into the maturity of Australian SCs, as established in other countries (Childerhouse et al, 2011d; Towill et al., 2002), presented an opportunity to utilise a robust diagnostic tool, QSAM, as explained further in Chapter 5. More specific literature reviews to accompany research questions and findings are contained in each of the three findings chapters (4, 5 and 6) as explored in Section 2.1.

Chapter 3 outlines the research design, method and methodologies used within this thesis, including the use of applied field research, case studies and mixed methods, assisting in achieving data, researcher and method triangulation (Childerhouse and Towill, 2011a; 2011b; Böhme et al., 2014a) throughout this research. Multiple paradigms are presented and an interpretivist, qualitative approach is taken to investigate research questions throughout this thesis.

Chapter 4 is the first of the three findings chapters. Chapter 4 presents the foundation and context for this thesis and focuses on Australian SMEs within manufacturing, and the state of their supply chains and value streams. QSAM is presented and utilised to establish an early insight into the state of SC maturity in Australian SMEs within manufacturing, through investigating two SMEs. Whilst these SMEs had histories of strong past performance, the changing competitive environments and ability to innovate was causing the potential future outlook to become concerning, which was discovered through conducting multiple QSAMs. QSAM is an applied diagnostic tool, described by researchers as being a rigorous, well-tested, “transferable” methodology (Childerhouse and Towill, 2011a, p. 635) that offers a context-free measure (Böhme, 2014a; 2014b), allowing for the diagnosis and benchmarking of performance (against an international database of knowledge) for practitioners/industry. It provides insight into supply chain maturity in practice and levels of systems uncertainty. In this research, QSAM is extended to include how SC maturity and systems uncertainty link to innovative opportunities.

Chapter 5 introduces cases of best practice from the United Kingdom, that are applicable to the Australian cases that were presented, and how their SCs have evolved over time and successfully survived. The rationale for choosing UK cases is explained further in Section 5.3. Cases such as these in the UK, to the researcher’s knowledge, were not evident in Australia at the time of this research. SMEs in North West of England were found to have similar histories in regards to being from previously strong industrial regions (in furniture, ship building, and textiles for example) using traditional

manufacturing methods. Manufacturing started to decline some years ago however (European Commission, 2016), resulting in the closure of many businesses. This compelled the existing SMEs to evolve to survive. This research discovered examples of best practice, whereby SCs evolved and businesses were able to rejuvenate the region (European Commission, 2016). This was done through SMEs incorporating innovative technology into their SCs in conjunction with traditional manufacturing. The adoption of such innovative technology was significant, as the SMEs were not initially viewed as being technologically advanced (such as those in aerospace or biomedicine), but they had the willingness and curiosity to learn and adapt to current environmental demands. Applied research was able to reveal learnings regarding the impact on manufacturing systems and the adoption process of an innovative technology, 3D printing/Additive manufacturing. The adaptation of the SMEs to the environment, adoption of 3D printing (as one form of innovative capability enhancement), and insight into the introduction of additional VSs from the introduction of innovative technology within these case studies were found to potentially be applicable to other organisations, including those in Australia.

Chapter 6 is the final findings chapter. This chapter takes a step back to look at an SME in their early, start-up stages. Although the cases of UK best practice were informative, they cannot simply be applied to the Australian context without translation. The context that a SC operates within impacts performance (Cuthbertson and Piotrowicz, 2011). By studying Company X, an Australian start-up company, such translation can occur. Taking what was learnt from the initial insights into SC maturity in practice in Australia in Chapter 4 and examples of best practice overseas in Chapter 5, further research was conducted into a single Australian case study, Company X. Through conducting applied research on a single longitudinal case study, it became evident that Company X encountered many common barriers to SC maturity and innovative opportunities that were evident in the other SMEs studied. As compared to the Australian and UK SMEs studied as part of this research, Company X's SC was still in its infancy. Apart from maturity, the other Australian and UK SMEs were also considered to be more traditional and more established as compared to Company X. Due to Company X being less mature, it allowed the researcher to gain an understanding of barriers to SC maturity as the SC grows. It also showed many changes due to Company X being an innovative start-up company whom manufacture 3D printers and operate in a turbulent environment. In order to keep up with the changes, design thinking was required (Bashiri and Tabrizi, 2010). Using applied research highlighted the barriers to assist the case company in creating an awareness and understanding of their SC and opportunities going forward. It also allowed the researcher to apply, test and extend a model which shows a consolidated view of the manufacturing system, the PDP model (Böhme et al., 2014a), and add a further dimension to three-dimensional concurrent engineering (Fine, 1998). Learnings from this

chapter will contribute to assisting other SMEs, as well as larger organisations, in their SC evolution journeys, adaption to common barriers to SC maturity and creating more innovative opportunities through capability enhancement.

Finally, an overall discussion of the thesis is presented in Chapter 7, followed by the conclusion in Chapter 8, including areas for further research and original contributions made to practice and academia through conducting this research. Next, the literature review is presented in Chapter 2.

2. Literature Review

Supply chains are at the heart of the way in which organisations operate and compete today; they also play a critical role in overall organisational performance (Wildgoose, Brennan and Thompson, 2012, p. 56).

2.1 Introduction

Supply chains (SCs) are of great importance to organisations of all sizes, with their importance continuing to increase (Beck, Hofmann and Stölzle, 2012). Wildgoose, Brennan and Thompson (2012) describe SCs as being at the heart of organisations, due to their significance to performance. SCs however, go beyond being the centre or heart of individual organisations. They are an important part of a network of businesses, each strategically designed to compete on multiple levels, from operational to strategic and tactical. As many researchers have acknowledged, it is SCs that compete against each other, rather than individual businesses (Christopher, 2011); thus, understanding an organisation's SC and how best to manage it can be said to be of importance to an organisation's success. SCs involve multiple departments, disciplines and knowledge bases coming together to ensure that raw materials and information are transformed into the product and/or service that the customer wants. The field of supply chain management (SCM) has been evolving over the years along with the configuration of SCs, due to impacts such as (but not limited to) changing business needs, and the introduction of innovative technologies and processes. Such pressures, as well as competition from around the world, have increased the need to consider the areas such as technology and innovation as well as alternate manufacturing methods (Rylands et al., 2016) that impact on the SC and business performance.

The purpose of this chapter is to explore key areas in SCM literature in order to identify and address the gaps in the literature and to form research questions, which are summarised in Figure 2.6. This chapter presents a broad literature review, that gives an overview of the main themes of this thesis, including SCM, SC maturity, innovation and barriers/enablers, that have the potential to impact on small to medium-sized enterprises (SMEs) in the context of Australian manufacturing. This research adopts the Australian Bureau of Statistics (2009) definition of SMEs, with SMEs consisting of less than 199 employees. Manufacturing and SMEs have been attributed to much success and the wellbeing of many countries over the years, being referred to as the backbone of the Australian economy (Evans, Bosua and Fourie, 2016), as well as the economies of other countries. An exploration of how to preserve SMEs and enhance their performance can therefore be beneficial from an economic/practice viewpoint,

as well as from that of academic research. SMEs also experience fast-paced changes in their environments, and whilst many larger organisations also encounter changes, larger organisations face challenges at a different clockspeed (Fine, 1998). This presents challenges for SME survival, but also opportunities for scholarly investigation into the lifecycles and challenges faced, as Fine (1998) discovered with his research of fast-paced industries/companies.

SMEs and the manufacturing industry have been facing changes, particularly from the introduction of innovative technology. Although technologies have affected manufacturing since the First Industrial Revolution, there is still much to learn, regarding the possible impacts that the next wave of technological innovation may have. This is particularly important to Australian SMEs, and to the question of whether SC maturity could attribute to enhancements in innovation capability (Böhme et al., 2014a). Some of the technologies from this recent wave are described as being “at the heart of most manufacturing processes” (Filipov and Vasilev, 2016, p. 71), and so their potential to create a disturbance or add to uncertainty within organisations could be substantial. When considering such impacts, Cohen et al. (2015) among others warn that complacency is not an option, and that further research into this area is warranted (Filipov and Vasilev, 2016).

To guide this research, after consideration of the literature, an overarching research question was formed. This research question is as follows:

- ❖ What is the current status of SC maturity and innovation within Australian manufacturing SMEs and how can this be enhanced through the adoption of innovative technology and/or processes?

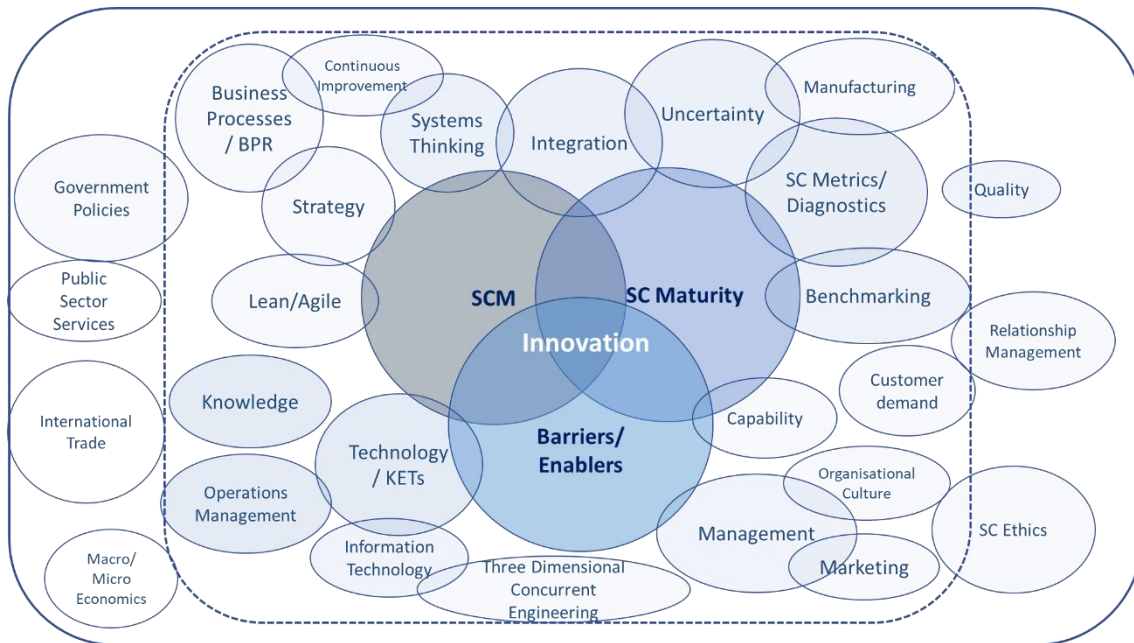
The overarching research question is further examined using five specific research questions, which are introduced throughout this chapter and summarised in Figure 2.6 in Section 2.9. The five research questions are divided across three separate findings chapters, Chapters 4, 5 and 6, each with specialised literature reviews to accompany the specific research questions and findings within each chapter.

The structure of this chapter is as follows: it begins by exploring the key themes and scope of this research, followed by SCM literature, including the background, definitions, scope and evolution of SCM. Next, SC literature in Australia is investigated, identifying key themes, followed by SC assessment techniques and tools, SC maturity, barriers to maturity, innovation, enablers and the impact on SCs. This chapter finishes with a conclusion.

2.2 Key themes and scope of research

Research, whether it is documented in a journal article or a PhD thesis such as this, has a set scope and is bound by limitations. Limitations may include (but are not limited to) time, resources, finances and even researcher knowledge or skill (Remenyi et al., 1998). Research can take many forms, due to the availability of different research areas, tools and methodologies (Remenyi et al., 1998), and it may not necessarily follow a linear process (Mackenzie and Snipe, 2006). The researcher may choose to follow multiple processes during the research process. As an example of this, Remenyi et al. (1998) present eight phases of research, including: (1) reviewing the literature; (2) formalising a research question (or questions); (3) establishing the methodology; (4) collecting the evidence; (5) analysing the evidence; (6) developing conclusions; (7) understanding the limitations of the research; and (8) producing management guidelines or recommendations (Remenyi et al., 1998, p. 64-65). Similarly, MacKenzie and Snipe's (2006) research journey adds the additional steps of considering the chosen paradigm, determining the area to investigate and the approach to research (preceding the literature review step), and further details the data type and collection process. In contrast, Lewis (1998) presents a six-stage process, specifically focusing on case-study methodology, separated into multiple phases, to assist with management or operational field work focusing on real-world case studies. These models share similarities in regards to focusing on an area of research, and using literature and other means of data collection to answer research questions and come to conclusions that may benefit scholarly and/or practitioner audiences. Considering these models and the need for direction throughout the research process, this research used a combination of each approach as a guide, with Remenyi et al.'s (1998) research phases being useful for structuring the thesis layout, and Mackenzie and Snipe's (2006) and Lewis's (1998) research frameworks informing the undertaking of the research process as per Figure 3.0.1 in Chapter 3. Key themes and the scope of the research have been summarised in Figure 2.1.

Figure 2.1: Key Themes and Scope of Research



Source: Based on Böhme et al., 2014b; Böhme, 2012; Childerhouse, 2002

Figure 2.1 shows the main themes of this research, which are initially introduced in a broad literature review in this chapter, followed by further detailed literature reviews in Chapters 4, 5, and 6. The bubbles within the inner dotted lines in Figure 2.1 show the main themes covered in this thesis. Those outside the dotted line, such as Government policies and environmental factors/economic impacts, are mentioned as they do impact on the SC; however, these areas are outside of the scope of this research and are not presented in detail.

At the heart of Figure 2.1 are the key themes of SCM, SC maturity, and barriers and enablers to achieving SC maturity, with innovation at the centre. Each of the main themes overlap due to being closely related within this research, and all are linked to the area of innovation, which is explored further in Chapters 4,5 and 6. This research begins with a broad focus on SC and SCM, specifically SCM within Australia, which provides context for this research. Closely linked to this is the exploration of the state of Australian SCs, particularly with a view to further understand SC maturity within SMEs in the manufacturing industry; which is investigated in greater details in Chapter 4, along with barriers to achieving SC maturity. Together, these key areas provide the foundation for this research, and the opportunity to further investigate opportunities for Australian SCs. Building upon this, is the area of innovation. Innovation and enablers, or key enabling technologies (KETs), that impact on SCs are explored in Chapter 5. This is due to the importance and impact of recent

advances such as Industry 4.0, with examples of best practice presented involving established/mature SMEs, and the impact this had on their SCs and value streams (VSs). The learnings in Chapter 5 have the potential to be applied in the Australian context. In Chapter 6, the SC of a less mature SME is investigated in a longitudinal study through mapping their journey of SC evolution and the impact of innovation on their SC. Through conducting this research, insight is provided into current and possible future states of Australian SCs, and the impact that innovation and innovative technology can have.

Surrounding the key themes in Figure 2.1 are areas such as the paradigm of systems thinking, which was adopted for this research and is central to SCM, as well as SC diagnosis to determine the state of SC maturity and the ability to benchmark performance, which is explored in Chapters 2, 3 and 4. SC integration, both internally and externally, also plays an important role in SC maturity, (Childerhouse et al., 2011b). Another key variable for determining SC maturity levels in this research is uncertainty, which is explored using the uncertainty circle model; as explained further in Chapter 4. The adoption and implementation of KETs are narrowed down and investigated in Chapter 5. Also included is three-dimensional concurrent engineering, as the interaction of product, process and supply chain can be important factors to consider for business strategy, performance and evolution as explored in Chapter 6. Other areas such as management and continuous improvement, which are topical as well as applicable to many organisations in the pursuit of improving efficiency, can relate to each of the key themes of this research.

Other areas, such as SC ethics, quality, international trade and Government policies, are shown in Figure 2.1 as being outside of the scope of this thesis. This does not discount the importance of these areas, as each plays an important role in business and research. However, while these areas are mentioned, they are not explored in detail, as they are outside the scope of this research.

Next, the literature review is presented. It begins with the introduction of SCM literature, and explores a broad review of literature in line with the key research themes in Figure 2.1.

2.3 Supply chain management background and definition

The disciplines of operational research, logistics and supply chain management have existed for many years. Speranza (2018, p. 830) stated “The history of transportation and logistics is as long as the history of mankind, but has been marked by recent milestones”; similarly, Chopra, Lovejoy and Yano (2004, p. 8) commented, “It is difficult to pinpoint the origins of our field.” The origins of SCM and the functions that constitute it can be traced back many years before the title of SCM was applied. SCM is said to have roots in logistics, transportation and the military prior to the 1950s (Ballou, 2006; Lummus,

Krumwiede, and Vokurka, 2001). According to the literature, the phrase “supply chain management” was introduced by management consultants in the 1980s (Oliver and Webber, 1992). SCM stems from systems theory, which is concerned with understanding a system in terms of all of its parts as a whole, and the interaction between them (Maani and Cavana, 2007). A systems thinking approach is said to “organize one’s thinking to understand the complexity of a real-world phenomenon more clearly” (Kefalas, 2011, p. 345), which applies to this research. Although the importance of SCs and SCM has been established in practice and academia (Wildgoose, Brennan and Thompson, 2012), Halldórsson, Larson and Poist (2008), LeMay et al. (2017) and Croxton et al. (2001), among others, have identified that there is not yet a consensus on a single definition of either term.

SCs can be defined as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer” (Mentzer et al., 2001, p. 4). SCM can be defined as; “the management of relationships in the network of organisations, from end customers through original suppliers, using key cross-functional business processes to create value for customers and other stakeholders” (The Global Supply Chain Forum, as cited by Lambert, 2014). Table 2.1 shows a sample of alternate definitions.

Table 2.1: Definitions of SC and SCM

| Definitions of SC | Definitions of SCM |
|--|---|
| “a network of connected and independent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users” (Christopher, 2011, p.4). | “Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies” (Council of Supply Chain Management Professionals, 2018, no pagination). |
| “the set of value-adding activities that connects a firm’s suppliers to the firm’s customers” (Harrison, Lee, and Neale, 2003, p. 4). | “...the recognition of a direct link between leadership and control of the supply function to the ultimate end customer and corporate |

| | |
|--|--|
| | competitiveness" (Morgan and Moncza, 2003, p. 42). |
| "...all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing, and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities. Supply chain management coordinates and integrates all of these activities into a seamless process" (Lummus and Vokurka, 1999, p. 2). | "an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user", as summarised by Ellram and Cooper (1990, p. 2) after reviewing multiple definitions. |
| La Londe and Masters (1994) refer to a supply chain as the passing of materials forward by a set of firms which convert raw materials into finished goods to sell to each other (e.g. between firms and wholesalers), down to the consumer. | "Supply chain management (SCM) is the management process of supply chain activities for maximizing customer satisfaction and realizing sustainable competitive benefit" (Abdel-Basset, Manogaran and Mohamed, 2018, p. 616). |

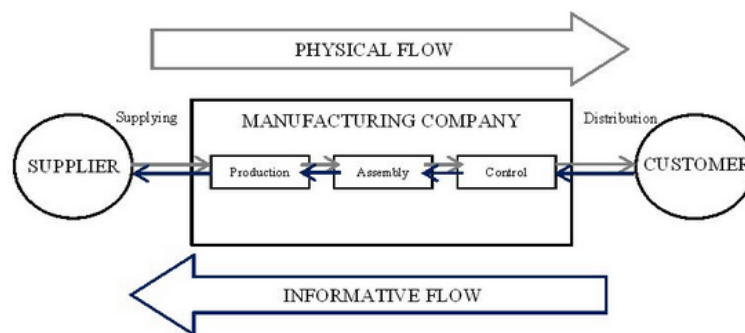
Source: Author

Though the definitions vary, some interesting changes, particularly for SCM, have occurred over approximately the last 16 years. Whilst the focus throughout the definitions still remains on the goal of delivering value to the end customer and other stakeholders, the themes of relationship management, networks and key-cross functional business processes have been introduced. Stevens and Johnson (2016, p. 24) stated, "The role of supply chain and the focus for SCM can therefore, be summarized as to support an organisation to win business completely by addressing the strategic imperatives of differentiation, cost advantage, resilience and dynamism (agility, flexibility, responsiveness)." This research adopts The Global Supply Chain Forum's (2014) definition of SCM and the view of Stevens and Johnson (2016) in regards to the role of SCM and SCs.

As with the multitude of definitions of SCs and SCM, there are also differing SC configurations that organisations may choose to implement. This may depend, for example, on the organisation's

chosen strategy, technological and environmental factors (Stevens and Johnson, 2016). Two examples of SCs have been included (Figures 2.2 and 2.3). This is not to dictate how SCs must look; it is merely to show simplified examples of two types of SCs. This includes a SC with physical and information flows between separate entities (Figure 2.2), and an integrated SC that incorporates suppliers and customers into the SC (Figure 2.3). These two examples have been provided as they represent opposite sides of a SC continuum, between low or nil integration and extended integration of a SC.

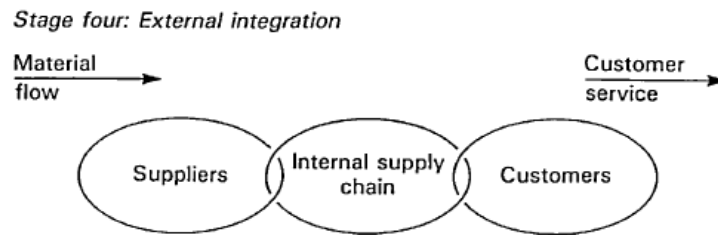
Figure 2.2: General Scheme of a Supply Chain, Underlining Materials and Information Flows



Source: Regattieri and Santarelli, 2013, p. 343

Figure 2.2 is an example of a manufacturing SC, comprising of key elements that allow for raw materials, procured from key suppliers, to be manufactured into products for the end customer. Each entity, from the supplier, to the manufacturing company to the customer is separate. There may be multiple inventory staging points throughout such a SC, and internal and external integration throughout the SC may be minimal. Importantly, Figure 2.2 included not only the physical flow of materials that are processed to become the end product, but also the information flow that is vital for the manufacturing company and the SC (Regattieri and Santarelli, 2013), to ensure that what is being produced is meeting customer needs. This information not only allows for feedback to the company about its products, but it may also allow the company to ensure that it is working effectively with suppliers to procure quality raw materials, maintain adequate inventory levels, and implement efficient processes that may allow for the continuous flow of materials through the SC.

Figure 2.3: Achieving an Integrated Supply Chain – Stage Four



Source: Stevens, 1989, p.7

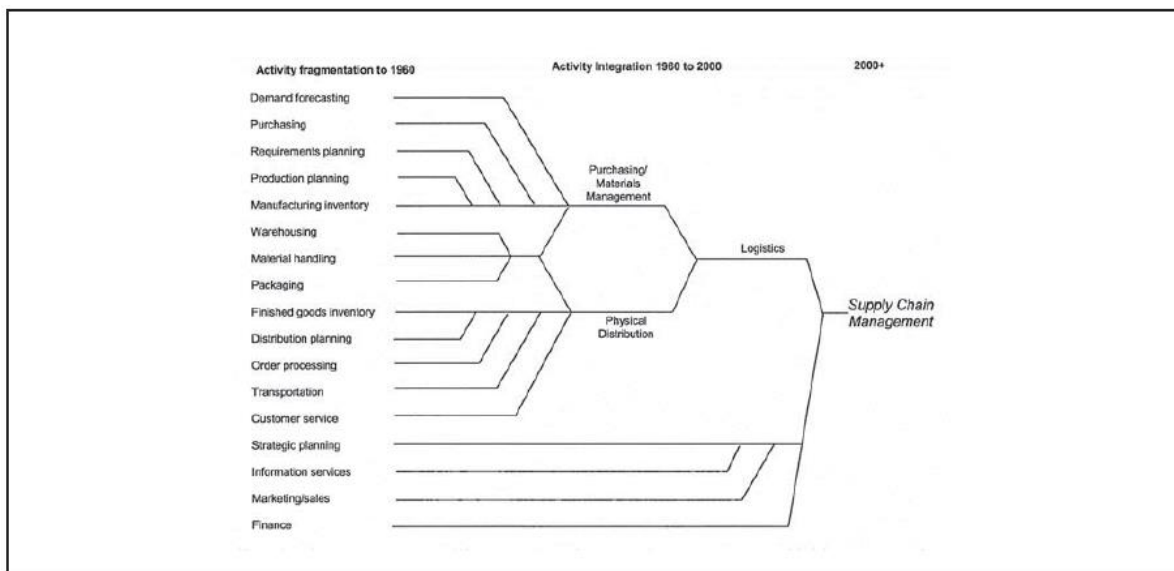
The SC shown in Figure 2.3 builds upon Figure 2.2, to represent the achievement of an externally integrated SC, with the suppliers, internal SC and customers coming together. In a study by Stevens' (1989), four stages of supply chains were originally identified, ranging from "baseline" (Stevens, 1989, p. 6), where departments are separate and inventories are staged at multiple points of the SC (Stevens, 1989), which is similar to the SC in Figure 2.2, through to "external integration" (Stevens, 1989, p. 7), which links suppliers, the company's internal SC and customers. According to Stevens (1989), external integration with suppliers and customers causes a shift in attention from the product to the customer, as well as streamlining processes and having the SC working together as a whole to achieve optimum efficiency. This may include, for example, sharing order information and decreasing inventories, including reducing the need for inventory to be kept at each point in the SC as in baseline SCs, largely reducing waste. SCs are constantly evolving however, and the externally integrated SC, as acknowledged by Stevens and Johnson (2016), is no longer the end point of SC evolution. Moving beyond the confines of the linear SC are network and collaborative SCs (Stevens and Johnson, 2016) that have emerged due to changes in technology, relationships and business needs, with suggestions that there will be further changes to come (Stevens and Johnson, 2016).

2.4 Supply chain management scope

Stevens (1989, p. 3) noted that "(t)he scope of the supply chain begins with the source of supply and ends at the point of consumption". The scope of SCM is broad, containing multiple functions, departments and entities. As discussed in Section 2.2, SCM is constantly evolving (Halldórsson et al., 2007; Larson and Halldórsson, 2002). This evolutionary process has been summarised by Ballou (2006) in Figure 2.4, which shows one example of the components or activities of SCM at different stages from the 1960s onwards. It depicts the many different business activities coming together and evolving to form important components of what many consider as being SCM today. For example, procurement

and planning tasks were amalgamated and separated from inventory, warehousing and handling of goods for instance. This allowed for the focus to be on two functions/departments, purchasing and materials management and physical distribution, instead of on thirteen different activities. These functions are then shown to have been integrated to form logistics, with departments such as Information Technology (IT), marketing and finance being kept separate. Halldórsson, Hsuan and Kotzab (2015, p. 575) describe SCM “as being at an early stage in its evolution”, with more changes to come. Importantly, as noted by Chopra, Lovejoy and Yano (2004, p. 10), “...the field needs to continually check its research against evolving industry reality”, and so it is expected that research and the evolution of the SCM field will continue to develop beyond what has been captured in Figure 2.4.

Figure 2.4: Evolution of Supply Chain Management



Source: Ballou, 2006, p. 379

Different streams or schools of SCM thinking have also evolved. In a review of literature, Bechtel and Jayaram (1997), summarise five of the schools of thinking available at the time of their research: “The functional chain awareness school” (p. 16), which as the name suggests, acknowledges the various departments or functions within the SC, with a focus on the material flow; “The Linkage/Logistics School” (p. 17), which is described as taking the next step towards establishing how functions can better harness their competitive ability through the connection or linkages between departments, with improved logistics and enhanced flow; “The Information School” (p. 18), which focuses on information flow throughout the SC and its members in all directions; “The Integration/Process School” (p. 18), which focuses on the SC from a systems perspective to best serve the customer, which the authors

describe as having more flexible SC functional arrangements or configurations than the linkage school; and the “Future” (p. 18), which could include SC relationships and the change of focus from SC to demand chains (Bechtel and Jayaram, 1997; Christopher and Ryals, 2014; Childerhouse, Aitken and Towill, 2002), among other changes.

There are also alternate views to those presented by Bechtel and Jayaram (1997), regarding not only the SC, but the evolution and composition of SCM and the relationship between SCM and logistics (Halldórsson, Larson and Poist, 2008; Klaus, 2009). Some studies replace, adapt or even rename SC and logistics theories (Larson and Halldórsson, 2002). According to Larson and Halldórsson (2002), how SCM is viewed in relation to logistics - from traditionalist, relabelling, unionist and intersectionist perspectives for example - can influence the role of SCM in organisations and academia. Traditionalists view SCM as “a subset of logistics” (Halldórsson, Larson and Poist, 2008, p. 128) with SCM having a focus on logistics outside of the organisation. Re-labelling, as the name suggests, replaces the term logistics with SCM (Halldórsson, Larson and Poist, 2008). Unionists “position logistics within SCM” (Halldórsson, Larson and Poist, 2008, p. 128), and intersectionists view logistics and SCM as integrating or overlapping disciplines (Halldórsson, Larson and Poist, 2008). Halldórsson, Larson and Poist (2008) note that each has either a narrow or broad perspective of SCM, with re-labelling and traditionalism being narrow, and intersectionism and unionist being broad. Overall, definitions, conceptions of and research into SCM, as well as the degree to which research focuses on the functions and organisational departments that are classified as being part of SCM (Ballou, 2006), vary. As mentioned, others studies have shifted their focus towards alternate areas such as demand chains instead of SCs (Christopher and Ryals, 2014; Childerhouse, Aitken and Towill, 2002), process maps and the breaking of SCs down into value streams to better identify and focus on areas of waste or improvement (Hines et al., 2006; Christopher, et al., 2009; Childerhouse and Towill, 2004). This research adopts a unionist-like view, with logistics being considered part of SCM. It also views SCs as comprising of individual value streams, rather than the term “value stream” being used interchangeably with the term “supply chain”.

Value streams (VSs), popularised by Womack and Jones (1996) (Childerhouse and Towill, 2006), have been defined as “only...the specific parts of the firms that actually add value to specific product or service under consideration” (Hines & Rich, 1997, p. 46), from beginning to end, including from the design stage to raw materials, final product and the end customer (Womack and Jones, 1996). Each VS may represent a certain product that is being reviewed that makes up part of the total supply chain (Childerhouse. Aitken and Towill, 2002). Childerhouse and Towill (2006, p. 358) note that “(a) practical differentiation is that a supply chain consists of a bundle of one or more multiple value streams”, which is the view that this research takes. Using VSs in applied research allows researchers and practitioners

not only to focus on key areas, but also to investigate how they impact on the wider SC or network (Rylands et al., 2016; Böhme et al., 2014c); they have been used in this way throughout this research.

Overall, whilst SCM can be viewed as a broad field with multiple definitions and possible SC configurations, it has been established as an important area for both academia and industry, and can be said to be a vital area that organisations need to manage (Anekal, 2018). Therefore, this section provided an overview of SCM and an introduction to establishing the importance of SCM as a focus area for further research. The next section explores SCM in the Australian context.

2.5 Supply chain management – an Australian perspective

Literature shows that the focus on SCM has received increased attention over the years, including in Australia. A review of Australian literature revealed that this interest does not appear to be restricted to a certain industry, with the spread of SCM research being quite broad. Industries encompassed in the various Australian studies include, but are not limited to, Australian agribusiness (Jie et al, 2013), automotive (Singh et al., 2005; Quek and Wang; 2017), manufacturing (Schliephake et al, 2009; Warren and Gibson, 2013), healthcare (Bhakoo et al, 2012; Böhme et al., 2013), road freight (Ferrer et al., 2010) and construction (Böhme et al., 2018), to name a few. These studies covered a number of topics, from technology such as RFID (Angeles, 2009), e-business models (London and Singh, 2013) and m-commerce (Lu and Swatman, 2009), to SC integration, development, relationships and collaboration (Rylands et al, 2015). Even though the industries and focus areas varied, the acknowledgment of the importance of the concept of the SC to business was a common theme. Table 2.2 summarises some key Australian SCM investigations and provides an overview of important topics in Australian SCM literature by industry.

Table 2.2: Supply Chain Themes in Australian Literature

| Industry: | Agriculture / Food / Grocery | Healthcare / Hospitals | Automotive | Textiles / Clothing / Footwear | Education | Defence | Wholesalers / Distributors | Financial | Manufacturing / Construction | Road freight / Logistics | Wine/ Alcoholic beverages | Mixed / Other |
|---|------------------------------|------------------------|------------|--------------------------------|-----------|---------|----------------------------|-----------|------------------------------|--------------------------|---------------------------|---------------|
| Theme / Topic: | | | | | | | | | | | | |
| Value chain management / Supply chain management - Howieson et al. (2013); Bhakoo, et al. (2012); Lu and Swatman (2009); Singh et al. (2005); Jie et al. (2013); Perry and Sohal (2001); Sohal et al. (2002); Wright and Lund (2003); Collie (2010); O'Keefe (1998); Sohal and Perry (2006); Prajogo and Sohal (2013); Sohal et al. (2002); Latif and Parker (2014); Andrew et al. (2008); Mollenkopf and Dapiran (2005); Closs and Mollenkopf (2004); Warren and Gibson (2013a); Warren and Gibson (2013b); Oke et al. (2013); Ferrer et al. (2010); Mahadevan et al. (2010); London and Singh (2013); Schliephake et al. (2009); Angeles, 2009; Böhme et al. (2014a); Böhme et al. (2014b); Fayezi and Zomorodi (2015); Quek and Wang (2017); Varsei and Polyakovskiy (2017); Uddin (2017); Bi (2017); Böhme et al. (2018) | x | x | x | x | x | x | x | x | x | x | x | x |
| Product attributes / innovation - Howieson et al. (2013); Oke et al. (2013); Böhme et al. 2014 (b) | x | | | | | | x | | x | | | x |
| Material flow / inventory - Howieson et al. (2013); Bhakoo, et al. (2012); Schliephake et al. (2009) | x | x | | | | | | | x | | | |
| Information flow - Howieson et al. (2013); London and Singh (2013) | x | | | | | | | | | | | |
| Relationships / SC networks / collaboration - Howieson et al. (2013); Bhakoo, et al. (2012); O'Keefe (1998); Latif and Parker (2014); Oke et al. (2013); Ferrer et al. (2010); Mahadevan et al. (2010); Uddin (2017) | | x | | | | x | | | x | x | | |
| M-Commerce / E-Business / E-Supply chain/ technology in SC - Lu and Swatman (2009); Sohal et al. (2002); London and Singh (2013); Angeles, 2009; Bi (2017) | x | | | x | | | x | | x | | | x |
| Contemporary issues in SC / industry challenges - Singh et al. (2005); Sohal and Perry (2006); Latif and Parker (2014); Mollenkopf and Dapiran (2005); Closs and Mollenkopf (2004); Warren and Gibson (2013a); Warren and Gibson (2013b); Böhme et al. (2018) | x | | x | | | | | | x | | | |
| Assessing management actions / SC's - Jie et al. (2013); Perry and Sohal (2001); Schliephake et al. (2009); Böhme et al. (2014b) | x | | | x | x | | x | | x | | | x |
| SC integration/relationship integration/ coordination - Sohal et al. (2002); Mahadevan et al. (2010); Angeles, 2009; Böhme et al. (2014b); Fayezi and Zomorodi (2015); Uddin (2017) | x | | x | x | | x | x | | x | | | x |
| SC visibility - Mahadevan et al. (2010) | | | | | | | | | x | | | |
| SC design/ structure (e.g. network)/ restructuring - Andrew et al. (2008); Varsei and Polyakovskiy (2017) | | | | | | | | x | x | | x | |
| Industry needs / SC competencies / professional development - Sohal (2013); Prajogo and Sohal (2013); Ferrer et al. (2010) | x | | | | x | | | | x | | | |
| Sustainability - Varsei and Polyakovskiy (2017) | | | | | | | | | | | x | |
| Contract practices - Quek and Wang (2017) | | | | | | | | | | | | |
| SC agility/ flexibility - Fayezi and Zomorodi (2015) | | | | | | | | | x | | | |

Source: Author

However, some topics or areas were not (to the author's knowledge) available in Australian SCM literature at the time of this research, such as SC maturity in Australia. SC maturity and integration, along with benchmarking, had appeared in international searches of SCM literature (Stevens, 1989; Frohlic and Westbrook, 2001; Lockamy III and McCormack, 2004; McCormack, Ladeira, and de Oliveira, 2008; Netland and Alfnes, 2011; Childerhouse et al., 2011b), along with mentions of the importance of each to SC research in academia, as well as for practitioners to be able to benchmark their performance in industry. The ability to perform an appropriate SC assessment and establishing SC maturity in Australia was therefore viewed as being of importance for this thesis, as a way to gain context and a foundation for this research. SC maturity differs for each organisation, depending on factors such as age, experience and industry. Levels of maturity can be established through various maturity models, which are explored more in Section 2.5. A maturity model "aims to aid companies in benchmarking the maturity of their operations relative to industry best practice" (Netland and Alfnes, 2011, p. 67). Regarding the assessment of SC maturity, Netland and Alfnes (2011, p. 66) stated that it "is crucial for the development of a coherent operations strategy that encompasses customers and suppliers...". Although there was mention of SC integration, this literature review identified a gap in regards to insight into SC maturity in Australia. After reviewing the Australian literature, this gap led to the first research question.

- Research question 1: How mature are Australian supply chains in practice?

The aim of this research question is to provide early insights through exploratory investigation. The research question is broad as the research considers different sized businesses and SCs, as shown in Chapter 5, however explores two case studies of Australian SMEs in manufacturing in more detail. This assists in providing guidance to the reader, rather than investigating SCs from multiple industries and sizes in depth. This allowed for the researcher to provide early insight into the state of SC maturity in Australia and to provide a foundation for this research.

Larger businesses have been the focus of many studies over the years (Fawcett, Jones and Fawcett, 2012), and have provided much valuable information for academia, as well as benefits for practice and the economy. Larger businesses have also been reported as having a greater survival rate in Australia, at nearly 80 per cent, as compared to smaller businesses (Australian Bureau of Statistics, 2018). Whilst this research does not discount the importance of large businesses, it does acknowledge the importance of SMEs and their survival.

SMEs have long established their importance to the Australian economy, as well as various economies around the world, such as the Mittelstand in Germany (Berlemann and Jahn, 2016).

Australian SMEs can be defined by multiple means, such as by levels of annual turnover or assets, or by number of employees (Australian Securities & Investments Commission, 2013; Royal Commission into Misconduct in the Banking, Superannuation and Financial Services Industry, 2018). This research adopts the Australian Bureau of Statistics' (ABS) (2009) definition that considers the number of employees a business has, with small businesses employing one to four people, and medium-sized businesses employing up to one hundred and 199 people. According to a report by the ABS (2018), in 2016-17, approximately 70 per cent of employing businesses, or nearly 609,000 enterprises, were found to have employed one to four people, whilst less than one percent, or nearly 4,000 enterprises, were found to have employed greater than 200 people. As these figures show, SMEs in Australia account for a large percentage of business and employment (Australian Securities & Investments Commission, 2013). This research has therefore chosen to focus on SMEs in Australia, in particular those within manufacturing and production.

Australian manufacturing has been changing (Evans, Bosua and Fourie, 2016). According to Stewart (2016) and the Australian Bureau of Statistics (ABS) (2012), Gross Domestic Product (GDP) has been dropping for many years since the 1970s and 1980s, with other industries such as healthcare, finance, mining and construction, increasing. There has been a shift in practice from manufacturing towards services, with a strong change in industry. These changes can arguably lead to a loss of manufacturing capabilities and competencies (Bernard, Smeets and Warzynski, 2017). The automotive industry among others within Australia, has been suffering as closures have been announced and have occurred. The announced closure of Ford and other manufactures has the potential to result in major job losses (IBISWorld Media Team, 2014; Stewart, 2016). These closures not only impact on employees and the direct SC, but also other parts of the SC, such as parts suppliers and local communities. This poses difficulties for manufacturing not only in Australia but also in other developed countries (Moutray and Swift, 2013). This research therefore focuses on Australian manufacturing.

In summary, whilst an array of Australian SCM literature is available, there is a gap with regards to SC maturity, in particular concerning Australian SMEs within manufacturing. An aim of this research is to address this gap, via research question 1. To answer this question, which asks how mature Australian supply chains in are practice, an assessment technique is needed, of which a range is available.

The next section explores supply chain assessment techniques to gain insight into how SC maturity can be established.

2.6 Supply chain assessment

Being aware of a business's SC, as well as how best to assess them, is important to businesses of all types and sizes (Netland and Alfnes, 2011). According to Ganasekaran, Patel and Tirtiroglu (2001, p. 71), "...in order to evolve an efficient and effective supply chain, SCM needs to be assessed for its performance". Whilst there are a multitude of SC assessment tools and variables to assess SCs available (Banomyong and Supatn, 2011; Netland and Alfnes, 2011), as well as sentiments as to the most-preferred techniques, there is an agreement in the literature that SC assessment overall is of vital importance to business and academia (Netland and Alfnes, 2011; Ganasekaran, Patel and Tirtiroglu, 2001; Pettit, Croxton and Fiksel, 2013; Banomyong and Supatn, 2011). According to Netland and Alfnes (2011, p. 66), "(i)n order to improve performance, companies need to map their overall current state of practices and point out which best practices they should pursue". SC assessment may include quantitative and qualitative methods (Banomyong and Supatn, 2011), financial and/or non-financial measures, on tactical, strategic and/or operational levels within an organisation (Ganasekaran, Patel and Tirtiroglu, 2001). As noted by Foggin, Mentzer and Monroe (2004), diagnostic tools for SCs have been found to be limited in literature, and predominantly quantitative.

A review of SC assessment techniques, found that the focus for analysis varied and that tools were available for multiple areas ranging from integration and maturity (Stevens, 1989; Netland and Alfnes, 2011; Naim et al., 2002), SC sustainability, environment and green SCs (Ntabe et al., 2015; Bastas and Liyanage, 2018), resilience and risk (Pettit, Croxton and Fiksel, 2013), to industry size, such as SME assessment (Banomyong and Supatn, 2011), tools for third-party logistics (3PL) providers (Foggin, Mentzer and Monroe, 2004) to assessment length in regards to time (Foggin, Mentzer and Monroe, 2004; Banomyong and Supatn, 2011). Table 2.3 summarises a sample of SC assessment techniques and tools.

Table 2.3: Supply Chain Assessment Techniques

| Supply chain assessment method/tool: | Used to assess: | Author(s): |
|---|---|----------------------------------|
| The Diagnostic Tool | Tool for 3PLs to assess SCs of potential clients | Foggin, Mentzer and Monroe, 2004 |
| Supply Chain Operations Reference Model (SCOR) | SC processes | APICS, 2018 |
| Balanced Scorecard | Organisational strategy, focusing on financial and non-financial performance measures | Kaplan and Norton, 1992 |

| | | |
|---|--|--|
| Supply Chain Performance Assessment Tool (SCPAT) | SME internal supply chain performance assessment | Banomyong and Supatn, 2011 |
| Supply Chain Resilience Assessment and Management (SCRAM™) | SC resilience | Pettit, Croxton and Fiksel (2013) |
| Quick scan audit methodology (QSAM) | SC integration / maturity | Childerhouse et al, 2011b; Naim et al., 2002 |

Source: Author

SC assessment techniques and tools are further described below.

2.6.1 The Diagnostic Tool

Foggin, Mentzer and Monroe (2004) identified a gap relating to the assessment of the SCs of potential clients for 3PLs. This resulted in the development of a diagnostic tool to assist with this. This tool can be summarised as follows; it allows for the 3PL to assess potential problems or “pain points” (Foggin, Mentzer and Monroe, 2004, p. 836) and requirements of possible clients, as well as the capability of the 3PL to address these in order to develop a plan of action for the 3PLs, that includes financial considerations (Foggin, Mentzer and Monroe, 2004). The tool, which has been described as being a more rapid diagnostic tool than others (Foggin, Mentzer and Monroe, 2004), consists of a questionnaire (with 140 questions), that the authors anticipate may take approximately an hour for the 3PL salesperson to complete.

2.6.2 Supply Chain Operations Reference (SCOR) Model

The SCOR model, developed over 20 years ago by the Supply Chain Council (APICS, 2018; Foggin, Mentzer and Monroe, 2004) is a commercial tool that allows for the assessment of business processes across organisations and SCs, and cross-industry benchmarking (APICS, 2018). APICS (2018, no pagination) describes it as being “the cross-industry, global standard for supply chain excellence”. SCOR focuses on management processes: plan, source, make, deliver, return (Schrödl, 2012; Ntabe et al., 2015) and enable (Supply Chain Council, 2012). SCOR is useful for organisations wanting to review their SC. SCOR “identifies and eliminates redundant and wasteful practices along supply chains” (Ntabe et al., 2015, p. 311).

SCOR has undergone various revisions since its introduction in 1996 (Ntabe et al., 2015), with APICS (2018) more recently releasing version 12. This version includes topical areas such as block chains and metadata, up-to-date management and training practices, sustainability standards and increased SC alignment (APICS, 2018), among other new features. APICS (2018) have also made applications and guidelines for executing SCOR available online. Due to the detail and number of

metrics within SCOR, however, it can be time-consuming to complete (Lemghari, Okar, and Sarsri, 2018: Purchasing, 1999).

2.6.3 Balanced Scorecard

According to Kaplan and Norton (1992, p. 71), “(m)anagers want a balanced presentation of both financial and operational measures”. After performing research with 12 companies over the period of a year, Kaplan and Norton (1992) developed the Balanced Scorecard which provides “top managers a fast but comprehensive view of business” (Kaplan and Norton, 1992, p. 71). It is described as being like an airplane cockpit (Kaplan and Norton, 1992), with various lights and performance indicators. The Balanced Scorecard focuses on four key areas: financial, customer, internal and innovation and learning perspectives (Kaplan and Norton, 1992). Kaplan and Norton (1993) have noted that although it can be useful for many businesses, as it is “a comprehensive framework that translates a company’s strategic objectives into a coherent set of performance measures” (p. 134), the Balanced Scorecard is not simply a template that is applicable to all businesses and industries. Various factors such as environment, strategy and products influence what each business may need to target in their individual scorecards (Kaplan and Norton, 1993).

2.6.4 Supply Chain Performance Assessment Tool (SCPAT)

In a review of SC performance measurement, Banomyong and Supatn (2011, p. 20) found that many of the available measurement tools were time consuming, describing them as being “complicated and difficult to use in real business settings”. With a focus on SMEs, Banomyong and Supatn (2011) developed a tool to assess the internal performance of the SC via a self-administered questionnaire that takes one to two days to complete (Banomyong and Supatn, 2011). It consists of financial and non-financial measures, focusing on nine activity areas, and has theoretical foundations. Findings from the assessment can be used to benchmark performance against other SMEs, and can assist in improving SC performance (Banomyong and Supatn, 2011).

2.6.5 Supply Chain Resilience Assessment and Management (SCRAM™)

The environment in which SCs operate is becoming increasingly challenging and uncertain. It demands that businesses and their SCs become more resilient in order to compete in such an environment. “Managing change is essential. In the corporate environment, not being prepared for change and not designing and managing a supply chain that can react and adapt quickly can be very costly” (Pettit, Croxton and Fiksel, 2013, p. 57). With this in mind, Pettit, Croxton and Fiksel (2013) developed the Supply Chain Resilience Assessment and Management (SCRAM™) tool for SC assessment. SCRAM™ is described as being a quick assessment that managers can undertake to assess and improve their resilience standing (Pettit, Croxton and Fiksel, 2013). SCRAM™ is survey-based and focuses on

vulnerabilities or “sources of change” (Pettit, Croxton and Fiksel, 2013, p. 57), that allow organizations to assess and improve their resilience, through identification of capabilities, strengths and weaknesses.

2.6.6 Quick Scan Audit Methodology (QSAM)

QSAM has been described as “a powerful methodology” (Banomyong and Supatn, 2011, p. 21), that provides a “health check” (Naim et al., 2002, p. 135) of SCs. It uses triangulated qualitative and quantitative data to gain insight into the SC. Major sources of “pain” are identified, as well as opportunities for improvement. The assessment takes approximately two weeks to complete and involves a team of researchers (Naim et al., 2002). QSAM allows for benchmarking between differing organisations and industries, with an international database available to compare performance. QSAM assists organisations in determining the maturity of their SC; this is explored further in Chapter 4.

In summary, SC assessment is important to organisations and industries of all types and sizes. There are a range of assessment tools available; however, factors such as the required to perform the assessment and the focus of the assessment tool need to be considered before implementation. In the case of this research, assessing SC maturity is of greater priority than assessing other SC characteristics, such as sustainability for instance. QSAM was chosen for this study, as it provides an ability to assess SC maturity; the tool is explored further in Chapter 4. The next section further discusses the subject of SC maturity.

2.7 Supply chain maturity

The importance of determining SC maturity has long been established in literature (McCormack, Ladeira and la Oliveira, 2008). Maturity is said to have roots in industrial engineering and management-related disciplines such as quality management (Fischer et al., 2016). In regards to maturity, including SC processes and evaluation, “...a process has a lifecycle that is assessed by the extent to which the process is explicitly defined, managed, measured and controlled” (Lockamy III and McCormack, 2004, p. 272). According to Koblen et al. (2014), supply chain maturity assessment, made possible via the many maturity models available, allows for the assessment of efficiency in the SC as well as systems, processes and quality for example. In a review by Szymczak, 2013, an array of supply chain maturity models was provided, which include but are not limited to Poirer’s SC maturity model, the SC proficiency model, and the supply chain evolution model. Further models or tools available to assess SC maturity were also presented in the previous section (Section 2.6). As highlighted by Szymczak (2013), although each SC maturity model differs, they all share a common theme of achieving SC excellence. SC maturity is associated with SC integration and collaboration, which in turn allows for an organisation and its SC to perform more efficiently (Rudnicka, 2016). The level of maturity within SCs can range from nil integration internally, all the way to full external integration where there is a

partnership between the SC members (Szymczak, 2013). SC maturity is important to SCM as investigating the maturity of a SC allows for the advancement of the SC due to the insight gained into areas where improvement is needed and the business objectives that are to be achieved (Szymczak, 2013).

By identifying levels of maturity, organisations can benchmark their performance and compare it to best practice (Netland and Alfnes, 2011), which is further explored in Chapter 4. Determining SC maturity has been described as being “crucial” (Netland and Alfnes, 2011, p. 66) to organisations in improving processes (Fischer et al., 2016) and performance, and to meet requirements from the supplier through to the customer. The focus and criteria required to verify SC maturity, such as integration (Szymczak, 2013), flexibility (Fischer et al., 2016), complexity (Szymczak, 2013) and uncertainty (Böhme et al., 2014), which is explored in Section 4.2, can be assessed on varying levels and with multiple measures depending on the model implemented.

According to a study by Böhme et al. (2014), Prajogo and Sohal (2004) emphasised that the maturity of management practices “are a prerequisite to any attempt at adopting, implementing or diffusing innovation within a firm and/or across its SC” (Böhme et al., 2014, p. 6533). Böhme et al. (2014), furthered this concept with a longitudinal study focusing on SC maturity being linked to the level of systems uncertainty; the study posited that lower levels of uncertainty assist with improved levels of innovation. This is due to the fact that time that would be spent fighting fires or dealing with unplanned events, could instead be used to meet business targets, for example. The focus on systems uncertainty also allows for the results of SC maturity assessment to be used in cross-industry benchmarking, or comparing “apples to oranges” (Boehme, 2008) due to it being a context-free variable. This means that organisations can be compared regardless of industry or size, and can then be benchmarked internationally (Böhme et al., 2014a, and Böhme et al., 2014b); this comparison can also provide a link to innovation capability. Uncertainty can be represented in various ways, such as by the uncertainty circle principle model, which depicts the four main areas of uncertainty in an organisation, which are explored further in Chapter 4. Interestingly, a review of literature by Böhme et al. (2014) revealed that uncertainty regarding to SC maturity has not been as widely used in Australian studies as compared to other concepts such as the Lean methodology.

To remain strategic, it is important for countries such as Australia, to consider their ability to be competitive, grow economically, respond to market needs and conditions (Thomas et al., 2012), maintain and attract a skilled workforce for the future (DIICCSRTA, 2013) and be innovative. Innovation and collaboration have been key areas of focus for the Australian Government (Australian Government – Department of Industry, Innovation and Science, 2018), which has been promoting

collaboration between industry and academia to enhance national performance. Thus, benefits from being able to determine SC maturity as well as innovation capability could potentially be of value to academia, practice and policy-makers.

In summary, establishing SC maturity is important to SCs in various industries worldwide. Various tools and assessment techniques are available that may each focus on different measures; this research uses systems uncertainty as a context-free measure that allows for the comparison and benchmarking of different organisations, as well as its ability to function as an indicator of organisational innovative capability. Although the literature appears to be scattered, this research has the potential to contribute to further in-depth knowledge through applied research within Australia. Additionally, through using uncertainty data, this research can contribute to benchmarking the maturity of Australian organisations (Appendix A - Supply chain maturity in practice sample) to that of international performance, which was not evident in the literature reviewed. This contribution can be useful for both practice and academia.

Importantly however, there are barriers to SC maturity that, in turn, can impact on innovation capability and an organisation's performance. The next section further explores barriers to SC maturity and innovation.

2.8 Barriers to supply chain maturity and innovation

A barrier can be defined as "anything that prevents access, progress, or union" (Collins, 2007, p. 46). Freel (2012) breaks down resource constraints or barriers into several categories: management and marketing, skilled labour, information and finance. In other studies, SC barriers (or enablers, depending on the context) may include such factors as culture (Hofstede, 1983), technology, human and physical capital (Moutray and Swift, 2013), silo mentality between departments/organisational structure (Christopher, 2011), financial constraints (Blanchard et al., 2012), trust within and between organisations, networking and collaboration, time (Loewe and Dominiquni, 2006) and uncertainty (Childerhouse and Towill, 2011d). A major barrier within organisations, as identified by Perel (2002) is that of management courage in regards to innovation and long-term planning, or even a fear of failure (Myers, 1984). It may be difficult for managers to justify investing in the necessary R&D to develop innovation capability if they only focus on the potential risk (Loewe and Dominiquni, 2006) without looking at the value it can bring. All of the barriers mentioned can have an impact on effective SCM. It is important for organisations to be able to identify and understand SC barriers to in order to enhance their competitive ability, meet goals (Fawcett, Magnan and McCarter, 2008) and remain innovative in an increasingly turbulent environment.

According to Perel (2002, p. 9), many managers feel that “innovation [is] essential for their very survival”. Innovation, which is explored further in Section 2.8, can be more broadly defined as “...the creation and delivery of new customer value in the marketplace with a sustainable business model” (Carlson, 2019, no pagination). Innovation of all types may face challenges or barriers, which can impact an organisation’s performance greatly, depending on, for example, the amount of investment in R&D, or how quickly competitors can innovate. The barriers may present such a challenge that organisations continue to perform the same day-to-day tasks rather than engage in innovation (D’Este et al., 2012). Due to this, it is important to note what potential barriers there may be to efficient SCs and the impact that they can have on innovation.

Assessing the barriers to SC maturity and in turn, innovation enhancement can assist in the innovation process and in demonstrating the value it can bring to organisations. Loewe and Dominiquini (2006, p. 24) focus on three key areas; investigating root causes and not just the obvious problems or issues regarding “leadership behaviours, management processes, people and skills, and culture and values”, working towards solutions, and finding the right solutions for the organisation, not just following existing best practices. This information can be gained through diagnostic tools, including surveys (Blanchard et al, 2012; Loewe and Dominiquini, 2006) and QSAM.

Although technology is important to innovation, people within SCs have been highlighted as being of greater significance (Halldórsson et al., 2008; Lueg et al., 2013). It is important to not only focus therefore on financial SC barriers but also barriers relating to people. Understanding those involved and the impact barriers have on innovation could help organisations compete more effectively. Understanding barriers in relation to SC maturity and innovation leads to the next research question.

- Research question 2: How do barriers to supply chain maturity impact on business innovation?

The next section explores the types of innovation and the potential impact that innovation and innovative technology can have on SCs.

2.9 Supply chain management and innovation

Innovation, as defined earlier, can relate to the creation of new value for customers through products, process, services or other aspects. Witkowski (2017, p. 765) regards innovation as “a process during which something completely new or improved is created, which transforms something which already exists”. Being innovative or having innovative capability “refers to the strength or proficiency of a bundle of interrelated organizational routines for developing new products/processes” (Peng et al., 2008, p. 735). Companies are increasingly focusing on innovation and their SCs to give them an edge over their competitors. While innovation and its impact on organisations though, is not a new concept,

remaining vigilant about innovation and capability is as relevant today as when Mair (1984, p. 16) commented, "Now, we can no longer afford to be complacent. Incorporating new technology into the design and manufacture of automobiles is absolutely necessary for survival". It is not only automobiles, but the wider manufacturing industry and beyond that are impacted continuously by different forms of innovation, which is explored further in Section 2.9. Understanding which innovations, their applicability and possible impact to SCs can assist organisations in optimising their performance. Innovation is complex. Lambert and Cooper (2000) established that innovation can go beyond the company, and that it belongs within the core network of the businesses, such as in the case of Intel (Fine, 2000). Various studies show that utilising such networks can improve SCs, the bottom line and performance (Böhme, 2009). Logistics and innovation go beyond "modern IT solutions. A sign of modernity can also be a way of thinking" (Witkowski, 2017, p. 765).

Innovation and SC improvement is sought by many, regardless of industry. Ageron et al. (2012) and others have found that companies constantly compete through the use of different forms of innovation, from technological advances, limited-edition products, green/sustainable products (Melander, 2018; Hernandez-Vivanco, Bernado and Cruz-Cázares, 2018), packaging (Gallopel-Morvan et al., 2012), design of a store and/or website, the country of origin, SC design (Thomas et al, 2012), business models (Wirtz and Daiser, 2018), and business process re-engineering (Böhme et al. 2014). Innovation can be described as either incremental or radical (Ageron et al., 2012). Innovation is often linked to companies with constantly evolving products such as the Apple iPod, creative environments such as the Googleplex, and cultures that actively promote creativity. Smaller organisations may be just as innovative; however, they may see it as how they do business normally, without having dedicated departments or even considering that how they operate is, in fact innovative (Branson, 2008). Smaller organisations may even look beyond their own company and SC and use their network to improve their innovation capability (Arlbjørn et al., 2011). Depending on the industry, the focus may be on product, process and/or service. In manufacturing, concepts such as just-in-time (JIT), lean and agile have been widely used to improve business processes and systems (Moyano-Fuentes and Sacristan-Diaz, 2012), whereas in other industries such as healthcare, the focus has been more towards developing physical innovative products and patient flows (de Vries and Huijsman, 2011). Table 2.4 summarises different key types of innovation.

Table 2.4: Summary of Different Types of Innovation

| Type: | Summary: | Example: |
|---|--|---|
| Radical: | <ul style="list-style-type: none"> • Described as being rarer than incremental. • “A change of frame” (Norman & Verganti, 2012, p.5), that can “result in discontinuities” (Garcia and Calatone, 2002, p.120). • “Often do[es] not address a recognized demand, but instead create demand previously unrecognized by the consumer” (Garcia & Calatone, 2002, p. 121). | <i>For example:</i> Thomas Edison’s light bulb (Norman & Verganti, 2012), the steam engine (Garcia & Calatone, 2002) and 3D printing. |
| Incremental: | <ul style="list-style-type: none"> • More common than radical innovation. • Involves improving upon an existing product or process. • Garcia and Calatone (2002, p.123) define incremental innovation as “products that provide new features, benefits or improvements to the existing technology in the existing market”. | <i>For example:</i> A new car model (Garcia & Calatone, 2002). |
| Both types of innovation can apply to: | <ul style="list-style-type: none"> • Products, processes, and/or services (Garcia & Calatone, 2002). | |

Source: Author

Innovation is not restricted to new products or technological advances; it can include collaboration, integration and the use of networking in the supply chain (Thomas et al, 2012; Pagell, 2004; Arlbjørn et al., 2011). The concept of collaboration and innovation can vary and may be within organisational departments, between similar organisation and between organisations and their customers (Gronroos and Helle, 2012). A common theme and important factor in many networking studies has been that of trust (Ageron et al., 2012; Rota et al., 2013; Gronroos and Helle, 2012; Wilding and Humphries, 2006). It is advantageous for mutual gain, flexibility, innovation, SCM and ultimately the success of the collaboration. Fawcett et al. (2006) also identified the commitment of management and the culture of the organisation as important elements for consideration.

Another important factor to consider in regards to organisational innovation is that of innovation speed (Kessler and Chakrabarti, 1996) or clockspeed (Guimaraes, 2011; Fine, 2000; Meijboom et al., 2007; Peng et al., 2013), which is explored further in Chapter 6. Clockspeed can be defined as “a composite measure of the rate of change along a number of dimensions exhibited by companies within different sectors of the economy” (Fine, as cited in Guimaraes 2011, p. 327). Innovative manufacturing methods that originated in companies such as Toyota and were adopted by Western companies in the 1990s may not be enough to compete in today’s marketplace (Fine, 2000). According to Guimaraes (2011), clockspeed can be broken down into three groups: organisational factor/SC, products, and process, called “three-dimensional concurrent engineering (3- DCE)” (Fine, 2000, p. 218). This approach looks

at not only the development of products to suit the manufacturing processes, but also a corresponding strategic SC (Fine, 2000). Clockspeed can play a part in industries from the fast-paced computer industry (Fine, 2000; Peng et al., 2013) to the slower-paced automotive and prefabricated-building sectors (Meijboom et al., 2007; Fine, 2000). Competition and demands change as organisations and their SCs mature, just as innovative capability may also. For example, to remain competitive, Intel required new technology rather than just improving on what they already had (Fine, 2000). They were able to work with new start-up companies to provide this new technology and were successful not in competing in the industry but in collaborating, building relationships and improving processes to remain competitive (Fine, 2000).

Whether the innovation is swift and radical, or slow and incremental, each form of innovation impacts on organisations and their SCs to varying extents. The different impacts can be seen throughout history during each industrial revolution. One of the major and more recent impacts on the manufacturing industry is that of Industry 4.0 (Xu, Xu and Li, 2018), which has seen both the introduction of new technologies and the refinement of others. Some of the key technological advances within Industry 4.0 and their impact on SCs will be explored further in the following section.

2.9.1 The impact of innovation and key enabling technology on supply chains

According to Christopher and Ryals (2014, p. 30), “[o]ne of the major business trends that will shape academic discourse in supply chain management is the impact of new technologies on the world of manufacturing”. Christopher and Ryals (2014, p.30) also posited that “these new technologies will transform the traditional paradigm of the ‘economies of scale’ to what some have termed the ‘economies of scope’. It has been suggested that due to this, future SCs will be focused on the transportation of smaller amounts and more customised goods (Christopher and Ryals, 2014). Whilst the importance of innovation has been established throughout literature (Perel, 2002; Ageron et al., 2012), further investigation into the impact of technology, particularly on manufacturing SCs is warranted, with relevance and importance to both practice and academia evident.

There are a multitude of environmental factors and influences that impact on the SC. Of particular note are the advances in innovative technology that are influencing how SCs are utilised and structured for example. According to Speranza (2018, p. 835) “[r]ecent technological and automotive advances are rapidly changing the way supply chains are managed and goods and people are transported”. Manufacturing has already begun to see the impacts of smart manufacturing and 3D printing/Additive Manufacturing (AM) to artificial intelligence (AI), robotics, cyber physical systems (CPS), the Internet of Things (IoT), cloud computing and big data (Xu and Duan, 2019), whether these impacts be direct and internal or through suppliers. Such technological advances, or key enabling

technologies (KETs) (Caggiano and Teti, 2018) can be summarised under the term “Industry 4.0”, or “the fourth industrial revolution” (Yin, Stecke and Li, 2018), which consists more broadly of innovative production and network connectivity (Xu, Xu and Li, 2018).

According to Schumacher, Erol and Sihm (2016, p. 162), “Industry 4.0 refers to recent technological advances where the internet and supporting technologies (e.g. embedded systems) serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile value chain”. Industry 4.0, which originated in Germany in 2011 (Chiarello et al., 2018; Dalenogare, et al., 2018), has been having an impact in both developed and developing countries around the world, including but not limited to the USA, China, Japan, France, Brazil (Yin, Stecke and Li, 2018; Dalenogare et al., 2018), and Australia (Australian Government – Department of Industry, Innovation and Science, 2018). Countries have begun investing more heavily in hubs, communities and technologies under the Industry 4.0 umbrella in order to enhance their competitive ability across a range of industries and disperse knowledge of Industry 4.0 (Dalenogare et al., 2018). According to Xu and Duan (2019), Industry 4.0 can assist SMEs as well as larger enterprises, due to the flexibility and accessibility it offers. SMEs generally have fewer resources than larger organisations, and can thus benefit from factory configurations that need less human interaction and more flexible ownership arrangements, as well as the declining prices of sensors and the greater access to valuable shop-floor data they provide (Brettel et al., 2014). Industry 4.0 has been receiving increasing attention in both academia and practice, spurred on by the opportunity to investigate a new field and the potential for greater profitability, respectively (Chiarello, et al., 2018). In a review of literature by Chiarello et al. (2018), a search on the term “Industry 4.0” showed a significant increase in interest in the field, as indicated by the increase in academic articles, from close to zero in 2012 to nearly 500 in 2016, with that number continuing to grow. Engineering heavily dominated the field with the most publications, followed by computer science and business, management and accounting (Chiarello et al., 2018); however, interest was spread across an assortment of fields. It is an evolving field, commanding increasing attention.

Throughout history technological advances and revolutions have allowed for the development of and progression towards what has been named Industry 4.0 today, as captured in Figure 2.5. Beginning in the 1700s in England, was the First Industrial Revolution, also known as “The Age of Steam” (Xu, Xu and Li, 2018, p. 2943). This revolution saw the significant invention of the steam engine and the use of steam power for both transportation and mechanical energy for tooling and production (Duarte, Sanches and Dedini, 2018). There was a shift from artisan handicrafts produced on a small scale (Duarte, Sanches and Dedini, 2018) to mass production. Iron-making and the textile industry were

significant to this revolution. The textile industry in particular was greatly impacted, with the introduction of machinery that allowed for larger-scale mass production. Transportation was improved as the steam engine technology was further perfected during this time also (Chin, Juhn and Thompson, 2006), allowing for a reduction in travel time. Steam powered ships could travel at a faster rate as compared to sailing ships that relied on wind power for example. During this time, there was a focus on the product and large-scale production. Technology continued to be perfected, and energy sources changed. The use of wood was being replaced by coal (Duarte, Sanches and Dedini, 2018) during the First Industrial Revolution; moreover, overtime iron-making began to give way to that of larger-scale steel production as the next industrial revolution neared.

The Second Revolution, known as “The Age of Electricity” (Xu, Xu and Li, 2018, p. 2943) followed. The introduction of electricity during the Second Industrial Revolution saw the introduction of the light bulb which could be used to light factories, the telegram and telephone to alter and improve communication, factory automation and assembly lines such as that of Henry Ford’s automobile factories (Wilson, 2014) and the creation of internal combustion engine (Lee et al., 2018). The focus was not just on product volume, but also variety (Yin, Stecke and Li, 2018). Automated assembly lines further improved mass-production capability (Tien, 2012), and electricity, gas and oil were used as sources of energy.

The Third Industrial Revolution, also known as “The Information Age” (Duarte, Sanches and Dedini, 2018, p. 194), saw the creation and introduction of the Internet, as well as other electronic advancements such as the semi-conductor, CDROM (Fitzsimmons, 1994), personal and portable computers, based on Babbages’ early computer ideas (Bromley, 1998), and the beginning of 3D printing/additive manufacturing (AM) (Prince, 2014). More-accessible computers and the impacts of the Internet, or World Wide Web (Strawn, 2014), brought about greater access to communication methods, information sharing and networks, both personally and professionally. Automation of high-tech products (Maxwell, 2014) and offices was possible, and different tooling and teaching methods were introduced (Fitzsimmons, 1994). 3D printing technology was also introduced (Prince, 2014), which led to possibilities for rapid prototyping (Hasan et al., 2013). Renewable energy became a focus as an alternative to relying solely on fossil fuel (Lee et al., 2018). Lee et al. (2018, p. 6) describe this time as “a fusion of the physical space and cyberspace”.

The Fourth Industrial Revolution, or Industry 4.0, has been described as being “an innovative framework premised on extreme digital connectivity” (Özdemir, 2018, p. 638) that can help with flexible manufacturing (Özdemir and Hekim, 2018). Lee et al. (2018, p. 6), propose the Fourth Industrial Revolution “as constituting super-disruptive innovation”, rather than just disruptive innovation. Syu

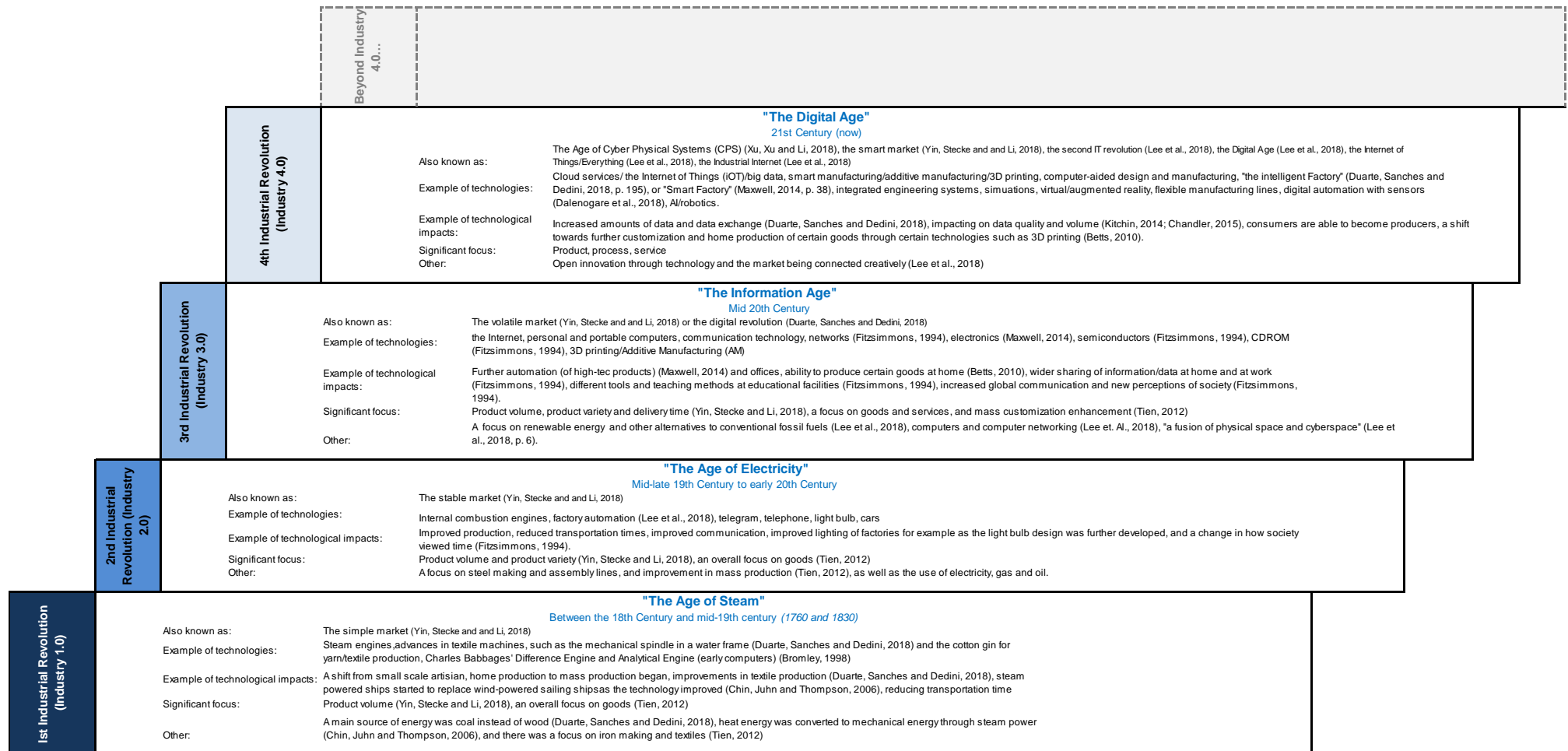
et al. (2017, p. 138387), describe Industry 4.0 as being “an important trend in factory automation”, and that it “increases the degree of computerization, digitization, and intelligence in the manufacturing industry” (Syu et al., 2017, p. 138388). Industry 4.0 has seen an increase in the amounts of data and data exchange (Duarte, Sanches and Dedini, 2018), or big data, which requires further storage capability and a consideration of data quality as well as quantity (Kitchin, 2014; Chandler, 2015). Manufacturing is becoming smarter, due to technology such as artificial intelligence/robotics, simulation, flexible manufacturing lines, digital automation (Dalenogare et al., 2018), and advancements in 3D printing/AM, moving beyond just using the technology for rapid prototyping and towards rapid manufacturing (Hasan, Rennie and Hasan, 2013). There are many significant technologies under the Industry 4.0 umbrella, and opposing views towards them. For example, there is no real consensus about whether technologies within Industry 4.0 are new or “a re-labeling of old technologies” (Chiarello et al., 2018, p. 244). Elements of certain ideas and technologies can be seen throughout the four revolutions, such as Babbage’s early ideas beginning around the early 1820s about computers being machines to calculate complex mathematical equations, rather than people (Bromley, 1998), to steam power, with power being manufactured rather than relying on muscle power (Rushmore and Lof, 1914), and the steam engine with railway networks, which encouraged the need for communication networks (Allenby, 2009).

The evolution of technology and progress does not stop at Industry 4.0. As Maxwell (2014) postulates, the next revolution or Industry 5.0, has been progressing concurrently with Industry 4.0 and may better the advancements that have appeared in Industry 4.0. Özdemir and Hekim (2018, p. 72) propose that Industry 5.0 will build upon Industry 4.0 by offering “three-dimensional (3D) symmetry in innovation ecosystem design”, with possible safeguards such as “built-in safe exit strategy”. Thus, being to assist with the possible threats or barriers faced, such as compromised data, cyber security threats, viruses and data hacking for example (Özdemir, 2018, p. 638). Although Industry 5.0 or “Beyond Industry 4.0” has been included in Figure 2.5, it is mentioned only briefly as it is outside of the scope of this research.

Irrespective of when a technological improvement or innovation is introduced, society is impacted (both positively and negatively) as technology advances, placing the focus on different factors such as sustainability or productivity improvement. Interestingly, and in line with systems thinking, technological advancements throughout history have made individuals think more about what they do and the changes these processes are undergoing. One such area is productivity, which has been changing since the First Industrial Revolution. “Productivity growth is stimulated by new technology, not only because automation streamlines work, but, more important, because it gives us an opportunity

to analyse the jobs we do as individuals, as work groups, and as large systems at the enterprise level”
(Diebold, 1983, p. 11).

Figure 2.5: Summary of the Industrial Revolutions



Source: Adapted from Yin, Stecke and Li, 2018; Xu, Xu and Li, 2018

After reviewing the literature, and considering the changes that have occurred throughout the ages within industry and SCs, it can therefore be said that it is important to study technology and the impact that it can have on organisations and the wider SC. The impacts of technological advancements vary from those within individual organisations to the wider SC, and the broader community. Some of the key technologies that form Industry 4.0 will be explored further in the next section.

2.9.1.1 **Cyber physical systems, big data, cloud computing and the Internet of Things**

According to Velásquez, Estevez and Pesado (2018, p. 264), two technologies within Industry 4.0 that are considered “key technological pillars” are that of big data and cloud computing. Closely associated to these are cyber physical systems (CPSs) and the Internet of Things (IoT).

CPS refers to the “Integration and networking of embedded systems with each other and the internet” (Fatorachian and Kazemi, 2018, p. 636), which “has resulted in the merging of the virtual world (cyberspace) and the physical world, generating Cyber-physical systems (CPSs)” (Fatorchain and Kazemi, 2018, p. 636). The terms CPS and Industry 4.0 have been said to have been used interchangeably in various studies (Xu and Duan, 2019); however, Xu and Duan (2019) propose that they differ theoretically. CPS has applications within and outside of Industry 4.0 and manufacturing, and Industry 4.0 does not solely focus on “the interaction between physical systems and computing systems” (Xu and Duan, 2019, p. 149). It spans the lifecycle of the product from raw materials through to the finished goods and customer service (Xu and Duan, 2019). Vast networks of humans and computers/machines are able to communicate due to CPS (Brettel et al., 2014), allowing for the physical world to be mapped as part of the digital, and machines to make decisions more autonomously (Nagy et al., 2018) as part of smart factories (Chen et al., 2018). Assisting with such networks and digital connections, influencing the need for reduced human interaction, is that of the Internet, or IoT.

The IoT “defines a global environment where the internet is the centre of connectivity for all intelligent devices” (Fatorachian and Kazemi, 2018, p. 635). Witkowski (2017, p. 767) among others, regards the IoT as offering “new possibilities in the area of performance”. Although the term “IoT” is becoming more widespread with the introduction of Industry 4.0, it is said to have been envisioned in 1999, with Kevin Ashton coining the phrase (Fatorachian and Kazemi, 2018). The IoT allows for greater connectivity of smart devices and is having an impact on an array of industries and SCs. Abdel-Basset, Manogaran and Mohamed (2018), summarise the impacts of IoT on the SC as being: (1) real-time data sharing and SCM, due to RFID and technology that allows for multiple sources of data to be collected and shared within the SC; (2) increased transparency of logistics, including costs, and increased ability to monitor the transport and condition of goods for example; and (3) improved inventory management due to technology such as sensors and IoT making data more readily available and accessible. It is also

said to aid in reducing uncertainties relating to the manufacturing process, as it increases the availability of real-time data (Huang et al., 2019). A considerable amount of data arises from manufacturing, or smart factories (Chen et al., 2018); this has resulted in another branch of Industry 4.0: big data.

Big data is an umbrella term (Xu and Duan, 2019) that refers to the colossal amounts of data produced as part of Industry 4.0 and its “production ecosystem” (Velásquez, Estevez and Pesado, 2018, p. 260). In recent times, the size of the data generated surpassed terabytes or petabytes in 2005 – 2010, and was last recorded in 2017 as reaching the magnitude of zettabytes (Xu and Duan, 2019). Big data can be characterised by volume, variety, velocity (Laney, 2001; De Mauro, Greco and Grimaldi, 2016) and value (Wamba et al., 2015). De Mauro, Greco and Grimaldi (2016) noted that although Laney (2001) is often cited in studies, they did not directly reference the term Big Data in regards to the “3 Vs”. Big data allows for greater availability and analysis of data from the shop floor, to beyond the production process. Big Data is said to assist with data analysis at a much higher level as compared to tools or methods previously utilised (Witkowski, 2017). In a literature review by Wamba et al. (2015, p. 239), positives or value for business from big data are summarised into the five areas of: (1) creating transparency, (2) enabling experimentation to discover needs, expose variability, and improve performance, (3) segmenting populations to customize actions, (4) replacing/supporting humane decision-making with automated algorithms, and (5) innovating new business models, products, and services. As with Özdemir (2018), Wamba et al. (2015) also warn of the potential negatives of big data to be aware of, such as data policies and access, as data becomes more connected and readily available. It can also be costly to implement big data and other technologies to compete in Industry 4.0. It should be noted that although there are costs associated with implementing various technologies as part of Industry 4.0, with larger industries often having more funds than SMEs, it is the strategy of an organisation that is significant to the use of big data to fulfil customer needs, rather than the size of the industry or organisation (Velásquez, Estevez and Pesado, 2018).

As the sheer volume of data increases, data storage becomes an issue. Many homes and organisations are now using cloud technology. Raut et al. (2018, p. 2688) refer to cloud computing as “technology which is based on the internet through which information is stored in servers and is provided software as a service (SaaS) and on request to the customers”. Cloud computing has the capability to store copious amounts of data or digital products produced, particularly as part of Industry 4.0 production processes that use multiple systems and sensors (Velásquez, Estevez, and Pesado, 2018, p. 2688). “Digital products are goods stored, delivered, exchanged and used in digital format” (Vazquez-Martinez et al., 2018), that range from e-books to organisational files and can be

saved on multiple clouds. Cloud computing is said to allow smaller entrants, or those with less to invest in technology, the opportunity to take advantage of the benefits that this technology offers, such as being able to store large amounts of data in the cloud with reduced costs and the ability to access the data from multiple sites around the world, without the need to invest in infrastructure or human resources (Velásquez, Estevez and Pesado, 2018; Vazquez-Martinez et al., 2018). As well as possible cost benefits, cloud technology that is well implemented and integrated allows for efficient data-sharing throughout the SC and in real-time, improving communication flow and possibly collaboration (Shee et al., 2018).

Complementing the innovative Industry 4.0 technologies mentioned so far, another technology that utilises digital information (transforming it into physical product), is that of 3D printing or additive manufacturing (AM). The accessibility of and interest in 3D printing continues to increase, even for smaller entrants, as it becomes more readily available to both organisations and homes around the world.

2.9.1.2 **3D printing/additive manufacturing**

A key form of innovation that Australia, USA, Singapore and the United Kingdom, among others, are investing in for example includes 3D printing or Additive Manufacturing (AM) (3ders, 2013a; 3ders, 2013b; Phillips, 2014; Petrick and Simpson, 2013). 3D printing, also known as AM, can be defined as “the layer-by-layer creation of physical objects based on digital files that represent their design” (Petrick and Simpson, 2013, p. 13) using printers to layer or lasers to burn materials (Pannett, 2014). Although this advanced technology has been around for longer than 25 years (de Jong and de Bruijn, 2013; Petrick and Simpson, 2013), it is continuing to gain attention and evolve. There is still much to learn about the impact that 3D printing can have on businesses, as well as its applications and the raw materials that are available. 3D printing has been described as being revolutionary (Goulding, Bonafe and Savell, 2013), magical (Massis, 2013), disruptive (Massis, 2013; Prince, 2014) and a “breakthrough technology” (Cohen, 2014, p. 69), that simplifies and accelerates the development and launch of products to market (Durakbasa, Bauer and Poszvek, 2017). 3D printing employs a variety of materials, from polymer, metals, bio, ceramic, cement, chocolate and more (Li et al., 2014; Prince, 2014; and Jai et al., 2016). Plastics and other polymers, however, are most commonly used (especially by smaller home printers). 3D printing has multiple benefits and disadvantages. It can bring the consumer closer to the point of production (Petrick and Simpson, 2013), allows for more customised production and the production of geometrically complicated parts (Rylands et al., 2016), and presents opportunities for the use of new IT and raw materials (Rylands et al., 2015), among other benefits. It also has disadvantages such as potentially lengthy production time and lower quantity (with a focus

on customisation rather than mass production), cost and available raw materials.

Innovative raw materials, as well as advanced hardware and software to create 3D-printed items are continuing to develop, especially in maker communities and high-tech organisations. 3D printing technology is continuously improving and the use of metals is increasing compared to other materials (RolandBerger, 2013). With these changes bring opportunities. It could create further possibilities for countries like Australia, with relatively large amounts of titanium and other raw materials (Balinski, 2014). With Australia already being a major exporter of raw materials such as titanium ore, this could positively impact on the SC by supporting shorter lead times, local manufacturing, and cost reductions; this could help keep Australia competitive, not just in mining but also in manufacturing (Spinks, 2014). As the technology improves, the use of 3D printing has evolved, from being heavily utilised for rapid prototyping, towards it being used further in the manufacturing process, or rapid manufacturing (Hasan, Rennie, Hasan, 2013). Each method uses different raw materials, which also has benefits and disadvantages. The object to be built, cost, time and the advantages and disadvantages all need to be considered before investing in or adopting the technology (Rylands et al., 2015), which is explored further in Chapter 5.

The literature regarding 3D printing and its impact on the SC at the time of this research was limited compared to that regarding engineering and other technical research (Rylands et al., 2015). Topics in business research included that of “prosumers” (Petrick and Simpson, 2014, p. 14), who are consumers that become the producers, reducing the time it takes to design a product and get it to market; accessibility of the technology; and waste reduction (Bak, 2003) to name a few. A gap in the research regarding the potential impacts of 3D printing and potential impacts for Australian manufacturing SCs was identified, and has been explored further in Chapter 5. 3D printing SC impacts include but are not limited to; reduced lead times, smaller inventories (Petrick and Simpson, 2013), reduction in waste compared to traditional manufacturing methods (Khan and Mhor, 2016; Petrick and Simpson, 2013), faster set up times for manufacturing due to reduced tooling (Petrick and Simpson, 2013), smaller batch production, printing at the point of consumption and leaner and more agile operations overall. As the technology evolves however, it is projected to have an even larger impact on SCs. According to Gravier, Roethlein and Visich (2018, p. 3) in regards to industrial scale 3D printing, it “...has begun, and is going to put traditional supply chains out of business”.

Other technologies that are impacting on the SC and manufacturing processes is automation, artificial intelligence (AI) and robotics, which will be explored in the next section.

2.9.1.3 *Automation, artificial intelligence and robotics*

Automatic can be defined as “operating mechanically by itself: (of a process) performed by automatic equipment; done without conscious thought...” (Collins, 2007, p. 38). To make processes automatic or to automate often refers to machines within the manufacturing process (Frohm et al., 2008; Collins, 2007). Automation has been in existence in the manufacturing process since the 20th century, with Henry Ford’s automotive assembly production line in the early 1900s highlighted as being noteworthy (Viswanadham, 2002). According to Singhal (1987), research into automation increased in academic journals and the business world in the 1980s (Singhal, 1987). Singhal (1987, p. 1) describes automation in manufacturing as being “crucial in the competitive battles in many industries all over the world”. With the introduction of Industry 4.0 however, the implementation and advancement of automated processes and tools, such as robotics and IT systems, are increasing. The ability to combine KETs, such as robotics and simulation, to simulate processes specific to a single machine or even an entire plant is made possible by the improvements in technology (Caggiano and Teti, 2018). Such advancements are assisting in decision-making for management and costs savings (as simulations can replace having to implement machinery in testing certain layouts and processes), and can also assist in process automation. Syu et al. (2017, p. 18388) commented that due to this progression in technology, particularly referring to robotics, that “the human element is gradually being replaced by machines in all fields”, due to benefits such as their accuracy and efficiency for routine tasks. Karabegović (2018) adds that robots and other machines also offer safety benefits by being able to perform tasks too dangerous for humans, and allow human workers to perform more creative or mentally difficult tasks.

Karabegović (2018, p. 2) describes robotics and robot technology as “one of the foundations of the fourth industrial revolution”, made possible due to the convergence of improvements in other technologies such as sensors and IT. This foundation and the convergence of KETs is attributed to making it possible to create and disseminate different types of robots (both service and industrial) in the workforce, that can interact with each other and human workers (Karabegović, 2018), as well as assist the manufacturing industry in the journey towards “intelligent manufacturing” (Hu et al., 2019, p. 570). In countries such as Japan and Korea for example, the number of robots per human, referred to as “robot density” (Schneider, Hong and Le, 2018, p. 29) is increasing, assisting in resource shortages (Schneider, Hong and Le, 2018). Robots are slowly being utilised for tasks outside of the manufacturing industry, and are progressing into the service industry as well (Schneider, Hong and Le, 2018). The ability of robots is also increasing as artificial intelligence (AI) for instance advances. Roman (2018, p. 37), defines AI as “the intelligence exhibited by machines or software”, that emerged in the 1950s. The term AI also refers to “the academic field that studies how to create computers and computer software capable of intelligent behaviour” (Roman, 2018, p. 37). The increase in robotics and AI, or intelligent

robots (iRobots) (Hu et al., 2019) has the potential to affect the management of manufacturing issues, inventory levels and resource allocation, bottleneck identification, and maintenance planning/repair for example (Hu et al., 2019; Roman, 2018), assisting in SC efficiency and customer service. Robots' shortfalls, such as being relatively limited by their ability to identify and adapt to damage like animals for instance (due to their programming) is being researched to improve the use of robots within and outside of the manufacturing industry (Cully et al., 2015). Schneider, Hon and Le (2018) refer to automation, robotics and artificial intelligence as potentially having a similar impact in terms of size of change to the community and policy makers as the steam engine, causing certain jobs to disappear and others to be introduced due to new technologies emerging.

Overall, many advances in innovative technology have had an impact on SCs over the years. Some key innovations, or KETs, that have been identified as part of Industry 4.0 are increasing in their importance and impact on manufacturing and the wider SC, whether individuals or organisations have adopted the technology or not. With such growth in technology adoption and possible changes that technology can have on organisations and the wider society, it is important for academia, policy-makers and practitioners to recognise and prepare for the upcoming changes.

In a study by Mittal et al. (2018) regarding maturity models and Industry 4.0 preparedness, it was discovered that there were few tools such as roadmaps and readiness assessments available for SMEs to deal with today's turbulent and challenging environment. More specifically "only a few studies specifically focus on supporting SMEs' evolutionary path and paradigm-shift towards 'Smart Manufacturing' (SM) or 'Industry 4.0' (Mittal et al., 2018, p. 194). It was noted that many SMEs are not prepared for Industry 4.0, and that further assistance, including education is needed (Sommer, 2015; Gualtieri et al., 2018). It was also noted that due to the importance of SMEs in the manufacturing sector (Sommer, 2015), the upcoming changes of Industry 4.0 could be quite considerable (Mittal et al., 2018).

After considering this and the various innovative technologies available, a gap in literature presented itself: the impact of 3D printing or AM on SCs, including Australian manufacturing SMEs, which was found to be far rarer in the literature than technical research in other fields such as engineering. This led to narrowing the impact of innovative technology on SMEs within Industry 4.0 to 3D printing/AM (as explored further in Chapters 5 and 6), and resulted in the following research questions:

- Research question 3: How do organisations adopt innovative technology into their existing supply chain?

- Research question 4: What is the business impact of innovative technology adoption the existing value streams/business manufacturing system?

In addition to these research questions, and on reflection of the importance of studying the evolution of SMEs as well as the low survival rate of SMEs in Australia as compared to that of larger businesses (ABS, 2018), in conjunction with the speed of innovation or clockspeed (Fine, 1998), it led to the desire to understand innovation in regards to less mature organisations, such as start-ups and SMEs in their early stages, that may introduce other forms of innovation. This required the researcher to investigate a less mature organisation, as explored further in Chapter 6, and led to the final research question:

- Research question 5: How do manufacturing start-up SMEs upscale the production of innovative products over time?

2.10 Conclusion

The most valuable contributions, however, will involve addressing real problems in real supply chains, and developing the theory to support managerial decision making in those contexts (Chopra, Lovejoy and Yano, 2004, p. 13).

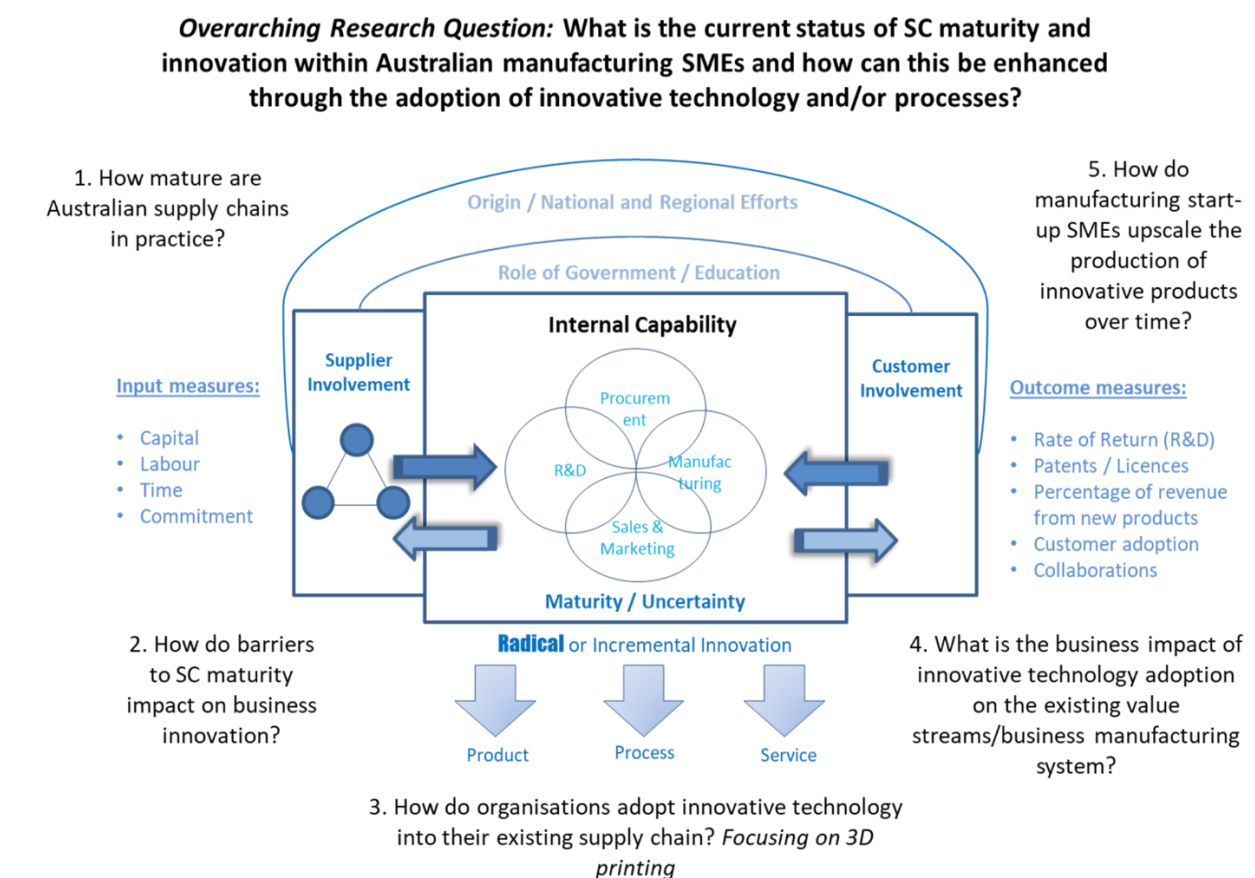
As with organisations in the real world, research is not a stranger to challenges and limitations throughout its various phases. Conducting a literature review can present challenges, as it requires constant revision from the researcher due to the continuous release of new research and findings (Remenyi et al., 1998). Even so, it is a valuable step in the research process.

As Chopra, Lovejoy and Yano (2004) have written, research that is focused on real-world challenges, has the potential to achieve significant contributions in both solving problems for organisations and in creating valuable insights for academia. Initial exploration into the literature and theories that can anchor such research is required.

This chapter aimed to provide such a background through exploring SC literature and providing a broad literature review, with a focus on manufacturing SMEs in the Australian context. The scope of the literature review included the key research themes of SCM, SC maturity, barriers and enablers and innovation, as captured in Figure 2.1, with further detailed literature reviews accompanying the findings in Chapters 4,5 and 6. The literature has been distributed across the three chapters due to it being specific to the findings in those chapters, and also due the logical progression of the key areas in this thesis.

This chapter began by presenting an introduction into the scope of the research, followed by an exploration of SCM literature, including definition, scope, evolution, a review of Australian SC literature; followed by SC maturity and barriers; innovation; and KETs and their impact on SCs. Through conducting the literature review, research questions motivated by gaps in the literature were formed; which have been summarised in Figure 2.6.

Figure 2.6: Summary of the Literature Review



Source: Author

Figure 2.6 summarises the overall literature review for this thesis, and includes the overarching research question, with the individual research questions below that are further explored in Chapters 4, 5 and 6. Each of the five research questions are interlinked, for example the SC maturity of an organisation impacts on its ability to adopt innovative technology in their SC and VSs. Understanding

what the barriers exist and how they impact on the SC are related to the growth or upscaling of organisations as well as existing entities. Each of the individual questions contribute to the overarching research question. Overall, a review of literature regarding SCM in Australia appeared to reveal a gap, presenting an opportunity to perform further in-depth applied research and add to knowledge. Through conducting the literature review, key tools for assessing SCs, including maturity levels, were discovered, as well as the potential for maturity to impact on innovation within SCs (Böhme et al., 2014). Innovation belongs to the wider SC, although the literature suggests that it is being poorly applied due to a lack of supply chain maturity in practice (Böhme, 2009; Halldórsson et al, 2008). Therefore, this research begins with a focus on establishing insight into SC maturity in Australian SMEs within manufacturing, to provide a foundation and context to then be able to further explore the barriers to SC maturity, as well as the link to innovation, KETs and the impact on SCs.

Chapter 3 introduces the research design, methods and methodology used to investigate the research questions, including applied research and case studies.

3. Research Design, Methods and Methodology

...your view on the nature of knowing will have a strong influence on the likely purpose of any research you choose to do, and on the methods you think it is appropriate to use to extend your knowledge. Indeed, it can be seen as the foundation upon which everything you do will rest on... (Cameron and Price, 2009, p. 58)

3.1 Introduction

As noted by Godin and Schouz (2016, p. 302), “research is more than a simple word denoting scientific activities”. Research can be defined as “comprising systematic data collection and interpretation of data, based on logical relationships rather than beliefs” (Saunders & Bezzina, 2015, p. 299). According to literature, research has a long history, evolving from the word *search* in the 14th (Godin and Schouz, 2016). Since then, it has continued to change to include concepts and terms such as “a research whole” (Godin and Schouz, 2016) or holistic, systematic, applied or basic, research and development (R&D) and innovation. Importantly, through impacts such as industrialisation and the two world wars, research moved beyond the walls of educational institutions or universities and began to span nations, including government, industry and the wider society.

This chapter includes the broad research design, method and methodology for data collection and analysis used to address the research questions (Table 4.1). This includes the ontological, epistemological and axiological approaches adopted by the researcher. Although the research design differs in among Chapters 4, 5 and 6, the commonality they share is that the research is applied and predominantly qualitative in nature. This research includes the use of QSAM, which is explored in Chapter 4, multiple case studies in Chapter 5, and a singular longitudinal case study in Chapter 6, with a more detailed explanation of each included in the methodology section of their retrospective chapters. Using such methods, data was collected from multiple organisations and in multiple contexts, including Australia and examples of best practice from the United Kingdom (UK).

Research, methods and methodology include many factors. Research can be classed as being intensive or extensive (Swanborn, 2010), qualitative, quantitative, or using mixed methods, to name a few. It is important to make clear the purpose (Saunders, Lewis and Thornhill, 2009) and structure of the research design, methods and methodology. In the case of this research, Saunders, Lewis and Thornhill’s (2009) model of the research onion has been utilised as a guide in order to assist with structuring this chapter. The research onion is a multi-layered diagram that assists in guiding the

researcher throughout the stages of research, from the outer layers of philosophies to inner layers of data collection.

Following the research onion as a guide, this chapter begins by providing the philosophical stance and research approach in the initial layers, followed by the research strategies, choices, time horizons and research techniques and procedures (Figure 3.1). Next, research quality is presented, as well as the role of the researcher, ethical considerations and the conclusion

3.2 Outer layers 1 and 2: philosophical stances – paradigms and approaches

As identified by Saunders et al., (2009; 2012; 2016), there are a number of philosophical stances or paradigms that one can choose to adopt. Paradigms are sets of beliefs, a way to “denote an implicit or explicit view of reality” (Morgan, 1980), or “a common perspective which underpins the work of a group of theorists in such a manner that identifies them as analysing social issues in the same way” (Morgan, as cited in Remenyi et al. 1998, p. 103). Kuhn (1970, p. viii) describes paradigms as “universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners”. Paradigms comprise of an ontology, “the realm of being” (Humphrey, 2013, p. 4) or reality, epistemology “the realm of knowing” (Humphrey, 2013, p.4), and axiology “the realm of values” (Humphrey, 2013, p.4) and provide a foundation for conducting research. Table 3.1 summarises these assumptions, including a continuum of examples, to show the extreme opposing views for each assumption.

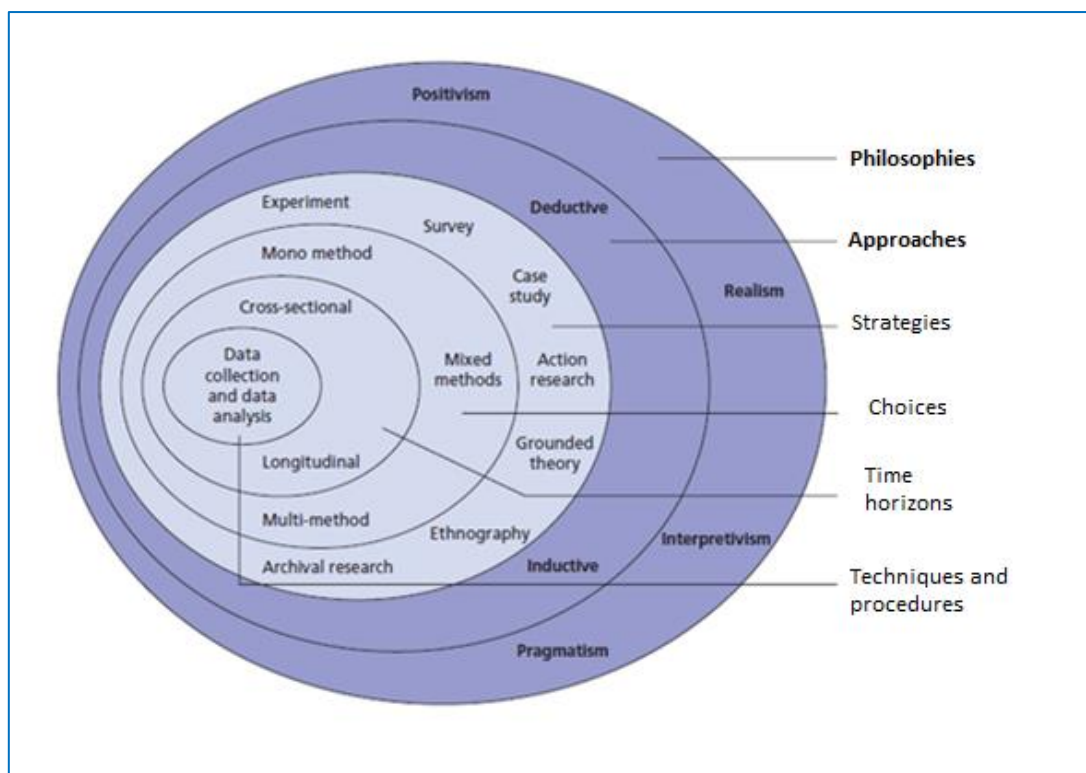
Table 3.1: Philosophical assumptions

| Assumptions | | Continuum | | Questions |
|---------------------|-------------|-----------|---------------------------------|--|
| Ontology | Objectivism | ↔ | Subjectivism | <i>What is the nature of reality?</i> |
| Epistemology | Positivist | ↔ | Non-Positivist / Interpretivist | <i>How can we know what we know?</i> |
| Axiology | Value-free | ↔ | Value-bound | <i>What is the role of values in research?</i> |

Source: Adapted from Saunders, Lewis and Thornhill, 2016, p. 129

As with philosophical assumptions, there are an array of paradigms that can be adopted in research. In the case of Saunders et al.'s (2009) research onion model in Figure 3.1, positivism, realism, interpretivism and pragmatism have been included, although there are other options or variations to these available in literature, such as critical, transformative-emancipation and dialectics (Humphrey, 1998; Shannon-Baker, 2016). Two dominant paradigms in the field of management include positivism and interpretivism (Mentzer and Kahn, 1995; Stuart et al., 2002; Remenyi et al., 1998); these have been summarised in Table 3.2.

Figure 3.1: The research onion



Source: Saunders, Lewis and Thornhill, 2008 as cited by Saunders, Lewis and Thornhill, 2009, p. 108

Positivism, which is more commonly associated with quantitative data collection (Mackenzie and Knipe, 2006), has the “goal to explain and predict reality” (Mentzer and Kahn, 1995, p. 232). Researchers do not see themselves as part of the research environment (Mentzer and Kahn, 1995) but more as observers. According to literature reviews by Kovács and Spens (2005) and Burgess, Singh and Koroglu (2006), the positivist approach has been found to be more prevalent in logistics and supply

chain management research. Remenyi et al. (1998, p. 33) describe the positivist researcher as “independent of and neither affects nor is affected by the subject of the research”. Remenyi et al. (1998, p. 33) also argue that positivism “will not lead to interesting or profound insights into complex problems especially in the field of business and management studies”, and that due to issues concerning people and organisations “it is necessary to go beyond positivism” (Remenyi et al., 1998, p. 95) and use a more interpretivist approach to research.

Table 3.2: Paradigm summary

| Paradigm | Methods (primarily) | Data collection tools (examples) | Ontology | Epistemology | Axiology |
|-----------------------|--|--|---|--|--|
| <i>Positivist</i> | Quantitative | Experiments Quasi experiments Tests Scales | Real, external, independent, ordered, one true reality | Scientific method, observable and measurable facts | Value-free research Researcher is detached, neutral, independent and objective |
| <i>Interpretivist</i> | Qualitative methods predominate although quantitative methods may also be used | Interviews Observations Document reviews Visual data analysis | Complex Socially constructed through culture and language Multiple meanings and realities | Focus on narratives, stories, perceptions and interpretations Create/contribute new understandings and worldviews | Value-bound Researchers are part of what is researched, subjective Interpretive Reflexive |
| | <i>Mackenzie and Knipe, 2006</i> | | <i>Saunders, Lewis and Thornhill, 2016</i> | | |

Source: Adapted from Mackenzie and Knipe, 2006, p. 199; Saunders, Lewis and Thornhill, 2016, p. 136

In contrast, the interpretivist or phenomenological approach is described as having “a goal to understand a phenomenon” (Mentzer and Kahn, 1995, p. 232), and “constructs meaning in terms of the situation being studied” (Remenyi et al., 1998), where the researchers are a part of the research or are considered as being interactive (Mentzer and Kahn, 1995) and not just observers (Morgan, 1980).

Interpretivism seeks a holistic understanding (Goldkuhl, 2012) and it is commonly associated with a qualitative approach to data collection (Saunders, Lewis and Thornhill, 2012).

This research has adopted the interpretivist or phenomenological paradigm. This is due to the applied nature of the study, involving field research, where the researcher is more than an observer. Interpretivist or phenomenologist research is also described as being suited to answering “what”, “how” and “why” questions (Remenyi et al., 1998, p. 96; Yin, 2014, p.2) and delving deeper into the context or situation being researched, which this research focuses on. According to Aram and Salipante (2003, p. 194) the “interpretative approach (is) a particularly useful way to frame interaction between academics and practitioners”. This is applicable to the research strategies chosen, as will be discussed in the following section.

The next step is to determine the research approach, as shown in the outer layers of the research onion in Figure 3.1. Although there are only two options - inductive and deductive approaches - showing in this version of the onion, it must be noted that there is also a third option of abduction (Kolko, 2010) available to the researcher.

As with the paradigm wars between positivism and interpretivism (Mingers, 2004), there have been shifts back and forth throughout the years between the adoption and acceptance of inductive and deductive approaches (Ormerod, 2010), as well as alternatives to these. The deductive approach may refer to “techniques, methods and tools for data searching and collection based on abstraction, formal modelling, mathematical simulation, generation by derivation etc” (Zait, 2015, p. 65) or “a framework of procedural rules for observational research designed to draw causal inferences” (Yom, 2014, p. 620). Deduction is more commonly associated with mathematics and quantitative research approaches (Yom; 2014; Palsa, 2013; Ormerod, 2010; Kolko, 2010) than is induction.

Thomas (2006, p. 238) refers to the inductive analysis approach as “approaches that primarily use detailed readings of raw data to derive concepts, themes, or a model through the interpretations made from the raw data by an evaluator or researcher”. Thomas (2006, p. 238) describes the process as findings “emerging” from data, “without the constraints imposed by structured methodologies”. Inductive approaches are often linked to qualitative research (Zait, 2015; Thomas, 2006) and grounded theory (Murphy, Klotz and Kreiner, 2017). Although there were elements of inductive and deductive approaches in this research, which Thomas (2006) notes happens frequently, it did not consist purely of discovery during research without having theoretical influence, nor was it constrained by structure. This research also had the possibility of new data creation, unlike both the inductive and deductive

approaches (Kolko, 2010). This research used a combination of both approaches, also referred to as an abductive approach.

According to Kolko (2010, p.20), abduction “can be thought of as the argument to the best explanation” and “allows for the creation of new knowledge and insight”. Abduction has been referred to as being more creative than inductive or deductive approaches (Kovács and Spens, 2005). According to Kovács and Spens (2005, p. 138), “...taking an abductive approach leads to new insight about existing phenomena by examining these from a different perspective”. Abduction is said to shift between induction and deduction, and “matches what many businesses and management researchers actually do” (Saunders, Lewis and Thornhill, 2012, p. 147). Awuzie and McDermott (2017, p. 357) also commented that by allowing researchers to shift between inductive and deductive approaches, they are also able to shift between “theory and data in a bid to develop new or modify existing theory”. Psychological research has also suggested that in addition to those in research and practice, people in their everyday life (Ormerod, 2010) also shift between these approaches. Thus, due to being able to utilise aspects of inductive and deductive approaches, as well as the creative aspect and applicability to research and practice, the abductive approach was found to suit this research.

The inner layers - including research strategies, choices, time horizons, techniques and procedures - will be explored in the following section.

3.3 Inner layers 3, 4, 5 and 6: strategies, choices, time horizons, techniques and procedures

According to Remenyi et al. (1998, p.44), a research strategy “may be thought of as providing the overall direction of the research including the process by which the research is conducted”. Multiple research strategies, such as surveys, experiments and case studies (as shown in Figure 3.1), can be used. It is important when choosing the research strategy that it suits the research questions posed (Remenyi et al., 1998; Yin, 2014), as each strategy may be suited to particular research question types, as shown in Table 3.3. In addition, the nature of and knowledge about the topic may also influence the research strategy chosen (Benbasat et al., 1987). As noted by Benbasat et al. (1998, p. 382) that whilst “no strategy is better than all others”, there are strategies that suit certain research more than others. For instance, Benbasat et al. (1998, p. 370) expressed their belief that “the case study research strategy is well-suited to capturing the knowledge of practitioners and developing theories from it”. Similarly, Yin (2014, p. 2) wrote that “doing case study research would be the preferred, compared to others, in situations when (1) the main research questions are ‘how’ or ‘why’ questions; (2) a researcher has little or no control

over behavioural events; and (3) the focus of this study is a contemporary (as opposed to entirely historical) phenomenon". In the case of this research, the research questions posed and areas being studied suit the use of case studies. For instance, the exploration of SC maturity regarding the Australian manufacturing landscape required further field research to take place in order to provide context for this research. This research does this by using a robust methodology, called QSAM, as discussed in Chapter 4, which had not been previously applied to the Australian context. Also, the topic areas of how innovative technology such as 3D printing/additive manufacturing is adopted by and is impacting on the SC, particularly that of manufacturing SCs, which are presented in Chapters 5 and 6, are considered more recent phenomena. Hence, as the area of SC maturity and innovative technology is in its infancy in Australia, a contemporary phenomenon presented an opportunity for exploration through case studies.

Case studies may involve qualitative, quantitative or mixed-methods research approaches to data collection. According to literature, there is a call for further mixed-methods research to take place in scholarly research, business and the social sciences (Fraser, 2014; Cameron and Price, 2009) to provide balance and improve knowledge and understanding in both the qualitative and quantitative fields. A review of the literature also revealed that surveys are most commonly used to collect data (Alfalla-Luque et al., 2013; Oke et al., 2013; Mentzer and Kahn, 1995; Frankel et al., 2005, and Prajogo and Sohal, 2013), but longitudinal studies are rare (Böhme et al., 2014a; Kuula, Putkiranta and Toivanen, 2014; Boone et al., 2013), and that there is a need for further applied and action research (Stuart et al., 2002). According to Mintzberg (1979, p. 586), "measuring in real organizational terms means first of all getting into the field, into real life organizations. Questionnaires often won't do". Therefore, using an applied, mixed-methods research approach, this research employed the use of case studies (multiple, singular/longitudinal) and the QSAM diagnostic tool to collect data. The use of case studies and QSAM were appropriate for answering the research questions (Table 3.3), as well as adding to applied knowledge in the field.

Table 3.3: Research questions and testing methods

| Overarching RQ: What is the current status of SC maturity and innovation within Australian manufacturing and how can this be enhanced through the adoption of innovative technology and/or processes? | | | |
|--|---|---------------------------------|-----------------|
| Research Question: | Objective: | Method for testing: | Chapter: |
| 1. How mature are Australian supply chains in practice? | Exploratory, establish context and investigate maturity as an indicator of innovation (Böhme et al, 2014a), theory testing/refinement | Two case studies and interviews | Chapter 4 |
| 2. How do barriers to supply chain maturity impact on business innovation? | Exploratory, establish context and investigate maturity as an indicator of innovation (Böhme et al, 2014a), theory building | Two case studies and interviews | Chapter 4 |
| 3. How do organisations adopt innovative technology into their existing supply chains? <i>Focusing on 3D printing</i> | Exploratory | Two case studies | Chapter 5 |
| 4. What is the business impact of innovative technology adoption on the existing value streams/ business manufacturing system? | Exploratory | Two case studies | Chapter 5 |
| 5. How do manufacturing start-up SMEs upscale production of innovative products over time? | Exploratory, theory testing/refinement and theory building | One longitudinal case study | Chapter 6 |

Source: Author

Research strategies can be pluralistic (Yin, 1994), and research questions may not strictly follow given rules, such as in Table 3.4. However, this provides a guide to research strategies. In the case of this research, the main research questions posed are “how” questions and suit the case study research strategy overall. A summary of when case study research is applicable is shown in Table 3.4.

Table 3.4: Relevant Situations for Different Research Strategies

| Strategy | Form of research question | Requires control over behavioural events? | Focuses on contemporary events? |
|-------------------|--------------------------------------|---|---------------------------------|
| Experiment | How, why | Yes | No |
| Survey | Who, what, where, how many, how much | No | Yes |
| Archival analysis | Who, what, where, how many, how much | No | Yes/no |
| History | How, why | No | No |
| Case study | How, why | No | Yes |

Source: COSMOS Corporation, 1983.

The next section explores case study research further, including its scope, benefits, limitations, process and case selection. Further details on each case selected in this research however, can be found in more detailed methodology sections in Chapters 4, 5 and 6.

3.3.1 Case study research

Among others in literature, Voss, Tsiriktsis and Frohlich (2002), and Mariotto, Zanni and de Moraes (2014) highlight the value of case study research within the field of management, especially in operations and supply chain management. According to Frohlich and Westbrook (2001) and Lewis (1998), researchers in operations management have called for more field-based research methods, particularly due to the increase in technological and managerial style changes. With regards to the importance of case study research, Mariotto, Zanni and de Moraes (2014, p. 359) declared that “case studies have been the source of some of the most trailblazing concepts in the field”. Voss, Tsiriktsis and Frohlich (2002, p. 195) credit field case research to discovering “breakthrough concepts and theories in operations management”, such as lean production. Case studies and the definition of what they entail vary (Gerring, 2004). Eisenhardt (1989, p. 534) describes the approach as “a research strategy which focuses on understanding the dynamics present within a single setting”. According to literature, case studies and case study methodology have a long history. Case study research has roots in social sciences (Voss, Tsiriktsis and Frolich, 2002), with more modern case research having been linked to works arising from the “Chicago school” (Denzin and Lincoln, 2003, p. 1; Elman, Gerring and Mahoney, 2016, p. 375) of the 1920’s and 1930’s. The Chicago school practiced sociology, including field-studies or ethnography to study culture and social lives using real-life examples to explain phenomena (Harrison et al., 2017), rather than relying solely on biology. Before this however, according to Elman, Gerring and Mahoney (2016) and Ruddin (2006), aspects of case studies have been traced back to the

works and period of Aristotle, before 400BC. From comparing constitutions and studying human behaviour (Ruddin, 2006), and causality (Malloy and Lang, 1993) to writing detailed accounts of animal behaviour/biology (Tipton, 2006), researchers have pointed out that Aristotle highlighted the importance of case research to his peers (Ruddin, 2006). This, amongst other studies and accounts shows the importance that case study research has had throughout history.

As with other research strategies, case studies have their strengths and limitations. According to Yin (2014, p. 3), performing “case study research remains one of the most challenging of all social science endeavours”. This can be due to researcher experience, which could limit the validity of the research (Yin, 2014), the scope of the case study, the amount of data collected and the perception of some that case study research may lack rigour (Yin, 1994), to name a few factors. Case studies are commonly linked to qualitative methods (Elman, Gerring and Mahoney, 2016; Herron and Quinn, 2016); however, they may use qualitative, quantitative and/or mixed methods (Eisenhardt, 1989). The number and type of case studies used in research vary, such as single or multiple case studies, depending on the researcher, the subject/case and whether the research is creating or testing theory, for instance (Eisenhardt, 1989; Yin, 2014). Table 3.5 summarises several types of case studies and their advantages and disadvantages.

Table 3.5: Summary of case study types

| Type/No. | Advantages | Disadvantages | Authors |
|--|---|---|---|
| Single cases | <ul style="list-style-type: none"> Holistic, in-depth study/ analysis of a case They can be used for theory creation and/or theory testing | <ul style="list-style-type: none"> Potential lack of generalisability – focus is limited to one case | (Voss, Tsikriktsis and Frohlich, 2002; Mariotto, Zani and de Moraes, 2014; Ulriksen and Dadalauri, 2016; Steinberg, 2015) |
| Multiple cases | <ul style="list-style-type: none"> External validity Triangulation (e.g. data, researcher) Findings from cross-case analysis (e.g. pattern identification and case comparison) Theory testing, creation, development and refinement | <ul style="list-style-type: none"> Less depth than a single case study Possible resource constraints Potential lack of generalisability (depending on number of cases) | (Voss, Tsikriktsis and Frohlich, 2002; Ridder, 2017; Yin, 2014) |
| Retrospective cases | <ul style="list-style-type: none"> Data collection for historical events | <ul style="list-style-type: none"> There may be difficulties determining cause and effect due to recollection of important events | (Voss, Tsikriktsis and Frohlich, 2002) |
| Longitudinal cases | <ul style="list-style-type: none"> In-depth analysis of a case over several points in time Theory creation/testing | <ul style="list-style-type: none"> Requires more time Possible resource constraints Potential lack of generalisability - focus is limited to one case | (Voss, Tsikriktsis and Frohlich, 2002; Yin, 2014) |
| Summary of case studies overall | <ul style="list-style-type: none"> Allow for the investigation of the real world, modern phenomena / study subjects in natural setting Triangulation (e.g. data, researcher) Validity May incorporate qualitative, quantitative and mixed methods Theory testing, creation, development and refinement Researchers can benefit from being immersed in a case or cases Suited to multiple contexts Allows for understanding of process complexities Allows researchers to learn from and to investigate areas with little or no existing data | <ul style="list-style-type: none"> Have historically been perceived as not being as rigorous as other quantitative methods Potential lack of generalisability May be viewed as too in-depth or too broad (depending on the number and type of case studies used) May be time consuming (e.g. to collect the data if a research protocol is not in place to provide scope, to prepare transcripts, and/or to analyse findings) | (Voss, Tsikriktsis and Frohlich, 2002; Yin, 2014; Ridder, 2017; Mariotto, Zanni and de Moraes; Gerring, 2004; Eisenhardt, 1989; Benbasat, Goldstein and Mead, 1987; Meredith, 1998) |

Source: Adapted from Voss, Tsikriktsis and Frohlich, 2002, p. 203.

Single case studies are suitable for analysing a case organisation in depth, particularly for, though not limited to, exploration (Yin, 1981), and may be utilised to create or test theory. Single case studies may focus on one organisation; however, within this they could explore multiple sources of data, issues and/or theories (Voss, Tsikriktsis and Frohlich, 2002). According to literature, there are mixed views of the use of single case studies in research. Mariotto, Zanni and de Moraes (2014), among other researchers, defend the use of single case studies in management research against the perception that they are not as rigorous as other methods, noting the abundance of surveys or more quantitative methods that are evident in literature (Voss, Tsikriktsis and Frohlich, 2002).

Moving on from single case studies, Benbasat, Goldstein and Mead (1987) note that multiple case studies allow for a broader view to be taken, for cross-case analysis to occur and for theories to be extended. Benbasat, Goldstein and Mead (1987, p. 373) describe the use of multiple case studies as “desirable when the intent of the research is description, theory building or theory testing”. Yin (1981, p. 101) adds that the use of multiple case studies “are appropriate when the same phenomenon is thought to exist in a variety of situations”. The use of multiple case studies allows for the researcher to obtain a broader understanding as compared to the use of a single case study.

Retrospective cases are most commonly used for historical data collection (Voss, Tsikriktsis and Frolich, 2002). As the name suggests, retrospective case studies allow researchers to look back in time and gain insight into key milestones, events and so on. According to Huber (1985, p. 943), “The use of retrospective reports from informants who were participants is a common research procedure in studies of innovation, business policy formulation, organizational change, and other decision-related processes or events.” As reported by Clark and Rowlinson (2004), the interest in and demand for historical research in regards to organisational studies is rising. Retrospective case studies have been described as being “less time-consuming” and more efficient than longitudinal case studies (Chandler and Lyon, 2001, p. 112), although they rely on “temporal stability” (Huber, 1985, p. 943) or participants recalling events accurately (Chandler and Lyon, 2001; Leonard-Barton, 1990). Leonard-Barton (1990, p. 250) commented that “the most significant weakness of wholly retrospective research is the difficulty of determining cause and effect from reconstructed events”, which “a longitudinal, real-time study” can assist with.

Lastly, is the longitudinal case study. Longitudinal can be defined as “data gathered during the observation of subjects on a number of variables over time” (Ruspini, 2002, p.3). Longitudinal research has been described as being rare (Böhme et al., 2014a) particularly in the field of supply chain and operations (Kuula, Putkiranta and Toivanen, 2014), which is “historically lacking” according to Boone et al. (2013, p. 232). Kuula, Putkiranta and Toivanen (2014) also found that longitudinal studies are scarce, with more evidence of research using single or multiple case studies and quantitative methods. Longitudinal case studies see the researcher involved in a case study for extended periods of time, allowing for an in-depth understanding of the case. Chandler and Lyon (2001) commented that longitudinal studies are suitable when researching entrepreneurship, as compared to cross-sectional studies for example, in gaining in-depth understanding. Whilst longitudinal case studies can be time-consuming and result in significant amounts of data and analysis for the researcher, to which Kuula, Putkiranta and Toivanen (2014) and Remenyi et al. (1998) partly attribute their scarcity, there are

multiple benefits of utilising longitudinal studies (Remenyi et al. 1998). A longitudinal study can offer considerable insight into the phenomena, theory or case being studied, as well as the ability to observe trends (Remenyi et al., 1998), as compared to other forms of case studies. According to Remenyi et al. (1998, p. 47), longitudinal research also holds value for business and management studies, as it “usually offers the best opportunity to obtain valuable insights into practices and policies”.

As with other research methods, there are strengths and weaknesses of case study research. Whilst a single case or longitudinal study allows for an in-depth investigation of a case, the potential lack of generalisability or the time taken to conduct the research may be viewed as a limitation. Similarly, although there are more cases investigated in multiple case studies, the potential lack of generalisability can be a disadvantage and the depth of the research may be debateable. As with research questions influencing the methodology chosen (Yin, 2014), the type and purpose of case studies are also related, with the research purpose influencing the type of case study chosen.

The purpose of case studies, such as for exploratory, explanatory or descriptive research, can vary (Yin, 2014). Case studies may be utilised to build upon, test and/or refine theories, as summarised in Table 3.6. As Yin (1994) highlighted, research strategies may be pluralistic, with case studies being any combination of exploratory, explanatory and descriptive, rather than the researcher being restricted to one strategy. This research largely focused on exploratory research, as shown in Table 3.3, which summarises the research questions and aims.

Table 3.6: Case study research – when/why? Matching research purpose with methodology

| Purpose | Research question | Research structure |
|---|---|---|
| Exploratory Uncover areas for research and theory development | Is there something interesting enough to justify the research? | In-depth case studies Unfocused, longitudinal field study |
| Theory building Identify/ describe key variables Identify linkages between variables Identify “why” these relationships exist | What are the key variables? What are the patterns or linkages between variables? Why should these relationships exist? | Few focused case studies In-depth field studies Multi-site case studies Best-in class case studies |
| Theory testing Test the theories developed in previous stages Predict future outcomes | Are the theories generated able to survive the test of empirical data? Did we get the behaviour that we predicted by the theory or did we observe another unanticipated behaviour? | Experiment Quasi-experiment Multiple case studies Large-scale sample of population |
| Theory extension/refinement To better structure the theories in light of the observed results | How generalisable is the theory? Where does the theory apply? | Experiment Quasi-experiment Case studies Large-scale sample of population |

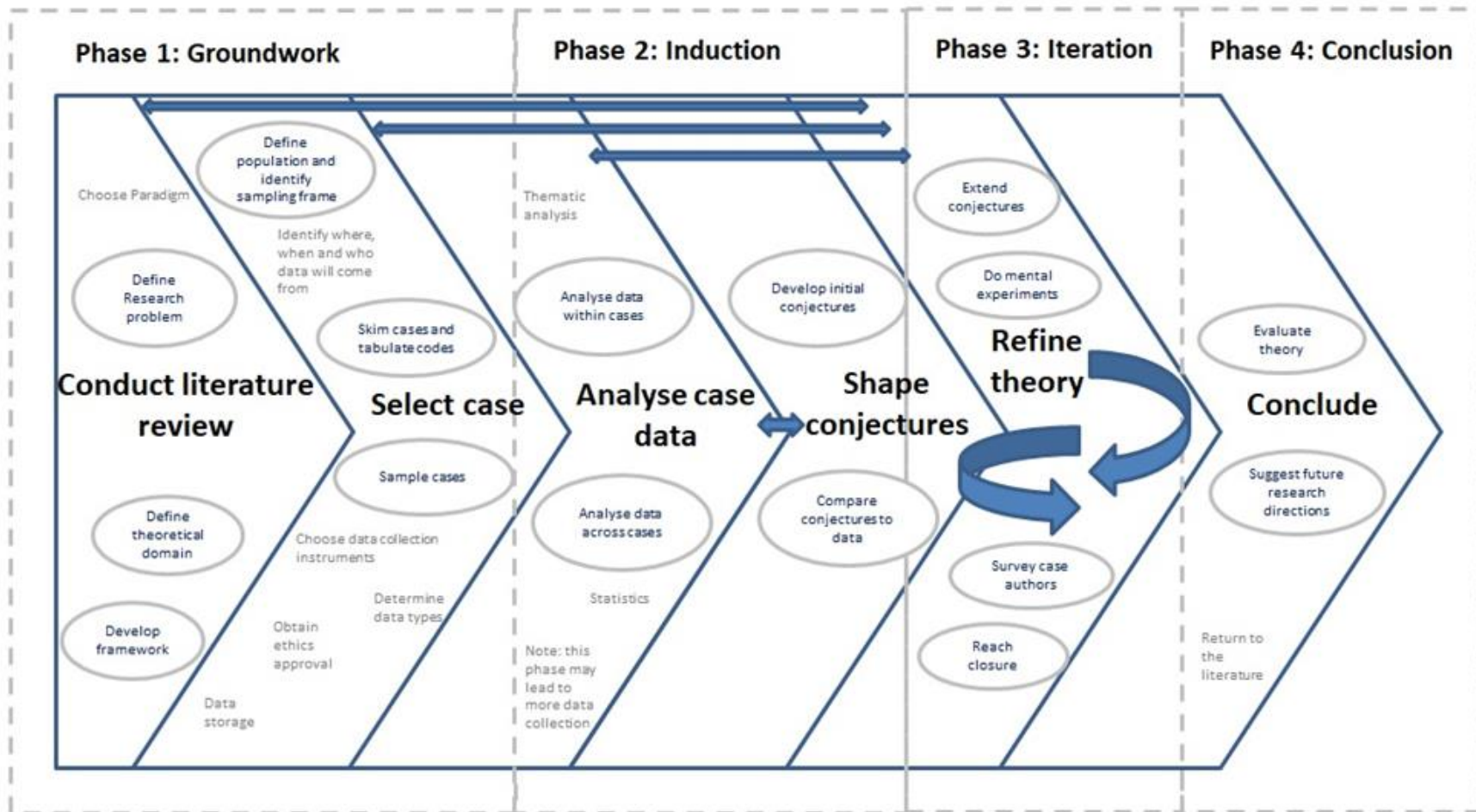
Source: Handfield and Melnyk, as cited and modified by Voss, Tsirikrisis, and Frohlich, 2002, p. 198.

Exploratory research has been described as aiming “to carve out a new niche, an entirely new puzzle, or a new assembly line” (De Langhe and Schlessler, 2017). According to Holliday (1964, p. 38) “the major emphasis in an exploratory study is on discovery of new ideas and insights”, in particular “where little knowledge is available” (Holliday, 1964, p. 38). In this research, exploratory case studies were suitable due to the infancy of the area being studied. To the author’s knowledge, at the time of this research there had not been a study conducted in the Australian context using the chosen diagnostic tool, QSAM. This was utilised in Chapter 4 to establish context for the overall research, which will be explored in Section 4.3.1. This aided in ascertaining SC maturity levels in the Australian context and establishing maturity as an indicator for innovation (Böhme et al., 2014a), and using uncertainty as a measure, as presented in Chapter 4. Also, the impact of innovative technology (3D printing or additive manufacturing) had been largely investigated from a technical or engineering standpoint in literature, as discussed in Chapter 5. This research aimed to view this innovative technology from a SC perspective, investigating the impact it can have on manufacturing systems and VSSs, for example. Each of the different case studies used to explore and answer the research questions followed the stages of case study research, as summarised and explained in the next section.

3.3.1.1 *Case study methodological process*

As Mackenzie and Knipe (2006) noted, research processes, projects and decisions rarely follow a linear path. It can be an iterative process whereby the researcher is required to revisit the literature and questions to refine their work (Lewis, 1998; Mackenzie and Knipe, 2006). Even so, it is important to have guidance and follow a systematic path during the research process (Mackenzie and Knipe, 2006). One such path for the case study methodological process, which this research followed, is shown in Figure 3.2. Possible iterations for consideration have been included throughout the process, as denoted by arrows. The process is explained in the following sections following Lewis’s (1998) methodological process phases.

Figure 3.2: Methodological process



Source: Adapted from Lewis, 1998, p. 459; Mackenzie and Knipe, 2006, p. 203

3.3.1.1.1 Phase 1: groundwork

The process begins with the initial groundwork, as shown in Figure 3.2. Reviewing a wide range of literature to determine where gaps and opportunities for theory creation, refinement or theory building exist, for example, is an important step in research preparation. It provides a foundation for the research scope and purpose, including research questions posed (Lewis, 1998) and paradigms chosen (Mackenzie and Knipe, 2006). This research, for instance, began with reviewing a vast array of SC literature, which was narrowed down to focus on SMEs in the Australian context, manufacturing, and the area of innovation, including innovative technology (3D printing/AM). Chapter 2 presented the broader literature review, with more specific literature included in Chapters 4, 5 and 6 for each set of findings. During this research, an initial review of the literature revealed a gap and presented an opportunity to further a methodology that had not been previously used in the Australian context, which then provided context for this research. This foundation then influenced the next important step, case selection, which will be explored in Section 3.3.1.2. Case selection is significant as this is where the sample is determined, including aspects such as case population/number of cases, research strategy and data types. During this stage, the researcher questions where the data is to come from, whom to include in the research, the purpose of the research and the timeframe for data collection, as well as establishing procedures to ensure ethical research (such as secure data storage) (Mackenzie and Knipe, 2006).

3.3.1.1.2 Phase 2: induction

The next stage is the analysis of case data. As noted by Lewis (1998), this stage involves two techniques to accomplish analysis from within the cases and across the cases. According to Lewis (1998, p. 462), these two techniques “can amplify the theorists’ ability to detect patterns and to develop an understanding for the ‘why’s’ underlying those patterns”. They allow for the researcher to become familiar with an in-depth study of the case, whilst also being able to compare these findings to other cases. The researcher may use a statistical/quantitative approach to data analysis or a more qualitative approach. The analysis may reveal gaps in the data (Mackenzie and Knipe, 2006), where the researcher would need to revisit the previous data-collection stage, or it may lead to the next stage where conjectures are established and shaped.

3.3.1.1.3 Phase 3: iteration

Following this is the stage of theory refinement. Conjectures are reviewed, theory is refined and literature is revisited through conducting “mental experiments” (Lewis, 1998, p. 465), in order to reach the next and final stage.

3.3.1.1.4 Phase 4: conclusion

Finally, following the reiteration of conjectures and theory, when “marginal improvement becomes small” (Eisenhardt, 1989, p. 533), is the conclusion. Limitations, further opportunities for future research, contributions of the research and a discussion of the findings are presented before arriving at a conclusion.

This research followed the systematic methodological process shown in Figure 3.2. The details of each stage can be found throughout the thesis; for example, the groundwork literature review in Chapter 2, detailed information on case selection and data analysis, in Chapters 4, 5, and 6 and an overall conclusion in Chapter 8. The aim of this section was to provide an overview of the methodological process which guided this research. The next section will provide a broad overview of the case selection for the research, with further details included in Chapters 4, 5 and 6 for each set of findings.

3.3.1.2 Case selection

According to Eisenhardt (1989, p. 537) case selection “defines the set of entities from which the sample is to be drawn”, which influences the findings. Case selection may involve purposive or randomly chosen cases (Seawright and Gerring, 2008). According to Seawright and Gerring (2008), each has advantages and disadvantages. Using randomness in selecting a small number of cases for instance can lead to inadequate results, or it can assist in overcoming potential researcher bias in case selection (Seawright and Gerring, 2008). In contrast, whilst purposive case selection, may be viewed as being biased, however, it could also lead to significant and more meaningful results for the researcher. Sykes, Verma and Hancock (2018, p. 229) describe the case selection process as “first-order research design decisions that chart the course for the depth and/or breadth of future findings”, which Eisenhardt (1989), among others in literature, agrees is an important step in the research process.

Cases selected in this thesis have been summarised in Table 3.6, which provides an overview of the case organisations, including size, a broad description, data-collection methods, timeframe and the chapters relevant to each case. Importantly, this research used purposive case selection rather than randomness (Yin, 2014; Seawright and Gerring, 2008). This was due to the need for only a small sample of cases to achieve meaningful results (Seawright and Gerring, 2008) and in-depth exploration through case studies, rather than a broader, larger selection of cases, for example, using a survey approach. The cases chosen are as follows in Table 3.7.

Table 3.7: Case selection summary

| Organisation: | No. of employees (approx.) | Product/description: | Data collection method: | Data collection conducted: | Relevant chapter: |
|---------------|----------------------------|--|-------------------------|--------------------------------|-------------------|
| Company 1 | 120 | Designer, manufacturer and wholesaler of electronic products (e.g. switch boards, fuse boxes and lighting) | Case study | October/ November 2013 | 4 |
| Company 2 | <200 | Printing and a provider of innovative solutions for print and media | Case study | December 2013 | 4 |
| Company A | 25 | Advance Engineering/ Manufacturing (Metal Product) – Filters and filtration solutions | Case study | June 2015 | 5 |
| Company B | 8 | Advanced Engineering / Manufacturing (Residential and Commercial) – Wallpaper | Case study | June 2015 | 5 |
| Company X | 8 | Advanced Engineering / Manufacturing - 3D Printers and solutions | Longitudinal case study | September 2016 to January 2018 | 6 |

Source: Author

The cases selected for this research were done so according to several factors. First, understanding Australian organisations and the state of SCs was of importance to this research in providing context and a foundation. As the state of Australian SCs is a broad topic, the focus was further narrowed down by organisation size, industry and location. SMEs, which consist of 199 or fewer employees, and the manufacturing industry were of interest due to the significance to the Australian economy, as well as practice and research, as established in the literature reviews in Chapters 2 and 4, and the introduction in Chapter 1. The location was also important, and was narrowed down to New South Wales and the Australian Capital Territory, Australia, assisting in researcher accessibility. Further to this, both of the cases were undergoing significant changes or challenges, and were experiencing a transformation or were at a cross-roads. Both faced barriers that required further investigation, and there was an opportunity for the researcher to gain early insights into the impact of an innovative technology that is affecting many organisations globally as part of the Industry 4.0 wave. This presented an opportunity for in-depth exploration, suitable for case study data collection to get an understanding of each case organisation from within (Mentzer and Kahn, 1995).

The significance of each of the cases in Table 3.7, can be broken down into stages. First, Companies 1 and 2 in Chapter 4 provide context and a foundation for this research/thesis. Early insight into current SC maturity within Australian manufacturing SMEs is established through case study investigation. Next, Chapter 5 examines Companies A and B to provide insight into best practices from abroad, particularly focusing on two mature SMEs that have adopted innovative technology into their manufacturing processes, which have influenced the SCs and VSs of both SMEs, which could assist in

understanding future states of Australian SCs that are also being influenced by such technology. Such cases were not available in Australia to the researcher's knowledge at the time of this research, and so these provided cases of best practice in which to learn from. Finally, Company X in Chapter 6 allowed for the researcher to use a longitudinal case study approach to investigate the journey of a less mature, highly innovative SME, and the process of growing and how innovative technology and processes are impacting on their journey of growth towards achieving a more mature SC. Through exploring such case studies, it allowed for the researcher to get an understanding of the Australian SC landscape and the impacts that environmental factors such as innovative technology and processes are having on SCs and their maturity. Details of the cases, including an overview of the organisations, interviewees and data collected, can be found in Chapters 4, 5 and 6.

In summary, the use of case studies in this research was suitable for multiple reasons: such as supporting the aim of understanding real-world phenomena and modern areas for research (Yin, 2014); there was scope for the researcher to be a part of the research (Mentzer and Kahn, 1995) and more than an observer; and it allowed for the exploration of areas that hold relevance to and involved the interaction of academia and practice, which in turn is posited with enriching the researcher through the process of conducting the case studies (Voss, Tsiriktsis and Frohlich, 2002). In particular, using multiple case studies allowed for cross-case comparisons (using uncertainty as the unit of analysis, based on the uncertainty circle principle in Figure 4.1), as well gaining an in-depth understanding into the organisations, due to the smaller sample size and the use of applied research. Further in-depth knowledge was also gained through employing the use of a single longitudinal case study, allowing for a deeper understanding of the organisation as well as the development and testing of models. Table 3.7 provided an overview of cases within this thesis, with further detail about the findings for each case being located in Chapters 4, 5 and 6. Further details within these chapters include descriptions of the organisations and data collection techniques (including interview/interviewee details) located in the detailed methodology sections that accompany the research findings in each chapter.

There are a variety of data collection techniques available for use throughout the different stages of research. Some of the key techniques relevant to this research are explored in the following section.

3.3.1.3 *Data collection techniques*

This research utilised case studies with multi-method data collection techniques. This allowed for various forms of triangulation, such as data and method, combined with researcher triangulation as part of the team approach (Childerhouse and Towill, 2011a; 2011b) used in Chapter 4. This provided validation and increased the robustness of the data collected (Thomas and Barton, 2011). This section outlines data collection techniques used throughout this research. Further exploration of the data

collected and data analysis however can be found in Chapters 4,5 and 6. Some of the data collection techniques utilised throughout this research overlap, due to using multi-methods of data collection that were often used simultaneously. To avoid duplication, all data collection methods have been described in this section. Data collection techniques used as part of the chosen diagnostic, QSAM (Thomas and Barton, 2011), including observation (Childerhouse and Towill, 2011a) and case studies, are as follows:

3.3.1.3.1 Semi- structured interviews

Interviews form an important part of data collection in this research. Interviews have the objective to “explore the views, experiences, beliefs and/or motivations of individuals on specific matters” (Gill et al., 2008, p. 292). As noted by Gill et al. (2008), there are three main types of interviews: unstructured, semi-structured and structured. Unstructured interviews, whilst providing freedom for the researcher, have also been described as being challenging (Ellis, 2016), in that the researcher requires knowledge and skill to be able to talk about topics and keep the interviewee engaged (Rowley, 2012; Ellis, 2016) without using a strict set of questions. This is said to be suited to exploratory research (Ellis, 2016). Rowley (2012) adds, however, that it can be difficult to generate data that can be easily compared between interviews using an unstructured approach.

Next are semi-structured interviews. Semi-structured interviews have been described as the most common form of interview (Rowley, 2012), especially in qualitative research (Rowley et al., 2012). Semi-structured interviews encompass both open and closed questions, often with more open questions used (Rowley et al., 2012). According to Ellis (2016, p. 104), “the key questions have been decided before the interview” and “the interviewer asks broadly the same questions but they have the freedom within the research protocol to explore some of the answers given”. Semi-structured interviews provide guidance for the researcher and interviewee, as well as flexibility during the interviews.

Lastly, there are structured interviews. Structured interviews have been likened to questionnaires (Rowley, 2012). According to Rowley (2012, p. 262), “quite a few questions are asked, generally answers expected are relatively short, and the questions are posed in the same order with every interviewee”. All interview types have benefits and disadvantages, however. Overall, according to Ellis (2016, p. 106), interviews “have the potential to create deep, rich data because they explore topics in considerable detail as opposed to surveys and questionnaires”.

Semi-structured interviews were used in this research due to the benefits of guidance, flexibility and being a part of the research protocol, which provides a selection of questions that can be explored further during the interview if required (Appendix B). Semi-structured interviews have also

been suggested as being suited to research and practice, and “are a particularly useful approach for encouraging well-informed managers, professionals and other practitioners to report on their attitudes, experiences, knowledge and understanding of work practices and processes” (Rowley et al., 2012, p. 93). As well as this, semi-structured interviews suited the University of Wollongong’s ethics requirements, as a requirement is that interview questions be submitted as part of the ethics protocol before research commences. As part of this research, interviewees from across the organisations (including management to production staff and across departments, for example) were selected for the case studies to gain a holistic view of the SCs being studied. Further details on interviewees selected, data collection and data analysis can be found in Chapters 4, 5 and 6.

3.3.1.3.2 Questionnaires

In addition to semi-structured interviews, the research protocol for this research also included questionnaires. According to Remenyi et al. (1998, p. 150), a questionnaire’s main purpose “is to obtain information that cannot be easily observed or that is not already available in written or computerized form”. The structure of questionnaires varies. They may include multiple forms of questions, from the use of scales such as Likert, nominal and ordinal (Leong and Austin, 2006; Remenyi et al., 1998), open and closed questions, and sections for additional comments, each with different benefits and goals for data collection. Open-ended questions, for instance, may help with delving deeper into the respondents’ understanding of a topic, which Leong and Austin (2006) noted as being particularly useful when trying to understand a phenomenon early in research. Likert scales or closed questions may assist in gaining short and quick answers to questions when more is known about a topic (Leong and Austin, 2006). Benefits of questionnaires include, but are not limited to, being low cost to administer, the speed of completion, the ability for getting feedback from individuals and groups, and depending on question types, they can provide ease of data analysis (Tashakkori and Teddlie, 2003), as compared to forms such as lengthy interview transcripts. Weaknesses may include limitations due to the length of the questionnaire, the difficulties posed by incomplete or missing answers, validity and low response rate by mail for example (Tashakkori and Teddlie, 2003), as well as a misunderstanding of questions by the respondent. As noted by Tashakkori and Teddlie (2003, p. 305), the combination of questionnaires and interviews has the benefit of being able to provide “a more complete and interesting depiction of the differences across samples” and assisting the researcher in understanding the data collected.

In the case of this research, there were multiple questionnaires that were a part of the protocol to be completed with key members of the selected organisation (Thomas and Barton, 2011), as shown in Appendix B. The questionnaires focused on the material flow, uncertainty present (which is

explained further in Chapter 4), and overall maturity of the organisation and chosen VSs through exploring key data on supply, demand, system controls and processes. As well as questionnaires administered by the research team, additional surveys could be deployed during the research to gain additional insight into the organisations being studied. Participants can complete such surveys anonymously and provide further comments that are not included in other data gathering activities such as interviews. This data, combined with the interview data in particular assists in gaining a deeper understanding and increases the validity of the data.

3.3.1.3.3 Archival data collection

Archival data “may be thought of as any sort of information, previously collected by others, amendable to systematic study” (Jones, 2010, p. 1008). Archival data may comprise of various documents, from letters, emails and diary entries, to financial documents, business records, board meeting minutes and public statements (Calatone and Vickery, 2009; Welch, 2000). The data may be open to the public or kept private and confidential, which can affect data transparency and accessibility (Heng et al., 2018). Although this, among other factors, could be viewed as a limitation of using archival data, various benefits have been to it; these include assisting with data triangulation and verification (Welch, 2000), assisting with challenging and/or explaining certain theories and phenomena (Welch, 2000), and being free from researcher bias, which affects research credibility (Calatone and Vickery, 2009). During the case study data collection in this research, a variety of archival data, including organisational charts, product sales figures, financial data and customer feedback statements, were collected. This assisted in gaining a more holistic view of the participating organisations and increased the robustness of data collected. Some of the archival data collected assisted the researcher in being able to map certain processes and fill in gaps during data collection.

3.3.1.3.4 Process/value stream mapping

According to Thomas and Barton (2011, p. 45), process mapping “provides a detailed understanding of the material and information flows for the business processes”. Process/value stream mapping (VSM) was also used during the case study data collection in this research. VSs were selected and processes mapped, including both the material and information flows. A VS can be described as “all the actions (both value-added and non-value added) currently required to bring a product through the main flows essential to every product” (Rother and Shook, 2003, p. 3), from design to production. Importantly, as noted by Rother and Shook (2003, p.3), employing a “value stream perspective means working on the big picture, not just the individual processes, and improving the whole, not just optimizing the parts”. VSM allows for researchers to identify wastes or “muda” (Behnam, Ayough and Mirghaderi, 2018, p. 64), highlighting where potential bottlenecks exist and where improvements can be made or waste minimised. Wastes that could be reduced in the production process may include, for example, time,

motion, over-production, additional processing/double-handling, faulty products, too much inventory or transport (Simboli, Taddeo and Morgante, 2014).

During this research, the researcher began the mapping process during the initial site tour of each case study organisation, then continued to add detail and gain verification throughout interviews and during the final presentation to the participating organisation; this is explained further in Chapter 4. The mapping process does not require elite technology; it can be done with a pencil and paper (Rother and Shook, 2003). Providing visual maps for participants to see can be beneficial to show where problems and opportunities lie, rather than just describing them. Rother and Shook (2003, p. 9) describe VSM as a “language” that can be taught to the organisation, which provides a tool for communication, managing change and planning.

3.3.1.3.5 Observation

The final technique employed in this research was observation. Conducting observations allows researchers to see people and organisations in their natural environments and states. As noted by Tashakkori and Teddlie (2003, p. 313), “observation is an important method because people do not always do what they say they do”. Having researchers conducting data collection may affect the setting, with workers being interrupted, for example, or tasks occurring that don’t ordinarily take place (Tashakkori and Teddlie, 2003). Of benefit however, is that observing production, a meeting or other normal work tasks may provide more information than a questionnaire or interview could. Observations as part of the initial site tour in this research, as well as additional visits, for example, to map processes are beneficial to the data collection process. The researcher is able to not only collect second-hand information during interviews about operations for instance, but also see for themselves what is happening and compile substantial notes and diagrams as part of the process.

In summary, each data collection technique played an important role throughout the case study process, with the use of multi-methods increasing triangulation of this research (Yin, 1999; Jick, 1979). According to Yin (1999, p, 1217) with regards to collecting multiple sources of data, “the more all of these techniques are used in the same study, the stronger the case study evidence will be”. The use of multi-method data collection techniques in this research assisted the researcher in gaining in-depth and robust insights into the participating organisations during data collection. In addition to this, the research protocols were designed and tested to enable standardisation, transferability and reliability of data collection and analysis (Childerhouse and Towill, 2011a; Atilgan and McCullen, 2011). This assisted in enhancing research quality, as will be discussed in the following section.

3.4 Research quality

As Voss, Tsikriktsis, and Frohlich (2002, p. 211) and others in literature have noted, “it is particularly important to pay attention to reliability and validity in case study research”. Although Voss, Tsikriktsis and Frohlich (2002) highlight reliability and validity in case studies, other factors affecting the quality of research more broadly are also important, including an assessment of rigour or trustworthiness (Lincoln, 1995), whether it be qualitative, quantitative (Roberts, Priest and Traynor, 2006; Ellram, 1996) or mixed methods research. Mentzer and Flint (1997, p. 200) refer to the degree of rigour in research as “[t]he level of attention paid to the research design”. According to Roberts, Priest and Traynor (2006, p. 41) in regards to research reliability and validity, there are “ways of demonstrating and communicating the rigour of research processes and trustworthiness of research findings”. Determining this may include the consideration of different factors such as; construct validity, internal validity, external validity and reliability (Yin, 2014), or credibility, transferability, dependability and confirmability (Lincoln, 1995). As Saunders, Lewis and Thornhill (2012) noted, it depends on the research being conducted and what criteria the researcher decides to adopt, as there are some terms, such as those adopted by Yin (2014) and Lincoln (1995) that refer to similar concepts but with different names, whilst other criteria are completely new and different (Lincoln, 1995). According to Yin (2014), the four criteria for research quality, including construct validity, internal validity, external validity, and reliability, have been determined as appropriate and recommended for use in conjunction with empirical social research such as case studies. This research therefore followed Yin’s (2014) four criteria for research quality.

3.4.1 Construct validity

Yin (1994, p. 34) describes construct validity as “especially problematic in case study research”, due to subjectivity and measures adopted. Improvements to construct validity in case study research can be achieved however. According to Ellram (1996, p. 105), construct validity is related to reliability and the data collection phase, and comprises of three main factors: “using multiple sources of evidence, establishing a chain of events, and having key informants review the case study research”. Improvement can be gained through using multiple sources of evidence and data, multiple methods and even researcher triangulation (Ridder, 2017; Böhme et al., 2014a; Childerhouse and Towill, 2011a; 2011b; Voss, Tsikriktsis and Frohlich, 2002; Yin, 1999; Johnson, 1997; Jick, 1979), for example. Triangulation can be described as “‘Cross-checking’ information and conclusions through the use of multiple procedures or sources” (Johnson, 1997, p. 283). Then, “[w]hen the different procedures or sources are in agreement you have ‘corroboration’” (Johnson, 1997, p. 283). According to Roberts, Priest and Traynor (2006, p. 44) and others in literature, “[t]riangulation is another way of enhancing the validity of qualitative research”. The triangulation that results from the multiple sources of data and

multiple researchers could reduce “informant bias” (Ellram, 1996, p. 105) and increase validity. Johnson (1997) gives a complete list of ways to improve validity in qualitative research.

3.4.2 Internal validity

According to Mentzer and Flint (1997, p. 204), “internal validity provides evidence of whether the relationship is causal, i.e., X causes Y”. Whilst it has been said that case studies in particular have significant importance, for example, to logistics research, due to being “rich in explanatory information” (Mentzer and Flint, 1997, p. 204), it has been said to be “...inapplicable to descriptive or exploratory studies (whether the studies are case studies, surveys, or experiments), which are not concerned with making causal statements” (Yin, 1994, p. 35). Identifying cause and effect, combined with the use of a research team (Böhme et al., 2008) assists with improving internal validity, such as in the case of this research.

3.4.3 External validity

“The extent to which the findings of a study can be applied to other situations refers to the question of external validity, or generalizability” (Merriam, 1995, p. 57). Some researchers view qualitative or case study research as not being as generalisable (Ellram, 1996; Merriam, 1995) as quantitative research. Yin (2009, p. 15) commented that “case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes”. Although the potential lack of generalisability has been identified as a possible weakness of qualitative or case study research, it is still possible to generalise from multiple and single case studies for example (Ellram, 1996). Generalisability can go beyond statistical sampling (Lee and Bakerville, 2003), and replicating the study and providing clear explanations and understanding of the research (Ellram, 1996) or having a database of knowledge, such as in this research, can assist in improving external validity or generalisability.

3.4.4 Reliability

According to Saunders, Lewis and Thornhill (2012, p. 192), reliability “refers to whether your data collection technique and analytic procedures would produce consistent findings if they were repeated on another occasion or if they were replicated by a different researcher”. Although field work can face difficulties and limitations, due to studying subjects in their natural environments that afford the researcher less control than other research environments (Benbasat, Goldstein and Mead, 1987), there are multiple methods of increasing research reliability. These may include developing a research protocol (Yin, 2014; Ellram, 1996), keeping a diary or comprehensive notes (Roberts, Priest and Traynor, 2006), using computer software such as NVivo (Roberts, Priest and Traynor, 2006) to assist in the coding and analysis of data, “ensuring technical accuracy in recording and transcribing” (Roberts, Priest and Traynor, 2006, p. 44), establishing a case study database (Ellram, 1996), as well as frequently revisiting

data collected and including quotes and accounts from interviewees/research participants (Roberts, Priest and Traynor, 2006).

Developing a research protocol (Yin, 2014) can assist with research reliability, as it provides guidance for the researcher as well as future researchers to be able to replicate the study. In this research, research protocols were developed for the case studies in Chapters 4, 5 and 6. These included semi-structured interview guides (Appendix B), questionnaires and documents providing the scope and design of the research, which were shared with participating organisations and individuals before data collection took place.

Data collected and notes taken by the researcher were frequently revisited during both the data collection and data analysis stages. This allowed the researcher to identify gaps that required further data to be collected, and also to analyse findings to gain an understanding of the data that could help answer the research questions. The researcher analysed the data without the use of computer software such as NVivo. Although there are limitations with manual analysis, such as the risk of researcher bias (Roberts, Priest and Traynor, 2006), and although using computer software has benefits such as reducing the burden of the workload associated with interview data coding (Remenyi et al., 1998), software also has limitations. There have been warnings that data can be over analysed and potentially taken out of context when there is “an over-emphasis on standardisation” that may render data to become “meaningless” (Burton, as cited by Roberts, Priest and Traynor, 2006, p. 43) and cause researcher “remoteness” (Remenyi et al., 1998, p. 114). The researcher in this study chose to assume closeness to the data in this case and avoid what has been likened to positivist research behaviour. As noted by Remenyi et al. (1998, p. 114), “A non-positivist stance assumes involvement with the research process through all stages, and particularly the analysis, as one person’s interpretation will be different from that of another or that assisted by software”. The researcher transcribed interviews and included additional notes such as background information and anything else pertinent to the case. Body language and attitudes noted during the interviews also influenced the data analysis, which Peräkylä (1997) noted are sometimes left out of transcripts. For example, transcribing the interview notes instead of employing third parties to do so, allowed the researcher to be further immersed in the data. Additionally, once findings were compiled, verification was sought through multiple means, further increasing the reliability of the research (Robert, Priest and Traynor, 2006). Verification occurred at several stages of the research process, such as during the data collection stages, during the final presentation to the participating organisations and also in the final reports provided, as explored in Chapter 4. Further verification occurred through a publication that was double-blind peer-reviewed (Rylands et al., 2016) and through feedback received from the participating organisations after

reviewing findings. Furthermore, impact statements were received from participating organisations. Examples have been included in this thesis (Appendix C). Finally, the researcher compiled the case study data into a database of knowledge. Documents included interview notes, process/VSMs, cause and effect diagrams, archival documents and participant information.

In summary, as with other research strategies, case studies have their benefits and limitations. This is especially so due to the use of field work with multiple participants and uncontrollable variables, rather than strictly controlled laboratory experiments (Rowley, 2002), which can affect research quality. Although multiple criteria can be selected to determine the research quality (Yin, 2014; Lincoln, 1995), and some have been characterised as being more positivist research or non-positivist research approaches, it is important that the researcher has chosen a set of criteria to follow to provide guidance and ensure that levels of reliability and trustworthiness are evident in the research (Lincoln, 1995). Importantly, the researcher has an important role to play throughout the research process, to ensure research quality and guidance; is discussed further in the next section.

3.5 The role of the researcher

The role of the researcher can vary, from being an outside observer regarded as separate to the research (Mentzer and Khan, 1995), to being embedded in and close to the data collected (Fink, 2000), and is influenced by numerous factors such as whether the research is qualitative or quantitative. As Sutton and Austin (2015, p. 226) note, qualitative research “can help researchers to access thoughts and feelings of research participants” in order to gain a further understanding of data collected. Qualitative research methods assist in understanding both the “how” and “why” behind behaviours or results (Sutton and Austin, 2015). On the other hand, quantitative research is the “how many”, and can be used to uncover “how many people undertake particular behaviours” (Sutton and Austin, 2015, p. 226). Collins and Cooper (2014, p. 89) describe qualitative researchers as requiring “both emotional maturity and strong interpersonal skills” to listen to others’ accounts, learn about their experiences, understand the information collected and decipher the meaning. The qualitative researcher is described as needing to be reflexive (Collins and Cooper, 2014; Pyett, 2003), able to perform self-scrutiny (Pyett, 2003), and able to balance “the need for creativity and rigor” (Pyett, 2003, p. 1170).

The researcher is part of the research (Mentzer and Kahn, 1995) and may need to be able to demonstrate agility in the field to respond to different conditions (Collins and Cooper, 2014). As noted by Rowley (2002), the case study researcher faces more uncertainty and less control over the environment and subjects as compared to research conducted in a laboratory setting. The case study researcher needs to lead the research; ensure rigour in data collection through triangulation (Pyett,

2003; Jick, 1979), increasing data validity, quality and researcher confidence (Jick, 1979; Welch, 2000); observe whilst being a part of the research by assuming closeness to the research; and exercise their knowledge and emotional maturity (Collins and Cooper, 2014) to actively “ask good questions, to listen and to interpret the answers” (Rowley, 2002, p. 22). This may involve the researcher working with practice and needing to be practice-relevant, through translating questions so that they are applicable to the environment, as well as ensuring that research benefits both parties through the application of theory without the researcher acting as a consultant (Böhme, 2012). The case study researcher also needs to be able to disseminate the research to applicable audiences, including practice and academia (Shriver, 2007). Through doing so, the researcher can assist in gaining exposure for and increase the impact of the research, potentially adding to knowledge in the field that may assist in bridging the gap between practice and academia.

Another important role of the researcher as stated by Sutton and Austin (2015) is to ensure that both the data collected and the participants are safeguarded or protected throughout the research process. Importantly, before this research was conducted, ethical consideration took place through following an ethical protocol, as discussed in the following section.

3.6 Ethical consideration/research protocol

Ethical consideration is a vital part of any research endeavour. As part of this research, the ethics application process included the preparation and submission of documentation such as participation consent forms, participant information sheets, interview questions, a letter of invitation from the case organisation, and information about the researcher. These documents were reviewed and approved by the University of Wollongong (ethics numbers 2013/453 and 2016/928). Ethical consideration and application were conducted before QSAMs and case studies commenced.

Following the University of Wollongong’s ethics-approval process (University of Wollongong, 2019), this research was considered low risk as it did not involve children, animals, experimentation or sensitive information related to the Australian Government. Information collected was kept confidential, with names of individuals and organisations being removed and replaced with pseudonyms to ensure their anonymity. The research scope and intention were fully explained to participants before research took place, with the participants involved in the data collection able to retract their involvement and provided data at any point during the research.

3.7 Discussion

There are many paradigms and methods for available for investigating SCs, as presented in this chapter. Over the years, there has been a shift in the application of paradigms and the viewpoints taken by

researchers. SCs have traditionally been viewed from a more positivist perspective, with more-qualitative approaches taken (Koroglu, 2006; Mackenzie and Knipe, 2006). The use of surveys and questionnaires have been dominant in the field of management (Affalla-Luque et al., 2013). There has been recognition in the literature however, that there is a real need for more applied, field research to take place (Stuart et al., 2002). In particular, there is great potential for longitudinal studies in the field, which have been identified in literature as being rare (Böhme et al., 2014a; Kuula, Putkiranta and Toivanen, 2014; Boone et al., 2013). Longitudinal studies allow for researchers to immerse themselves for a longer period of time in a particular setting, to gain a deeper understanding of the workplace/environment being studied. Whilst longitudinal studies can be time-consuming to conduct, they allow researchers to collect substantial amounts of data and insight into a phenomenon that could be argued as going beyond the capability of performing an online survey.

The researcher chose to perform case study research, including a single longitudinal study, with the aim of gaining insight into organisations and adding to applied knowledge in the field regarding SC maturity, barriers/enablers and the impact of innovative technology on VSs and the greater SC. Case studies allow researchers to utilise multiple data collection methods and tools, such as QSAM (which is explained further in Chapter 4), and for various forms of triangulation, such as methodology, data and researcher (Böhme et al., 2014a), which increase data quality and validity. The use of multiple case studies in this thesis allowed for cross-case comparison, utilising uncertainty as the unit of analysis (following the uncertainty circle principle in Figure 4.1), and exploratory research into multiple SCs, whilst the longitudinal case study allowed the researcher to focus on the evolution of a single SC as well as the application and testing of a model over a period of approximately 16 months.

Such applied research approaches have been attributed to helping bridge the researcher-practitioner gap (Böhme, 2012). This is important, especially as being able to solve real-world problems and relate them to academia (which in turn impacts on practice) has been highlighted in literature (Chopra, Lovejoy and Yano, 2004). Although there is evidence of barriers and limitations in all research, such as time required to undertake the research or the number of case studies chosen, the methodology used throughout this research, including an exploratory, applied approach (incorporating the use of case studies and QSAM) as explored in this chapter, presented opportunities to contribute to knowledge and answer the research questions.

3.8 Conclusion

In conclusion, it has been established that having a clear research design and overall strategy is important to the research process and in providing guidance to the researcher (Saunders, Lewis and Thornhill, 2009). This chapter aimed to present an overview of research design options available and of the strategies used throughout this thesis. This chapter presented the broad research design, methods and methodology, beginning with the outer layers of the research onion (Saunders, Lewis and Thornhill, 2009) as a guide, including philosophical assumptions and approaches, in the selection of an interpretivist and abductive approach. It then proceeded to explore the inner layers, including the specific research strategy of case studies (including both multiple and longitudinal), followed by a broad overview of cases selected and data collection techniques (with more specific information in Chapters 4, 5 and 6), research quality, the role of the researcher and ethics.

The overall scope for this applied research was focused mainly on Australian manufacturing SMEs to address the research questions and to provide context for this research. Exceptions to this include two of the case studies mentioned in Section 3.3.1.2, which are examples of best practice from North West England (presented in further detail in Chapter 5). By using an applied case study research approach, it assisted in gaining a greater understanding of the organisations being studied, as well as experience in the methodology. Chapter 4, explores Australian case studies and the diagnostic applied to gain early insight into the state of SC maturity.

4. The current state of supply chain maturity and innovation in Australia

It is becoming increasingly apparent that a major re-appraisal of the way in which companies compete is now required and a new model of competitive strategy is emerging. It is based on the premise that increasingly a firm competes through its capabilities and competencies; in other words, by how well it manages the fundamental processes involved in satisfying customers. One of the most complex and therefore potentially critical processes in gaining competitive advantage is the supply chain process
(Christopher and Juttner, 2000, p. 5).

4.1 Introduction

As Christopher and Juttner (2000) and other researchers have ascertained, the importance of SCs cannot be underestimated by academia or practice. SCs, regardless of organisational context or country of origin, are used by many as competitive weapons (Ketchen et al., 2008; Bell, Autry and Griffis, 2015; Tompkins, 2015; Beck, Hofmann and Stölzle, 2012), in that competitive advantage is gained through effective management of the SC. According to Stevens (1989, p. 3), “The design and operation of an effective supply chain is of fundamental importance to every company.” Understanding the current state of SCs in practice enables SCs to be better managed and streamlined, and has been linked to assisting in increasing innovative opportunities, as Böhme et al. (2014a) found in their research. This research focuses on SCs, particularly Australian SMEs in the manufacturing sector. The previous chapter presented methods by which a SC can be analysed, particularly in ascertaining levels of SC maturity. This chapter further explores the chosen methodology and research findings to address the gap in literature surrounding SC maturity in Australia, particularly in the manufacturing sector, and the link to innovation.

Research identified that manufacturing has strategic importance to the nation in which it is situated (Soosay et al., 2016; Kurfess, 2013). Soosay et al. (2016, p. 9) describe manufacturing capabilities as “an indispensable source of competitive advantage”; thus, further research in this area is warranted. Manufacturing in Australia has been changing in more recent times. There has been a shift towards the service sector and a decline in more-traditional manufacturing, such as in the automotive industry (Galloway and Zervos, 2017). This decline within the manufacturing sector not only damages the immediate organisations, but it has the potential to affect the entire SC. The effects of the change in industry are felt by both large and small organisations, with many SMEs being impacted, as the Australian business sector comprises of over 95% SMEs (AiGroup, 2017; Gilfillan, 2015), which is a

significant percentage. As with the *mittelstand* in Germany (Berlemann and Jahn, 2016), SMEs are important to many countries (Kumar, Khurshid and Waddell, 2014) and can improve economic resilience if well managed. Also, of importance is an organisation's innovative capability. There has been a recent push by the Australian government regarding increasing innovation in organisations of all sizes (Australian Government, 2015; 2016). Organisations also recognise that they must innovate to remain competitive. In order to do so, organisations should examine their SCs in order to understand their SC maturity and capability (Böhme et al., 2014a).

This chapter focuses on SC maturity in Australia. Identification of a gap in the literature surrounding SC maturity in Australia meant that without conducting this initial research it would have been challenging to gain an understanding of, or to establish context for this thesis. Childerhouse and Towill (2011b) and Böhme (2012) called for further applied SC diagnostic research to be conducted to gain a better understanding of challenges and good practices in the real world. Australia was named (amongst other countries) as a future place for research in order to build up a more comprehensive and representational database of SC knowledge (Childerhouse et al., 2011d). Applied research has been shown to benefit the universities and practitioners that are involved in it (Grün, 1987), and was suitable for this research. Through the use of an exploratory, applied approach, this study assists in strengthening current research and in closing the divide between theory and practice. The ability to diagnose diverse SCs and their maturity levels is difficult due to many factors, such as context and organisational type and size. Measures that take these differences into account and make it possible to fairly compare organisations from diverse industry backgrounds are desirable (Böhme et al., 2014a). This research uses an applied diagnostic tool that allows for such analysis.

The research contributes to the QSAM database of knowledge, and includes early insights into the maturity of Australian SCs in practice, using a well-tested and rigorous applied research method that had not been conducted in the Australian context before. This research aims to add to knowledge in the field of SC maturity, cause and effect, barrier analysis and innovative capability in Australia, by answering the following research questions:

- Research question.1. How mature are Australian supply chains in practice? and;
- Research question 2: How do barriers to supply chain maturity impact on business innovation?

The structure of this chapter is as follows: it begins by exploring literature on uncertainty and innovation in SCs, followed by the applied methodology (QSAM) used within this chapter. The chapter then presents an introduction to the Australian data, with findings presented on two Australian cases that are focused on in-depth (including an electronic designer and manufacturer, and a make-to-order

(MTO) printing house). Within these two organisations, six VVs are explored in detail using cause and effect analysis and systems uncertainty. Following this, the Australian data is used in a cross-case comparison, followed by the discussion and conclusion.

4.2 Literature review

4.2.1 SC maturity, uncertainty and innovation

SCs can be defined as “identifying the desired strategic outcomes for the firm and developing, implementing, and managing over time the resources, processes, and relationships (within the firm and across the supply chain) that seek to make the attainment of such desired outcomes inevitable” (Melnyk et al., 2014, p. 1889). SC management has evolved beyond that of a single internal function, such as logistics or distribution (Ballou, 2006; Done, 2011), or a single firm; it now encompasses external clusters or supply chain networks (Stevens, 2016). The importance of understanding the SC and levels of integration and maturity have been highlighted by various researchers in literature (Childerhouse et al., 2011; Böhme et al., 2014b). According to Stevens (1989), increased SC integration leads to benefits such as improved operations and customer service and decreased costs, as well as assisting an organisation towards achieving a “seamless supply chain” (Towill and Childerhouse, 2006, p. 757), where material and information flow seamlessly from end to end (Towill and Childerhouse, 2006; Archibald et al., 1999; Christopher, 2011). More researchers are beginning to link SC integration with SC maturity and systems uncertainty (Childerhouse, 2011a; Böhme et al., 2016; Wong et al., 2011; van Donk et al., 2008; Stonebraker and Liao, 2006; Ayree et al., 2008; Trkman et al., 2007), revealing that SCs that are more mature exhibit less systems uncertainty.

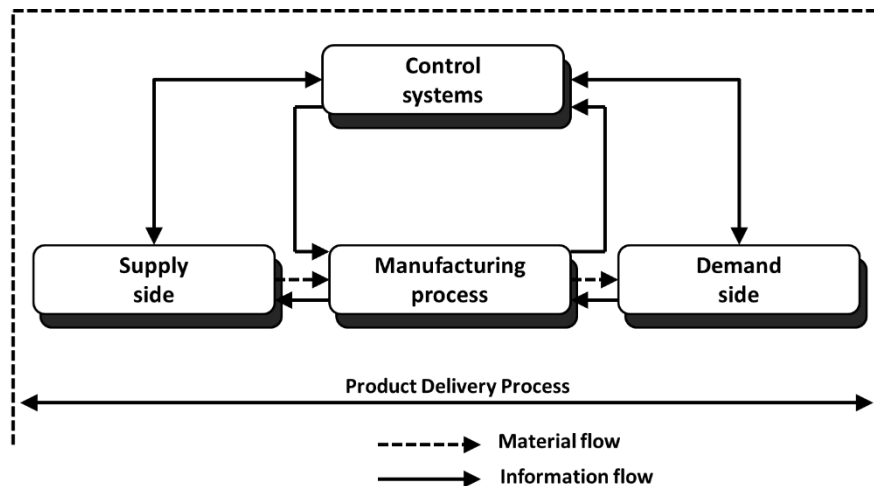
The concept of systems uncertainty has also been linked to business innovation, meaning higher levels of SC maturity resulted in higher rates of business innovation through the tight integration of core internal functions with external customers and suppliers (Böhme et al., 2014c; Prajogo and Sohal, 2003; 2004). Innovative capability can be assessed through “systematic analysis and comparative benchmarking” (Francis and Bessant, 2005, p. 175) and improved awareness of issues and opportunities within processes via process mapping (Burgess, 1994) and through the use of diagnostics such as “causal-relationship maps” (Salama et al., 2009, p. 34). These types of assessments enable organisations to gain a better understanding of their own supply chain practices, drive continuous improvement and increase innovation capabilities within their business. Stevens (2016, p. 36) states that “the role of SCM as an enabler of business success will not go away”; thus, increasing an understanding of one’s organisation’s SC and its strategic significance is of great importance (Estampe et al., 2013). This understanding of the SC can be enhanced through benchmarking.

SC maturity benchmarking is well established in practice (Kohlegger et al., 2009); however, it is not as well established in academia. Benchmarking SCs can be done through multiple assessment techniques, as identified by Böhme et al. (2016). Examples of benchmarking include, but are not limited to, Supply Chain Operations Reference (SCOR) (Huan, 2004; Delipinar and Kocaoglu, 2016; Lakri et al., 2015), Data Envelopment Analysis (DEA) (Wong and Wong, 2008) and QSAM (Childerhouse and Towill, 2010; 2011a; 2011b; Böhme et al., 2014a). (Further assessment techniques are referred to Chapter 2). Whilst the SCOR model is suitable for assessing SC reliability and processes (Sellitto et al., 2015), it has limitations (Delipinar and Kocaoglu, 2016; Wang et al., 2010) such as not being suitable for use in certain industries (Persson, et al., 2010) or not taking into account the context (Böhme, 2012) or customer/supplier interfaces (Huang and Mak, 2000). DEA, which has been described as being “a powerful mathematical tool” (Kuah and Wong, 2011, p. 151), can also be used to benchmark supply chains and their efficiencies (Janvier-James and Didier, 2011). DEA is said to depend highly on precise data, which may face methodological challenges such as the availability of required data in real-world situations or case studies (Kuah and Wong, 2011), affecting data integrity. Additionally, variations of DEA have been described as being complex and reliant on large sample sizes (Kuah and Wong, 2011). This research utilises QSAM, as it is a well-established, “transferable” (Childerhouse and Towill, 2011a, p. 635), rigorous methodology that uses data, method and researcher triangulation (Böhme et al., 2014a). QSAM (Childerhouse and Towill, 2010), which is described in more detail in Section 4.3, is based on the manufacturing system (Parnaby, 1979; Parnaby and Towill, 2009a; 2009b; 2010; 2012), encompassing systems thinking and the uncertainty circle model (Mason – Jones, 1998; Aitken et al., 2016). QSAM uses cause and effect analysis and systems uncertainty data to compare and benchmark organisations regardless of context or size.

As shown in Figure 4.1, Mason-Jones and Towill (1998, p. 17) identified four SC uncertainty areas, the combination of which they named the “uncertainty circle”. The uncertainty circle uses a context-free measure and forms part of the QSAM protocol. The uncertainty circle, as explained in detail in Naim et al. (2002), assists in identifying improvement areas or root causes, and in generating an uncertainty profile or Euclidean Norm (EN) score based on supply, control, process and demand systems uncertainty (Appendix item B). Using a four-point Likert scale in the uncertainty questionnaire, the formula for calculating the Euclidean Norm (EN) is; “ $EN = \sqrt{[(\text{Our processes} - 1)^2 + (\text{Our controls} - 1)^2 + (\text{Our supply side} - 1)^2 + (\text{Our demand side} - 1)^2]}$ ” (Böhme et al., 2016, p. 251). According to Towill (2000), the EN uncertainty score provides a reference point for each VS under analysis, which shows its maturity level (with higher levels of maturity showing lower levels of systems uncertainty), allowing for benchmarking comparison. Using this applied methodology makes it

possible to research and benchmark Australian organisations as compared to international organisations, due to uncertainty being a context-free measure (Böhme, 2014a; 2014b; 2012).

Figure 4.1: Uncertainty circle principle



Source: Mason-Jones and Towill, 1998, p. 17

Capturing uncertainty profiles and levels of maturity in organisations also assists in exploring potential innovative capability. Applied longitudinal research conducted by Böhme et al. (2014c) demonstrated that reducing levels of systems uncertainty increased the innovative capacity, as the case organisation was able to better focus their efforts on product development and on working in partnership with critical suppliers. Lowering uncertainty levels has been described by Böhme et al (2014c, p. 6533) as “a critical step towards increasing flexibility and innovation capability, as it frees up valuable engineering time for pursuing breakthrough innovations, and for growing innovation within processes and the wider supply chain”. Burgess (1994) described similar findings regarding increasing time for innovation and awareness of organisational issues and opportunities. Prajogo and Sohal (2003; 2004) also explored the correlation between uncertainty, organisational maturity and increased innovation within organisations, whilst Wang et al. (2016) investigated levels of standardisation within organisations and its positive impact on product and process innovation, as well as lowering process uncertainty. Low levels of systems uncertainty and increased maturity can therefore be argued to be a precursor to innovation. Not only is innovative capability important in organisations and their associated SCs, but it has been said that “a high-performing innovation system can underpin the overall competitiveness of an economy” (Australian Government, 2016, p. 1). It is the objective of the present research to diagnose SC

maturity in practice and investigate the link between uncertainty and innovation capability in more depth. The next section presents the methodology chosen to assist in SC diagnosis (QSAM).

4.3 Methodology

4.3.1 Quick Scan Audit Methodology (QSAM)

4.3.1.1 QSAM Introduction

The diagnostic tool used as part of this research is termed QSAM. QSAM stems from systems theory and can be linked to the manufacturing system (Parnaby, 1979; Parnaby and Towill, 2009a; 2009b; 2010; 2012) and the uncertainty circle (Böhme et al., 2013). QSAM is an established methodology that originated in Cardiff University's Logistics Systems Dynamics Group (Thomas and Barton, 2011) in the 1990's (Childerhouse and Towill, 2011a, and Böhme et al., 2012). It was first used as a diagnostic tool in the automotive industry (Towill, Childerhouse and Disney, 2002) to assess SC integration (Böhme et al., 2014). Since then it has been used in other industrial contexts, such as engineering to order (ETO) and health care (Böhme et al., 2013; Böhme et al., 2014) in small to large organisations, as well as in different countries such as the UK, Germany, Thailand, New Zealand (Aitken et al., 2016) and now, through this research, Australia (Böhme et al., 2014b). QSAM is a mixed method approach to data collection and analysis (Böhme et al., 2012), that can be described as a "health check" (Childerhouse and Towill, 2011, p. 6) for organisations. QSAM allows for the comparison and benchmarking of different organisations, industries and contexts based on selected VSs performance and focuses on uncertainty as a measure. As noted by Aitken et al. (2016), it can be difficult to find a measure that is both transferable and objective to compare different SCs due to their differing levels of complexity. Uncertainty is relevant to many organisations, as it can be present regardless of industry or size, for example, and can impact on SC performance, with higher levels of uncertainty tending to reflect higher levels of "fire-fighting" required. Uncertainty is a context-free measure (Böhme, 2014a; 2014b) and is appropriate for SC assessment as part of QSAM. Uncertainty has also been linked to innovation in organisations (Böhme et al., 2014a), which is applicable to this thesis.

As the QSAM approach incorporates the use of mixed methods, data and researcher triangulation (Böhme et al., 2012), the robustness of data collected is increased. Literature suggests that surveys are commonly used (Affalla-Luque et al., 2013). Whilst surveys and questionnaires have their strengths (Tashakkori and Teddlie, 2003), QSAM allows researchers to gather more in-depth field data than surveys alone. QSAM allows researchers and practitioners to work together to provide a "rigorous supply chain assessment" (Childerhouse and Towill, 2011, p. 5), which can benefit both parties through identifying improvement areas and data that is underpinned by theory, to benchmarking performance

with an array of organisations internationally and adding to the QSAM database and teachings for future academics/practitioners. The QSAM network consists of multiple researchers from around the world, who since 1997 (Aitken et al., 2016) have collectively conducted QSAMs on more than 120 VSs, adding to the international QSAM database of knowledge. The scope of QSAM is explained further in the following section.

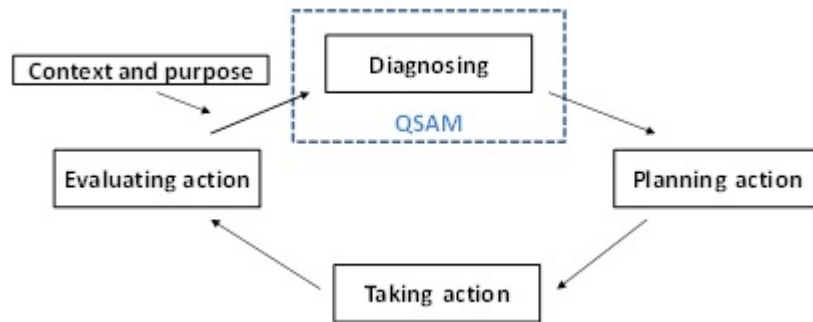
4.3.1.2 **Scope of QSAM**

QSAM is applied research with a scope that could be likened to the first two stages (understand and document) (Naim et al., 2002) of the UDSO business process reengineering process (Watson, 1994). Banomyong et al. (2005) also linked multiple stages of QSAM to the action learning process, such as adding data to the QSAM knowledge base and identifying areas for improvement. QSAM can also relate to the diagnostic stage of action research, (Figure 4.2). Action research, which originated largely from the work of Kurt Lewin (Coughlan and Coghlan, 2002), involves multiple stages as shown in Figure 4.2, and “seeks a more effective method of organizational decision making involving the whole organisation in identifying needs, solving problems, laying out plans, and implementing decisions” (Cunningham, 1976, p.216). Action research involves the person researching being a part of the research rather than just an observer, working with practitioners (Helskog, 2014) and looking into more than just one section of the supply chain (Westbrook, 1995). It allows researchers to learn from the organisation, and, in the process, also from each other (Levin, 2012, and Rowley, 2003). Action research can have benefits for both the organisation, by assisting with problems, and the researchers by adding to or creating theory or knowledge (Gummesson, 2000; Näslund et al., 2010, and Dickens and Watkins, 1999). Although QSAM and action research share similarities, QSAM is only part of the action research cycle. As with the action research cycle, QSAM begins with the researcher building context and determining what they are studying and why. This includes contemplating possible research questions or hypotheses (Näslund et al., 2010) and getting background information on the organisation to be researched. QSAM however, focuses on the diagnostic stage only.

Importantly, the role of QSAM is not to solve all of the organisation’s problems; nor is it to have the QSAM team present for the entire improvement or re-engineering process after the QSAM. Rather, it is to provide unbiased guidance by identifying “major pain(s)” (Childerhouse and Towill, 2011b, p. 7) as well as “quick hits” (Childerhouse and Towill, 2011b, p. 5) in a health check of the SC at that point in time. The organisation can then choose to implement the improvements or not. QSAM provides the foundation for the next stages of the action research cycle of planning and taking action, as well as an evaluation of action taken that the organisation executes. If the organisation chooses to do so, they can

engage the QSAM team for a follow-up QSAM to take place to get an update on their performance in comparison to the original diagnostic.

Figure 4.2: Action research cycle



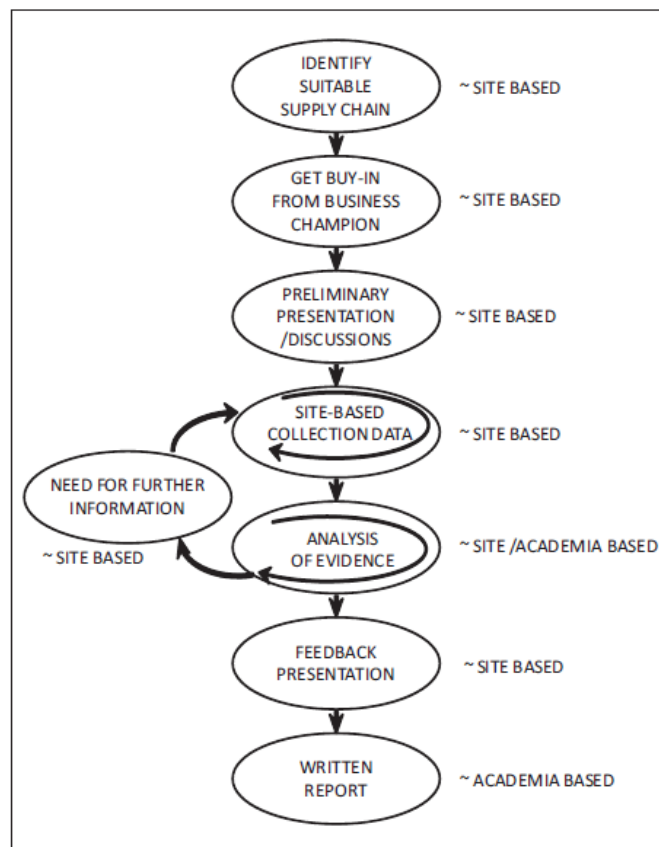
Source: Adapted from Rowley, 2003, p. 133

As with UDSO and action research, QSAM comprises of multiple stages, which are further broken down and presented in the next section.

4.3.1.3 *The QSAM process*

QSAM uses a team approach and requires a business champion from the host organisation to be involved (Naim et al., 2002). The QSAM team typically consist of four to six people and takes place over approximately two weeks (including conducting the research and providing the final feedback presentation). In the case of this research, the team consisted of five researchers for both QSAMs. QSAM consists of several stages, which have been summarised in Figure 4.3. QSAM involves multi-method data collection, such as semi-structured interviews, observations, process mapping and surveys to name a few, as presented in Chapter 3. Sample interview questions, guides, quantitative data collection requirements and benchmarking of SC maturity can be found in the Appendix (Appendix A and B).

Figure 4.3: Simplified QSAM process flow



Source: Böhme et al., 2012, p.372

The QSAM stages (Böhme et al., 2012, p.372) are as follows;

- **Stages 1 and 2 – “Identify a suitable supply chain” and “Get buy-in from (the) business champion”:** The process begins with an organisation being selected (or alternatively an organisation approaching the researchers), and a business champion being elected from the organisation. The business champion is a valuable point of contact during the whole process, as they assist the QSAM team in coordinating the diagnostic, including assistance in getting others from the organisation involved in the process.
- **Stage 3 – “Preliminary presentation/discussions”:** Next, the QSAM team of researchers go on site to make their preliminary presentation, which outlines the QSAM process and allows researchers and organisational representatives to introduce themselves. This step also allows for discussions about possible problems, VS identification (Childerhouse and Towill, 2011b), the development of survey and interview schedules, and a site tour to assist in familiarising the researchers and also in collecting valuable observations to be used as part of the diagnostic.

The duration of this step is approximately half a day (Childerhouse et al., cited in Naim et al., 2002, p. 140).

- **Stage 4 – “Site-based collection (of) data”:** This stage takes place on site over the period of several days (Naim et al., 2002). It consists of collecting multiple data types from questionnaires/surveys, interviews, process mapping (Childerhouse and Towill, 2011), observations and other sources such as archival data that the organisation may provide (including warehouse data, financial figures, and so on). Those chosen to take part in the interviews are from multiple sectors and can range from management to those on the shop floor.
- **Stage 5 – “Analysis of evidence”:** During this stage, triangulation of data takes place (Naim et al., 2002). The team must brainstorm and analyse all of the findings to not only gain insight into the organisation, but also to determine if any further data needs to be collected (which may require additional time on site). Diagrams such as cause and effect (Naim et al., 2002), VS or process mapping and information collected during interviews for example assist in identifying areas such as root causes (for the initial problems identified), best practice, additional areas for improvement and potential improvement opportunities. Importantly, findings also assist researchers in benchmarking each organisation’s SC. This stage takes approximately three days (Childerhouse et al., cited in Naim et al., 2002, p. 140).
- **Stage 6 – “Feedback presentation”:** The findings are then compiled and presented to the organisation. The final feedback presentation is important not only for the organisation to obtain valuable insights into good practice and possible improvement areas, but also for the researchers as validation. It provides an opportunity for discussion regarding the findings, future plans and the potential need for any further assistance, and takes approximately half a day (Childerhouse and Towill, 2011, p. 7).
- **Stage 7 – “Written Report”:** Following this, a written report is provided to the organisation shortly after the feedback presentation takes place. This stage may take approximately three days (Childerhouse et al., cited in Naim et al., 2002, p. 140).

As with other methodologies, the QSAM diagnostic tool has strengths and weaknesses, which are summarised in the next section.

4.3.1.4 *Strengths and limitations of QSAM*

As with other research strategies, although the QSAM diagnostic can be applied to multiple settings, there are benefits and disadvantages of doing so; these have been summarised in Table 4.1.

Table 4.1 Strengths and limitations of QSAM

| Strengths: | Limitations: | Authors: |
|---|---|---|
| <ul style="list-style-type: none"> • QSAM is transferable and can be applied to multiple settings/industries/organisations, as it uses a context-free measure • It provides an in-depth investigation into selected organisations • Data, method and researcher triangulation • A team is used, assisting in the range/amount of data collected and data analysis (e.g. each team member has specific knowledge/expertise) • It is established and robust, and provides a holistic view of the SC • There is an international QSAM database of knowledge and an international network of researchers (academic value) • There is a QSAM protocol, that assists with data collection and replication of research (within and between research teams) • A health-check/benchmarking is provided to the organisation (practitioner value) with minimal interruption during data collection • Researchers and practitioners interact to create value for academia and practice | <ul style="list-style-type: none"> • Gaining access to an organisation and buy-in from a business champion potentially poses difficulties • The process can be time-consuming depending on amount of data collected and data analysis required to meet research objectives; also, the layout and/or number of sites an organisation has can also be a factor • Team members need to be trained in QSAM before conducting the diagnostic. Their expertise/knowledge can also be a potential limitation • Certain methods and methodologies might be perceived as being superior to others, or QSAM could be misunderstood • The involvement of business employees as QSAM team members could complicate the process | <p><i>Childerhouse and Towill, 2011b; Towill and Childerhouse, 2006; Childerhouse, Naim et al., 2002; Disney and Towill, 2008; Thomas and Barton, 2011; Aitken et al., 2016; Atilgan and McCullen, 2011; Naim et al., 2002; Böhme et al., 2007; Böhme et al., 2013; Böhme et al., 2014b</i></p> |

Source: Author

Although limitations have been listed, the researcher found that the strengths outweighed the weaknesses for this research. As Childerhouse, Disney and Towill (2009), among others have found, QSAMs can generate substantial amounts of data. Whilst a copious amount of data was collected for this research, the time taken for data analysis, as shown in Sections 4.4 and 4.5, was not viewed as being burdensome. Instead, the researcher perceived it as a positive experience, as it allowed the researcher to gain in-depth knowledge of the participating organisations and increased experience in the QSAM process. The researcher was fortunate to have buy-in from the participating organisations, bypassing the potential issue of gaining access to conduct the QSAM. Also, the researcher had an experienced QSAM leader to lead and teach the QSAM process. As expressed by the experienced QSAM leader during the research, the QSAM process is learnt by team members with interaction at different levels, from observing in the first QSAM to participating in the second, and then leading the following QSAMs.

The next section presents an overview of the Australian case studies and VSs that have been explored to date, predominantly using the QSAM method for data collection.

4.3.1.5 *Overview of Australian cases*

Since conducting the first Australian QSAM in 2013 as part of this research (Böhme et al., 2014b), there have been additional VSs analysed using the QSAM diagnostic. Table 4.2 shows an overview of cases, including those within the scope of this research, that were selected for further in-depth exploration in this chapter, including the VSs of Companies 1 and 2. The aim of this section is to provide an overview of the Australian QSAMs conducted to date, with further data analysis contained within the findings in Sections 4.4 and 4.5.

Table 4.2: Australian VS data

| VS: | Company / Market sector: | Product/ description: | Value adding activities: | Data collection method: |
|------------|---------------------------------|--|--|--------------------------------|
| VS1 | Company 1 – Industrial products | Box for switches | Procurement and dispatch | QSAM |
| VS2 | Company 1 – Industrial products | Modular switchboard | Design, engineering, training, procurement and distribution | QSAM |
| VS3 | Company 2 – Printing | Off-set (booklet) | Making the plate, sending the sample to client, waiting for approval, receiving approval, plating, scheduling, printing, drying, folding, stitching, and dispatch. | QSAM |
| VS4 | Company 2 – Printing | Digital (printed brochure with components) | Scheduling, printing, folding, stitching, and dispatch. | QSAM |

| | | | | |
|-------------|------------------------------------|---|---|-------------------------|
| VS5 | Company 2 – Printing | Stitch book (printed booklet with staples) | Printing, cutting, folding and stitching | QSAM |
| VS6 | Company 2 – Printing | Envelope (printed envelope with printed paper inside) | Printing, cutting and finishing | QSAM |
| VS7 | Company 3 – Mining | Coking coal (high-quality coal used for steel-making) | Mining, breaking, washing and export | In-depth interviews |
| VS8 | Company 4 – Manufacturing | Lawnmower (gardening tool for domestic use) | Design, procurement, customer relationship management, and assembly | In-depth interviews |
| VS9 | Company 5 – Health care / Hospital | Patient/ patient flow in ED | Treatment, assessment | QSAM |
| VS10 | Company X – Manufacturing | 3D printers | 3D printer design, software and solutions/services | Longitudinal case study |

Source: Author

Table 4.2 contains QSAM, interview and case study data from six Australian case studies, each with different levels of intensity. This data forms part of the QSAM research protocol, comprising of international data for over 120 VSs (including the European automotive sector), as referred to by Towill (2000) and Childerhouse (2011a). The organisations or interview partners chosen for this research were selected due to their “potential to help contribute to the research objectives rather than by concern for randomness” (Stuart et al., 2002, p. 426). The overview provided in Table 4.2 shows the range of QSAM diagnostics that have been occurring in the Australian context since late 2013, including the variety of industries in which it has been conducted in, ranging from industrial to manufacturing, mining, printing and healthcare.

The next section presents the two QSAMs that are the focus of this chapter for Companies 1 and 2.

4.3.1.6 *Introduction to the Australian QSAM data for Companies 1 and 2*

The previous section described the QSAM diagnostic, including the scope and process, and gave a broad overview of Australian cases and VSs that have been analysed to date. This section aims to narrow the focus to two organisations, Companies 1 and 2, in which two QSAMs were conducted on six VSs. This was done so using cause and effect analysis and determining systems uncertainty profiles via the application of the uncertainty circle model (as in Figure 4.1). This was done to establish a greater understanding of the findings beyond that of a single EN score alone, as well to benchmark the organisations, identify cause and effect variables, common barriers and explore how improving one’s in-house operations or SC maturity is linked to increasing innovative capability for Australian SCs (Böhme et al., 2014a).

To determine such findings, QSAM uses multiple methods of data collection, as explored in Chapter 3. These include semi-structured interviews; process, SC and VSM; surveys/questionnaires; archival data collection; observations during site visits; as well as cause and effect analysis, that is explored further in this chapter. The findings from each method are compiled in this chapter to produce a snapshot or “health check” for each organisation, which includes exploring the root causes through cause and effect analysis, and determining an uncertainty profile that allows for the benchmarking of both organisations.

An overview of the data collection for each of the organisations has been summarised in Table 4.3. Approximately 42 researcher days were devoted to each of the on-site investigations of Companies 1 and 2 during the QSAMs, in order to evaluate the SC status and to assess the maturity of both SCs and their innovative capability.

Table 4.3: Data collection overview – Companies 1 and 2

| Company: | Data collection period: | Value adding activities: | No. of researcher days: |
|-----------------|--------------------------------|---|--------------------------------|
| Company 1 | October/November 2013 | Design, engineering, procurement, assembly, testing, distribution | 42 |
| Company 2 | December 2013 | Plating, printing, cutting, folding, stitching | 42 |

Source: Adapted from Böhme et al., 2014b

Semi-structured interviews were conducted in both organisations during the data collection stage. In Company 1, interviews were approximately one to two hours each, with 18 interviewees in the initial stages (as well as additional persons such as “pickers” or warehouse staff spoken to during site visits). In Company 2, interviews were also one to two hours each, with 28 interviewees across four sites (one in the Australian Capital Territory and three in New South Wales). The interviewees ranged from warehouse staff through to the Managing Director, with some interviewees revisited during the “analysis of evidence” stage. Interview participants from both organisations are summarised in Appendix E.

In the next section, findings from Companies 1 and 2 are explored in detail.

4.4 Findings

4.4.1 Company 1 overview

Company 1 is a designer, manufacturer and wholesaler of electronic products. They were established in 1956 and are 100% Australian-owned and operated. They have approximately 120 employees and are classed as a small to medium sized enterprise (SME). Their product portfolio is large, containing products such as switchboards, fuse boxes and lighting. Their customer base is predominantly domestic (with approximately 97% repeat customers) consisting of resellers/wholesalers, switchboard manufacturers, OEM and a small percentage of contractors or utilities. Company 1 have suppliers from Australia, Europe and Asia. Company 1's SC has been included in Appendix F. The company has evolved over the years, experiencing ownership changes since it was first established. At the time of this research, Company 1 was facing significant decisions regarding growth opportunities and competition challenges.

In order to evaluate their supply chain status, a QSAM was conducted in October/November 2013 to assess the maturity of Company 1's SC and innovative capability. Approximately 42 researcher days were devoted to the on-site investigation of Company 1 during the QSAM. Two VSs were selected for investigation, based on their market share, value-adding processes and representation of the organisation. These included products "VS1" (boxes for switches and fuses) and "VS2" (modular switchboards). Research rigour was achieved via data, method and researcher triangulation through the use of a diverse team collecting and analysing multiple sources of data and receiving validation from the organisation of the analysed data.

4.4.2 Company 1 – cause and effect analysis

The data collected was analysed using cause and effect analysis, which has the benefit of creativity and structure (Doggett, 2005; Friendendall, 2002). Once cause and effect analysis has been finalised, the subsequent cause and effect diagram shows the VS operating within the greater organisation (Böhme et al., 2014a). This includes predictor variables and causal relationships (Childerhouse and Towill, 2004; Doggett, 2005). It also exposes problems that may be less visible or hidden deeper within an organisation that require more than a 'quick-fix'. According to Doggett (2005, p. 34), there is an underlying cause to every problem, and "if a root cause of a problem is not identified, then one is merely addressing the symptoms and the problem will continue to exist". Through cause and effect analysis this problem can be avoided. Barriers identified during this analysis are done so by an entire team, allowing for researcher triangulation (Böhme et al., 2014a). Individual bias is therefore avoided

by taking into account the different opinions and expertise of all team members. Further benefits of cause and effect analysis include but are not limited to, identifying process inefficiencies (Islam et al., 2016) and root causes, gaining required feedback and approval from the host organisation (Böhme et al., 2014a) using systems thinking; assisting with problem-solving and more-efficient use of resources (Wilson, Dell and Anderson, 1993), and uncovering gaps that require further research.

The process of developing the cause and effect diagrams in this research, involved systematic analysis whereby key issues were identified, analysed, discussed and mapped by the researcher. The result of this analysis was Figure 4.4, which shows the underlying issues or major pains of the organisation, including inefficiency as well as missed opportunities. It also shows the root causes leading to this, such as unclear business strategy and poor integration of information systems (IS), and more-visible issues such as high levels of firefighting and double-handling. All of these cause and effect factors contributed to inefficiencies impacting on operational performance and will be covered in further detail. Of note is that the cause and effect diagram in Figure 4.4 received verification from Company 1 during the feedback presentation, and assisted in providing data for addressing the second research question:

- Research question 2: How do barriers to supply chain maturity impact on business innovation?

functions of how to achieve this in an integrated way. This became particularly evident during interviews. According to the Product Manager, *“we have a strategy at a high level, but it is not broken down for the company as a whole. Plans are around but not documented”*. The National Sales Manager added that there is *“no defined strategy, mission or vision statement”* for marketing. The IT manager said that *“there was not a written strategy, but there was an understanding to improve business efficiency by monitoring and improving relevant systems, and also to improve costs”*. This lack of direction resulted in unclear objectives, lack of key performance indicators (KPIs) and poor policies and procedures. This hindered the achievement of their strategic goals, as well as causing weak uniformity, or silo mentality, across the organisation. Challenges associated with having an unclear business strategy were affecting strategic alignment, making core competencies unclear, and causing variations in customer service, leading to a major pain of ineffectiveness, missed opportunities and lost sales. Risk or uncertainty for internal processes is increased if the strategy is unclear, as stated by Böhme et al. (2014) and Ritson et al. (2012).

4.4.2.2 **Root cause 2: limited supplier relationship management**

It became evident throughout data collection that supply uncertainty for Company 1 was high. Key international suppliers were unreliable and domineering, demonstrating high levels of power in their relationship with Company 1 (Böhme et al., 2008). Even though it was reported that product managers and suppliers were in regular contact, this was not reducing supply uncertainty. The product managers would divulge specific information regarding their products and planning, whilst the supplier would not. The information flow in this case favoured the supplier, which was becoming detrimental to Company 1. It appeared to be a parasitism-like relationship (Nagler, Hyžný and Haug, 2017, p. 1), which has been described as being perhaps the most *“widespread strategy among animals”* to survive over millions of years. Like the parasite Corallanidae, which Nagler, Hyžný and Haug (2017) describe as acting like mosquitos feeding off of other creatures in the ocean, the supplier in this case is able to *“feed”* off Company 1 in regards to intellectual property (IP). This opportunistic behaviour by suppliers allowed them to gain insight into Company 1’s IP, whilst continuing to offer unreliable service, increased supply uncertainty. Such supplier dominance also resulted in high inventory levels or buffer stock being ordered to counteract supply uncertainty. Situations such as these can result in the bullwhip effect (Towill et al., 2007) whereby stock ordered does not match the demand, resulting in either costly stock-outs or the holding of excessive stock.

In this case, extra inventory was being ordered when it was not needed to avoid stock-outs and to ensure that Company 1 could remain responsive to their customers’ needs. Data collected showed that expected arrival dates for products from Suppliers A and B changed four times within 18 days.

The adjusted ETA jumped from being an earlier arrival date to five days later than the original date (Appendix F). The materials coming from Supplier A in Asia had at least three estimated arrival dates in less than one month, as compared to Supplier B in Europe who could more accurately estimate their arrival without any changes to shipment arrival dates throughout the month. This poor supplier performance made it difficult to plan inventory and added to supplier uncertainty. According to the Finance Director, *“The cost of losing an order is substantial compared to the cost of inventory. I would like around 90 days of inventory, though a ratio shows that (Company 1) may not be able to meet customer orders”*. Due to the supply uncertainty in this case, the warehouse on-site had almost reached capacity, with managers exploring options to invest capital into a larger warehouse. Container storage was even being used on-site for overflow inventory at the time of the QSAM.

Another element adding to supply uncertainty was contract management. The contractual management was weak with regards to managing the power differential with the key supplier. This was due to the manager in charge of this area not having the level of experience or time needed in the position to restructure agreements, or possibly to source alternative procurement opportunities or suppliers. This inefficiency had the knock-on effects of poor supplier performance, increased lead times, extra airfreight and higher inventory levels beyond the capacity of the warehouse, among others. For example, almost 20 electrical components and metal cable cleats were shipped via airfreight from two suppliers over the period of less than one week (Appendix F). Shipments were often not consolidated, with orders being placed with the same suppliers every second day (instead of bulk orders once a week or so) for five or less pieces per order. In a sample of five orders over a period of six days, 40% of orders were for single pieces only. Whilst airfreight is time efficient, it is also an expense that could be reserved for more-critical circumstances or bundled to reduce day-to-day expenses, rather than becoming the everyday norm. The Managing Director also acknowledged this challenge during an interview, expressing that *“one of the big challenges faced by the company is that there is a high level of airfreight, which is reactionary and needs improvement”*. Company 1’s poor planning resulted in increasing costs, where orders could have been consolidated if forward planning was conducted or other means of transport (depending on the real urgency of the parts requested) used.

4.4.2.3 **Root cause 3: poor IS integration**

The QSAM also revealed evidence of multiple poorly linked IT systems. Additionally, the systems were not being used to their full potential, with data-cleansing issues identified (including obsolete stock, stock location, picking slips and availability errors for example). It became evident during data collection that whilst 49,532 stock keeping units (SKUs) existed in Company 1’s system, only 6,579 were

active. The system required attention and cleansing. Picking errors according to the system were less than 0.5%; however, differed greatly to internal customers findings of greater than 15% (Appendix F). Picking accuracy was approximately 70-75% accurate for internal customers, and not all quality incidents were being recorded in the system (which could have assisted in avoiding reoccurrences of the same issues). Further, it was discovered that warehouse staff spent on average two to five hours per week finding SKUs, resulting in approximately \$13,000 to \$33,000 in inefficiencies annually, depending on whether Company 1 classed it as a good or bad week. Inefficiency in IT/IS for forecasting, order prioritisation and processing, stock replenishment and the business strategy impacted on visibility and accessibility to crucial data within the company, as well as customer service. *“Availability of information is a problem”* (National Sales Manager). The Internal Sales Team Leader noted that *“the biggest gap (in regards to information availability) is in the visibility around backorder dates of products”*. The order placement process faced uncertainty due to a convoluted process that resulted in orders not always being directed to the nearest warehouse or distribution centre (where the inventory may have been available). For example, an interstate order would be placed, which would go directly to the NSW head office. If the head office did not have the product available to fulfil the order, the system would place it on backorder, even though inventory may have been available where the order had been placed. This affected delivery performance and increased daily firefighting, resulting in unsatisfied customers. The Internal Sales Team Leader also added that *“at the moment, CRM is not being used to its full potential and Sharepoint access for [the] Sales team that are mobile can make communication difficult and inefficient. The [Sales] rep needs to be able to hand over enquiries to Customer Service and keep moving. Sales need to focus on selling”*. The National Sales Manager also commented on systems and information flow, noting that *“CRM is seen as a chore instead of an information tool”*. Other systems issues existed due to limited access as a result of licencing; as a result, select systems were limited to the finance department. This root cause of poor IS integration resulted in the major pain of managerial and operational inefficiency for Company 1. It also added to poor forecasting, lack of supply chain visibility and data issues, it affected decision making and cause and effect understanding, as well as increased firefighting.

4.4.2.4 **Root cause 4: tacit knowledge**

Although a high level of employee knowledge and experience was apparent during data collection in Company 1, it was evident that much of this was tacit knowledge. The increased risk or systems uncertainty of losing integral company information created a need to generate explicit procedures. The large levels of tacit knowledge within Company 1 impacted on decision making, as it was heavily guided by intuition or gut feeling (art versus science) (Sadler-Smith and Shefy, 2004), as well as stock

keeping, daily firefighting and inefficiency. Company 1 put itself at risk by not capturing key information and using the IT/IS infrastructure to disseminate it and increase visibility. The National Sales Manager commented that *“there is a lack of documented processes for each role, which can be seen as a strength and a weakness”*. The strength that the National Sales Manager was referring to was in relation to being flexible and responsive, although the weakness of this was knowledge loss and process clarity surrounding each role. Another issue that surfaced during discussions with managers, including the Managing Director, was that of knowledge loss due to an aging workforce and retirement. This risk was also linked to innovative opportunities by the managers. The Finance Director stated, *“We have an aging population of workers and don’t have the dynamic innovative environment of other companies,”* adding to the risk of knowledge loss if information was not made explicit and missed opportunities if the organisation did not adopt more innovative ways. *“[Company 1] is not innovative. [Company 1] is seen to run the risk of living in past glory and seem to need to be more innovative”* (Finance Director). As identified in the new growth theory, *“knowledge may increase productivity by stimulating technological progress”* (Mueller, 2007, p. 356). Knowledge in this case is viewed as an *“essential driver”* (Mueller, 2007, p. 356). Not being able to systematically exploit knowledge for further business opportunities can therefore hinder innovation.

4.4.2.5 **Root cause 5: lack of quality management**

Embracing ISO 9001 and continuous improvement was also assessed as a root cause during the QSAM. Whilst Company 1 has ISO 9001 accreditation, it did not go beyond the minimum requirements to actively maintain it. Certification such as ISO accreditation has been found to have positive effects on organisations (from internal processes, meeting customer needs to financial benefit) (Feng, Terziovski and Samson, 2008). Such accreditation however needs to be supported by senior management and staff needs to be adequately trained and provided with resources to successfully implement and maintain it (Feng, Terziovski and Samson, 2008). *“I was given 50% of my time to focus on quality management, but in reality, it was closer to 20%”* (Acting Quality Manager). Because staff did not actively log or track quality performance, similar issues arose repeatedly, as the causes were not properly understood, communicated or documented. The same issue of a faulty switchboard, for example, could have been avoided if it was understood why it had been occurring. This also affected key performance indicators (KPIs) and picking accuracy in the warehouse, which was approximately 70%. Issues such as poor process management led to the *“major pain”* of managerial and operational inefficiency.

Company 1 added to their major pains of inefficiency and missed opportunities by trying to improve their service to customers whilst neglecting in-house issues. The Project Manager asserted that

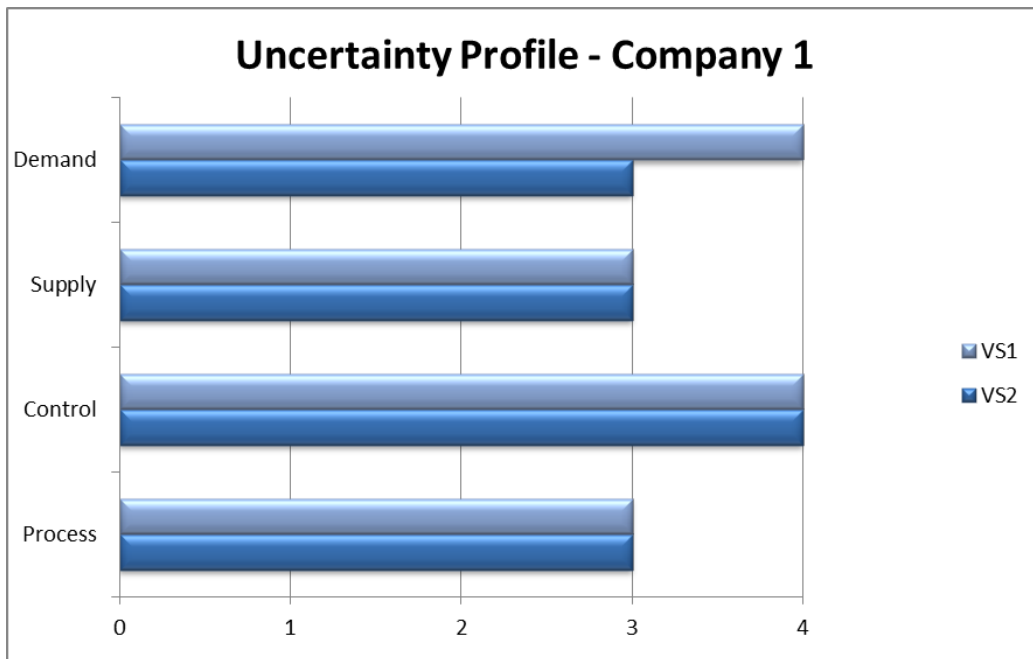
Company 1 would “bend over backwards for customers” in providing service excellence. Due to this, daily firefighting increased across the departments and buffer inventory was procured to avoid stock-outs. *“Approximately two to three hours per day are spent firefighting (in demand planning and procurement). Mostly backorder management, chasing up shipments or incorrect deliveries”* (Buyer, Procurement Department, Company 1). Management inefficiencies and IS added to uncertainty, with demand uncertainty being high due to seasonal peaks, quotations and non-core items, a lack of streamlining of the multiple forecasting systems (and management by “gut feeling”), knowledge-sharing across departments and lack of customer priority. Daily firefighting, combined with the other barriers faced by Company 1, ultimately impacted on opportunities missed, due to the need to find solutions to daily issues rather than develop new solutions to remain innovative and competitive.

Each of these root causes affected another area of the organisation. For example, unclear strategy led to lack of direction and alignment, and poor IT/IS integration impacted on stock visibility, incomplete data and forecasting accuracy, which then affected inventory levels, lead time, customer service and even quality management. The inefficiencies in turn detracted from value-adding activities and R&D efforts that could assist in organisational innovation, growth and competitiveness. Although these issues were evident, it is important to note that there was also evidence of good practice in Company 1 that was highlighted during the feedback presentation and report (Appendix D). The barriers that the QSAM process identified resulted in increased levels of systems uncertainty (as shown in Figure 4.5, the uncertainty profile); this is explored in the following section.

4.4.3 Company 1– uncertainty profile

Company 1 had multiple barriers impacting on demand, supply, process and control uncertainty. In order to understand the maturity of a SC or the benchmarking position of an organisation, including the ability to compare performance to other Australian or international studies, the data was codified using the uncertainty circle model. This allows the comparison of organisations regardless of context such as industry and geographic location (Böhme et al., 2014a; 2014b; 2012). As Figure 4.5 shows, the uncertainty, or EN scores, for both VSs (“VS1” and “VS2”) in Company 1 were high across all four areas (with 1 being low uncertainty, and 4 being high uncertainty). Demand and control for both VSs scored unfavourably, showing the highest levels of uncertainty with a score of 4 out of 4 for control uncertainty. Process and supply followed closely behind, scoring 3 out of 4 for uncertainty. Overall, “VS1” (boxes) had the highest uncertainty, with an EN score of 5.1, followed by “VS2” (techno) with an EN score of 4.6. In this case, the uncertainty profile for both VSs were similar, excluding slight variation in demand uncertainty, with “VS1” scoring 4 out of 4, and “VS2” scoring 3 out of 4.

Figure 4.5: Uncertainty profile for Company 1



Source: Author

Table 4.4 summarises the findings for Company 1. Barriers identified in Figure 4.4 have been categorised based on the uncertainty circle model. The major drivers of uncertainty and reason for the overall EN scores for each VS can therefore be more clearly identified via Table 4.4. Lack of visibility between departments and systems, large amounts of tacit knowledge and convoluted processes all added to the high levels of daily firefighting that Company 1 faced, and increased systems uncertainty across the four categories.

Table 4.4: Summary of systems uncertainty in Company 1

| Systems uncertainty: | Examples from Company 1: |
|----------------------|--|
| Demand | Seasonal demand, lengthy quotation period, reactive, short lead times expected by customers, daily firefighting, lack of streamlined systems/multiple forecasting systems, top 10-20 customers not clearly identified, lack of order priority, and manual processes. |
| Supply | High variation in expected arrival dates, high inventory levels, limited warehouse capacity, additional container storage onsite, unreliable and dominant suppliers. |

| | |
|---------|---|
| Control | Multiple poorly integrated IT systems, lack of KPIs, lack of policies and procedures, unclear strategic direction, stock and location integrity accuracy, mixed forecasting methods, data visibility for sales representatives and a large amount of SKU's in the system. |
| Process | Order placement uncertainty, convoluted process, backorders, and high levels of airfreight, high buffer stock, manual processes. |

Source: Author

In summary, the systems uncertainty and barriers explored in Company 1 were discovered to be obstructing the organisation from achieving higher supply chain maturity. It also impacted on innovation due to missed opportunities and inefficiencies, detracting from valuable R&D and in-house improvement opportunities.

4.4.4 Company 2 overview

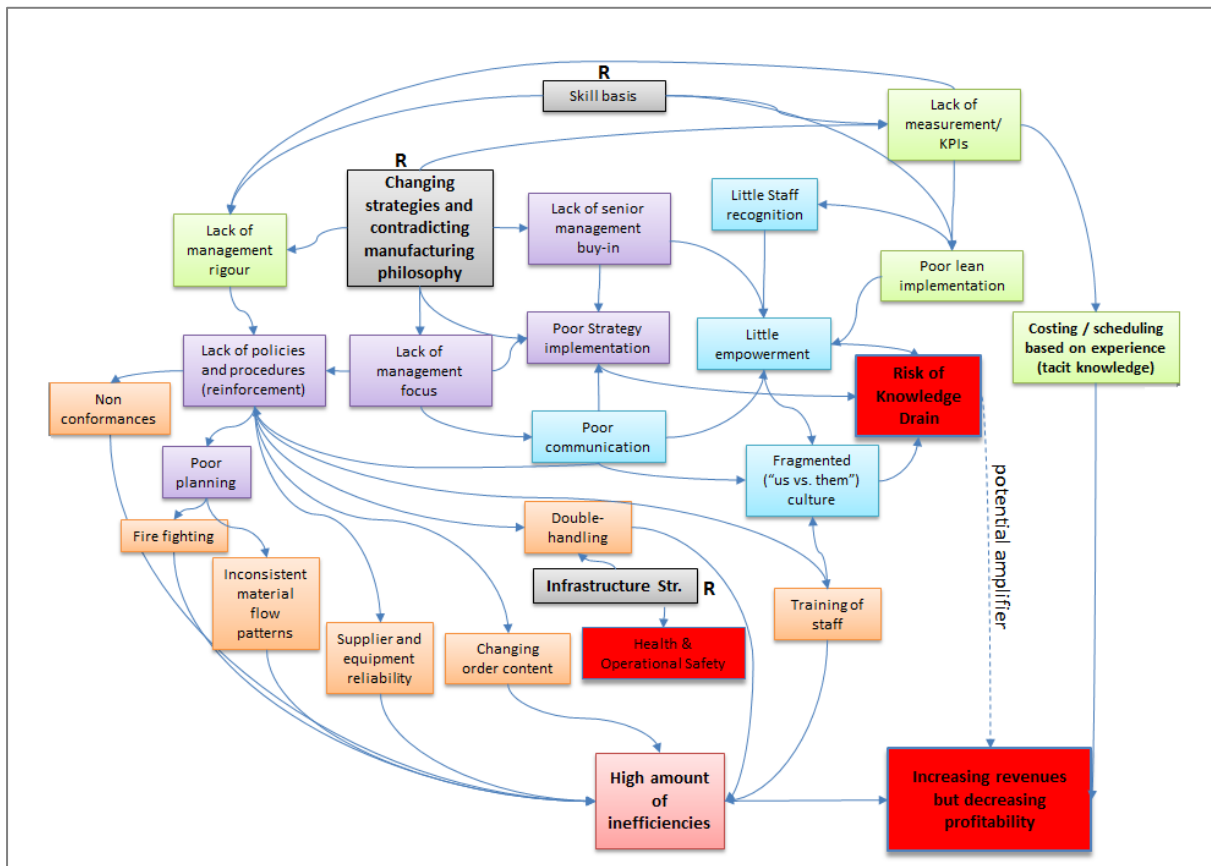
Company 2 is an Australian printing house, described as being an innovative solutions provider for print and media. The product is highly customised; hence the operations strategy is make-to-order (MTO). Company 2 was established in 1994, has an owner who is a third-generation printer, and operates with fewer than 200 employees. The owner of Company 2 has a fervent view of innovation and technology, stating that *“the future of the printing industry lies in value add (i.e. bringing print to life through combining print and IT)”*. Company 2 is an SME with four sites in Australia (three in New South Wales and one in the Australian Capital Territory), as shown in their SC (Appendix G.1). Demand in each region and printing equipment and technological capability determined the final products produced at each site. Printing solutions ranged from digital, ultraviolet and offset printing. Though the sites and products produced at the time of this research differed, the overarching objective for the company was stated as follows: *“to provide total solutions to customers and for each site to be centres of excellence”*. Company 2 had commenced implementing lean practices to assist in achieving these goals. Customers were predominately domestic, with some in New Zealand. For the Australian Capital Territory site, approximately 80% of customers were from the Federal Government. Orders were often time-critical, with some local customers receiving deliveries twice daily. In NSW, there was a new site approximately 80 kilometres away from the original site which was a hub that dealt with the finishing of prints. It was assisted by government funding and aimed to assist with increasing employment in the region. Each of the sites worked together to produce print and media solutions for their customers.

A QSAM was conducted in December 2013 to assess the maturity of Company 2's SC and innovative capability. Approximately 42 researcher days were devoted to the on-site investigation of Company 2 during the QSAM. Four VSs were selected for investigation, based on their market share, value adding processes and representation of the organisation. These included products "VS3" (offset), "VS4" (digital), "VS5" (stitch book) and "VS6" (envelope). The next section further explores data collection and analysis.

4.4.4.1 *Company 2 – cause and effect analysis*

Data collected for Company 2 was also subjected to cause and effect analysis, with strategic issues, cultural barriers, management rigour, and communication issues becoming evident. A deeper investigation into these factors revealed root causes relating to strategy, contradictory manufacturing philosophies, a convoluted material flow pattern (infrastructure) and knowledge/skill gaps became apparent. Figure 4.6 applies a systems-thinking approach, that regards different aspects as being interrelated. For instance, a lack of policies and procedures led to poor planning and non-conformances, increasing "firefighting" and inefficiencies. Poor communication impacted on a lack of employee empowerment and an adversarial culture ("us versus them"), resulting in an increased risk of knowledge drain. Root causes for such issues have been depicted in Figure 4.6 via an "R".

Figure 4.6: Company 2 cause and effect analysis



Source: QSAM feedback presentation

4.4.4.2 Root cause 1: contradictory manufacturing philosophies and changing strategies

At the time of this research, Company 2 was in the early stages of lean implementation, although the process was inconsistent across the four sites and senior management were not unanimously confident that lean was the correct philosophy to follow. In an introduction given to the QSAM team, Company 2 described themselves as *“an agile organisation with good turnaround times”* (Owner). This worsened inconsistency in strategy or strategic alignment across the organisation, with sites not working to their optimal potential, and demand uncertainty affecting performance efficiency. Whilst the application of lean philosophy can potentially be successful in the printing industry (Reitner et al., 2014), it needs to be well understood by the organisation and suit the overall business strategy. According to interviews, the market valued different offerings from price to adaptability and speed to market. For Company 2,

“the order winner is a combination of flexibility and price” (General Manager – Sales). *“The main thing that customers are sick of is other companies not delivering on time and the lack of reliability. They value our reliability and flexibility”* (Manager). The ability to respond to market needs to avoid an acrimonious customer base meant that it was important to align manufacturing philosophies and business strategy across all four sites in Company 2. It became apparent that the organisation’s staff and management did not have a clear understanding of the manufacturing philosophy or the overall strategy. When employees (including management) were asked about their understanding of the business strategy during interviews, the responses were mixed. *“Honestly, I don’t know. It could be having a clear production schedule”* (Customer Service). *“The overall strategy of [Company 2] is to grow the business. Management above me don’t really filter it down”* (Production Manager). Although strategies existed with regards to creating centres of excellence, offering solutions to customers and business growth, they were not made transparent or well communicated throughout the business.

4.4.4.3 **Root cause 2: site infrastructure**

Inefficiencies caused by the unclear strategy or contradicting manufacturing philosophy also affected infrastructure at Company 2. One of the major sites in NSW was noted to be operating at capacity in regards to dispatch warehouse and machine usage. Employees at the site were forced to double-handle product, which impacted on plant efficiency and productivity as well as increased the risk for workplace safety incidents. Sites were interrelated and dependant on each other. In some cases, printing would occur at one site and then need to be shipped to another site for finishing before it could be delivered to the customer. Customers enjoyed high levels of flexibility, which created a great deal of uncertainty in the Sales and Operational Planning department. This uncertainty further filtered down to the logistics department, which was often forced to schedule and reschedule at the last minute, adding pressure and cost to the organisation.

Additionally, each of the sites required clear visibility of inventory and documented production capacity because they did not operate in isolation. Each site managed accordingly, as a failure at one site could have a heavy impact on the others (especially if the order was time-critical or required certain technology or equipment that was site specific). *“Each site in (Company 2) helps each other. A lot of jobs can’t be done at Site A and come here. They tend to be urgent”* (Production Manager). Whilst it was positive that each site assisted one another, *“There are big logistics costs to transfer between sites, which is a major stumbling block”* (Production Manager). Demand at Company 2 was extremely time-critical and often erratic across the four sites. It was influenced by environmental factors such as major world events and breaking news (for media clients), Government changes in legislation, currency

or competition, making it difficult to forecast demand. Such environmental factors, which are summarised in Appendix G.2, were identified during a strengths, weaknesses, opportunities and threats (SWOT) analysis (Gürel and Tat, 2017) conducted on Company 2. This in turn impacted not only on efficiency and forecasting accuracy, but also the work-life balance of the lean workforce across the sites. There was reportedly more than one hour per day per site of rescheduling work required. The Logistics Manager said that *“If I could schedule logistics a week out, we would be able to get it cheaper. Consumer demands constantly change (for example, the colour of print needed depending on whether Lady Diana and Prince Charles had a boy or girl meant that printing is done at the last minute).”*

There was increasing pressure to achieve the short lead times just in time (JIT) demanded by the industry; thus Company 2 tolerated rising costs. However, Company 2 did not provide the required investment (in time and resources) to make operations work. Production worked overtime, warehouses were almost at capacity, investment was not put into sites (even in minor areas such as signage to increase visibility for customers) and last-minute changes added to costs and increased stress on employees. Moreover, IT performance and machine down time at each site was of concern. At one site in NSW, IT issues resulted in at least one hour per day of non-value-adding time in Customer Service due to slow-response time. A significant amount of planning was also being done outside of the system and was not being cascaded or made available to all sites. This resulted in incomplete and inaccurate data. Internal delivery in full on time in specification (DIFOTIS) was estimated to be approximately 50% in one NSW site, with their schedule stability declining as each day passed. Data showed that one day ahead was 95%, whilst two days ahead declined to 60-70% accuracy. This, combined with a lack of communication, resulted in increased costs, such as freight not being charged. In one instance, this was extremely costly (involving 61 different locations and costing Company 2 \$6,000 in freight). *“A lot of communications should be on [System X], but not all have access”* (Human Resources). *“More people need to be able to access [System X]. At one of the other sites there is just one person with access”* (Logistics Manager).

As well as IT systems, machine downtime was also concerning, as it impacted on production, especially in the ACT (Appendix G.3). According to the General Manager, *“reliability of equipment impacts on manufacturing capability. Downtime through malfunction is significant”*. Similarly, the Production Manager added, *“High downtime in process industry is a problem in general and especially in particular when you have no redundant machine”*. Increasing downtime without backup machinery or any penalties for suppliers impacted on operations and increased uncertainty for Company 2. Sample data revealed that, on average, 17.66 hours out of 88.06 hours average cycle time was value adding. Whilst this differed across sites, for most it was no more than 20-30% value-adding time. Data also showed that performance for the offset printer VS was broken down into three categories: poor, good or great

(Appendix G.4). Out of 50 jobs, only 14% were classified as 'great', 28% 'good' and 58% were 'poor'. Service level agreements and investment in infrastructure (including IT) were required at each of the sites in Company 2 to help improve overall performance.

4.4.4.4 **Root cause 3: skill basis/knowledge**

Company 2 faced the risk of knowledge loss, due to much of the knowledge being tacit rather than explicit. There was a lack of documents, policies and procedures, and inconsistent skill bases among the sites. It was evident that job descriptions were lacking detail, affecting both current employees (in providing clearer direction) and the hiring and training of new employees (as tasks were not sufficiently documented). At the time of the research, it was evident that Company 2 was at high risk of knowledge drain, with the results of the QSAM staff survey (see Appendix G.5) showing that employees felt that Company 2's management did not view work-life balance and breaks as important. *"Clients come first"* (Despatch Manager), so employees would strive to meet the highly uncertain demands from customers by working flexible hours and high levels of overtime. The longevity of this was questionable, however. When asked about this situation, a Production Manager expressed that *"if I had one wish it would be that all of the hard and long hours and lots of overtime could be cut-down. It would be an improvement. Wages get overtime but salaries do not get this or bonuses. It (the hard work and long hours) is an expectation"*. A print production press room employee noted, *"After working six days per week, a mind refresh would be good from the problems at work. If I'm unavailable, an engineer can get called in, though I have a lot of tacit knowledge that is needed."*

Knowledge drain increases the risk of inefficient operations and productivity. This risk has been identified and linked in Figure 4.6 as a potential amplifier to decreasing profitability. This is due to the Sales team working hard to increase sales, which was resulting in increased overtime hours, the workload on casual workers, non-conformities and reduced margins. Samples of overtime expenses can be seen in Appendix G.6 and G.7 for full-time and casual employees. It was evident from the four months of sample data that full-time employees were working on average an additional 1,044.75 hours and casual employees an average additional 1,184.56 hours per week. This translated to a total of \$76,281.25 in overtime for fulltime and casual employees per week. Costs were increased due to using more casual employees than full-time employees. This also increased uncertainty and non-conformities as the casual staff were less experienced and familiar with the operations than the full-time employees. One HR staff member commented that, *"long hours are being worked by all, as shown by the average sick days"*, which was not conducive to productivity or growth of the business.

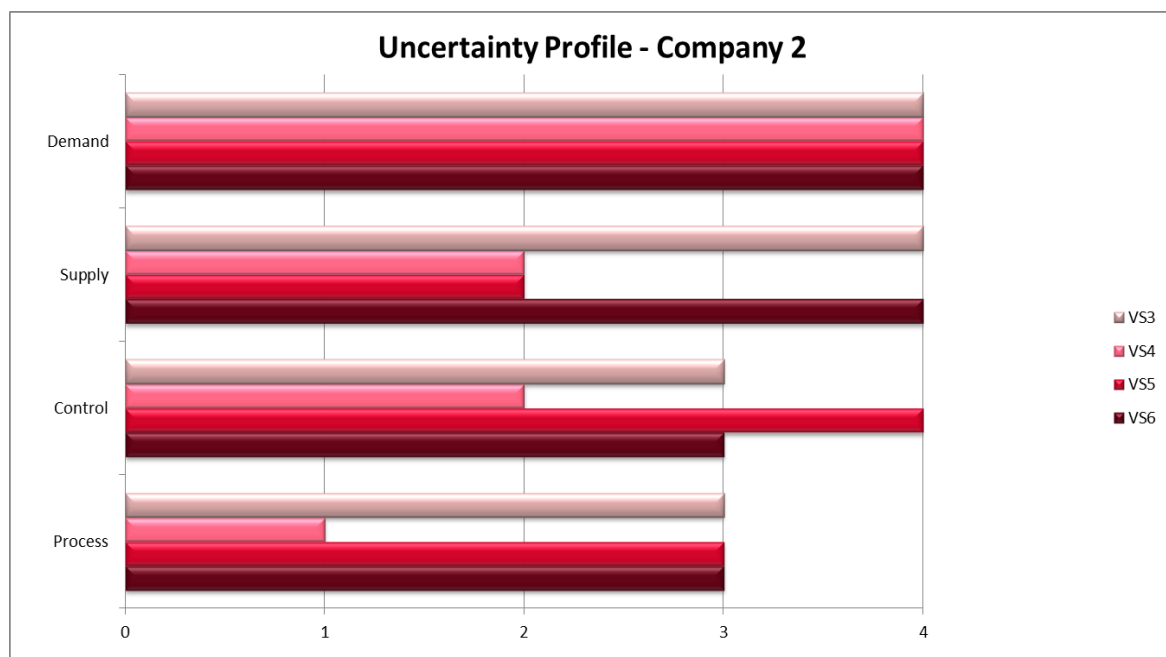
Although negative aspects and root causes were identified, the QSAM also revealed positive aspects that were evident during the study and presented to Company 2 during the feedback session. These were included in the QSAM final report to the company (Appendix D.2).

4.4.5 Company 2 – uncertainty profile

To gain an understanding of the SC, four VSs at Company 2 were chosen for assessment, “VS3”, “VS4”, “VS5” and “VS6”, or offset printing, digital printing, stitch book and envelopes, respectively, which were Company 2’s main products. Data collected on each VS allowed for the production of an uncertainty profile, as shown in Figure 4.7. While the profiles for each differed, the highest level of uncertainty for all VSs was clearly demand (with a score of 4 out of 4 for systems uncertainty). This correlated strongly with other data collected in interviews and archival data, allowing for data triangulation (Childerhouse and Towill, 2011a; 2011b).

Using the EN scores to assess and compare each of the VSs, it became apparent that, overall, “VS4” (digital) was the better performer, with an EN score of 3.3. This was followed by “VS5” (stitch book), with an EN score of 4.8, and “VS3” (offset) and “VS6” (envelope) both scoring the highest and least favourable level of systems uncertainty, with an EN score of 5.1.

Figure 4.7: Uncertainty profile for Company 2



Source: Author

Table 4.5 summarises each of the four sources of systems uncertainty identified in Company 2. The summary allows for the easy identification of uncertainty drivers as per the uncertainty circle model. It was evident that factors such as erratic demand from customers, unreliable suppliers and inefficient internal systems and processes were causing Company 2 to put more effort into fixing problems rather than into developing solutions.

Workloads were constantly increasing to keep up with demand, adding to labour and overtime costs. Company 2 were so focused on getting through their day-to-day workloads that they did not invest in their future or have time to reduce their overall systems uncertainty. This in turn impacted on Company 2's innovative opportunities, as day-to-day operations took priority over R&D.

Table 4.5: Summary of systems uncertainty in Company 2

| Systems uncertainty: | Examples from Company 1: |
|-----------------------------|--|
| Demand | Time critical /sensitive, erratic, impacted by major events (local and world-wide), difficult to forecast, firefighting, tight deadlines, and rescheduling. |
| Supply | Poor IT performance, machine downtime, unreliable suppliers with low accountability, slow-response time, lack of redundant machines, and limited supplier penalties. |
| Control | Limited system visibility, inaccurate data, low internal DIFOTIS performance, and lack of communication. |
| Process | Limited value-adding time, high rework, inefficiencies, and poor machine performance. |

Source: Author

In summary, evidence shows that the systems uncertainty within Company 2 was high across the four VSs. According to the EN scores, the most mature VS was that of "VS4" (with an EN score of 3.3), which was the closest to achieving internal SC integration as compared to the other three VSs in Company 2. The next section uses systems uncertainty data and the cause and effect analysis in a cross-case comparison between Company 1 and Company 2.

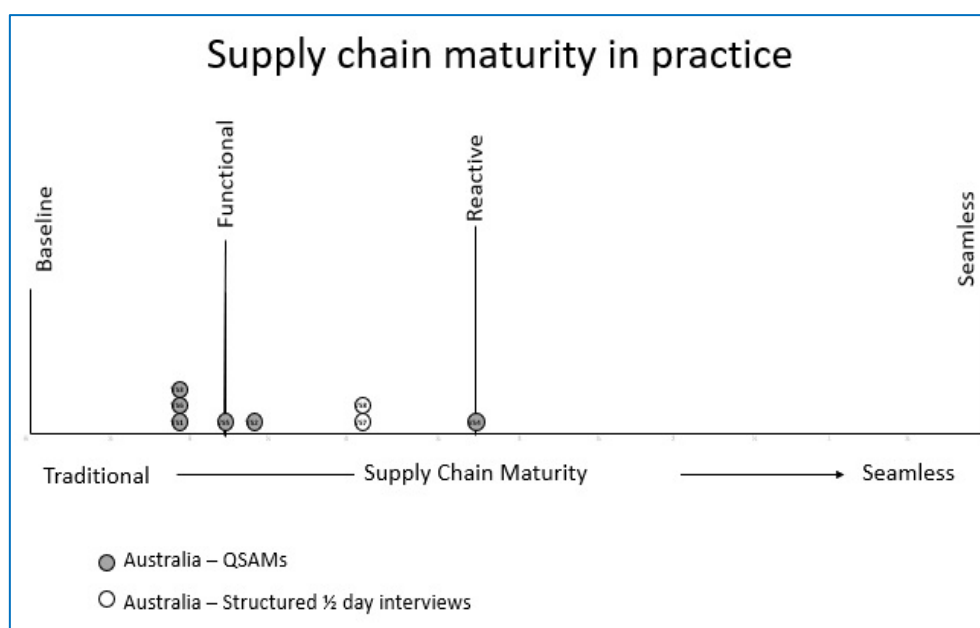
4.5 Cross-case comparison and exploration of common barriers

The cross-case comparison focuses on common patterns across both Companies 1 and 2. In the first instance, the uncertainty profiles are mapped onto Stevens's (1989) four-stage supply chain integration framework. This framework, which allows for companies to be compared equally regardless of context (Böhme, 2014a) has been successfully applied to other companies in various industries and countries around the world (Childerhouse et al., 2011d; Böhme et al. 2014b; Towill et al., 2002). The uncertainty profiles from these two case companies stem from the two QSAMs plus semi-structured interviews with supply chain managers and site visits that complement that data, increasing validity. An overview of the Australian supply chain maturity in practice data has been depicted by grey and white dots (showing whether they were QSAMs or interviews) in Figure 4.8. The figure is based on Stevens's (1989) model showing levels of SC integration, from the low-level "baseline" integration (Stevens, 1989, p. 6), to functional, internal and external integration or "seamless" (Towill, 2000, p. 122) supply chains. The level of integration has been linked to SC maturity (Broft et al., 2016; Aryee, Naim and Lalwani, 2008; McCormack, Ladeira and de Oliveira, 2008; Childerhouse et al., 2011d), with integrated supply chains demonstrating process maturity and overall improved performance. The benchmarking position of Australian VSs in Figure 4.8 provides early insight into supply chain maturity and addresses the first research question:

- *Research question 1: How mature are Australian supply chains in practice?*

As Figure 4.8 shows, the benchmarking position range is towards the lower end of the spectrum, with most of the VSs being benchmarked around the level of functional integration. These results show that higher levels of systems uncertainty, explored earlier in this chapter, affected the maturity of individual VSs and the overall SC. Although 50% of the VSs are benchmarked as either functional or lower, erring towards the more traditional baseline SC and demonstrating low maturity levels, 50% of VSs are above this point, demonstrating slightly higher maturity levels; these VSs are on the path to getting their "in-house" in order by progressing towards internal integration. Thus, these results provide early insights into the state of supply chain maturity in Australia, showing low maturity overall of the chosen case studies.

Figure 4.8: Supply chain maturity in practice – Australian data



Source: Author (adapted from the QSAM feedback presentation)

Following the identification of SC maturity in practice in Australia, a cross- case comparison was conducted. This allowed for the exploration of common barriers faced by both, that in turn impacted on SC maturity and innovative opportunities. This exploration assisted in addressing the second research question:

- *Research question 2: How do barriers to supply chain maturity impact on business innovation?*

Whilst an array of barriers was identified in Companies 1 and 2, as shown in the cause and effect diagrams (Figures 4.4 and 4.6), commonalities were evident. The common barriers identified have been summarised in Table 4.6. The table examines each barrier in terms of the systems uncertainty categories of demand, supply, control and process uncertainty. Each of these barriers were major drivers for high uncertainty levels in those individual categories; however, also had knock-on effects across the whole organisation. They impacted on inefficiencies and/or caused missed innovative opportunities, as well as hindering the overall maturity of the SC. The uncertainty profiles for both Companies 1 and 2 in Table 4.6 show the average rounded EN scores (taking into account the multiple VVs studied) that arose from the barriers identified. As can be seen, the uncertainty profiles are very similar in both cases, signalling that improvement is required across the board.

Table 4.6: Cross-case analysis – summary of common barriers linked to systems uncertainty

| Systems uncertainty: | Barriers from cross case analysis: | Company 1 uncertainty profile: | Company 2 uncertainty profile: |
|----------------------|---|--------------------------------|--------------------------------|
| Demand | Lost sales/ missed opportunity, forecasting accuracy, unclear marketing/sales/acquisition (unclear future plans for growth, obfuscated branding, ambiguous strategy), and firefighting (data capture and management, order prioritisation, stock location, forecasting, urgent/unplanned orders, high agility demanded, order errors/returns, material flow) | 4 | 4 |
| Supply | Convolved material flow, KPIs (e.g. DIFOTIS not captured), unclear communications between suppliers and organisations, lack of strategic alignment, lack of visibility, procurement skills requiring attention, firefighting, lack of IT interfaces, and lack of support for R&D | 3 | 4 |
| Control | Skills/capabilities – management (quality, operations, supplier relationship management, IT, demand planning, HR, strategic, sales, marketing), mixed management ideologies/philosophies , fragmented/ lack of meaningful KPI's or drivers (inventory accuracy, customer call availability, revenue, sales), fragmented culture ('us versus them'), ambiguous business strategy, unclear/unfocused communication (multiple sources, varying templates, ambiguous targets, unclear of state of organisation, unclear core competencies), firefighting and multiple/unreliable IT systems (various channels, poor information dissemination and IS integration) | 4 | 3 |
| Process | Processes/procedures/standards/policy (high levels of experience, explicit documents outweighed by implicit knowledge, gut-feeling versus calculated decision-making tools and forecasting), firefighting and convolved material flow (backorders, orders between sites, stock visibility) | 3 | 3 |

Source: Author

Both organisations were busy with day-to-day operations, reducing time spent on value-adding activities. Poor process maturity in these cases led to missed market opportunities. For Company 1, the Finance Director discussed branding as one of the missed opportunities. In Company 2, it was information from top-level management, such as innovative barcode scanning to make printed media more interactive for the customer, that would not always penetrate further down into the organisation. Often Operations and other departments were left to work in isolation or silos, unaware of the opportunities. Major pains such as missed opportunities, inefficiencies, and decreasing profitability across both cases were due to much more than what the organisations identified. These pains were driven by multiple barriers or root causes, as identified via cause and effect analysis.

Barriers relating to demand-systems uncertainty were driven by multiple sources of inefficiency. These ranged from lack of forecasting accuracy (which would often be based on experience rather than systems) resulting in rising costs to meet fluctuating demand, to confused branding and business strategy, that would have top management and operations staff working towards different goals. Each of the demand barriers identified were adding to firefighting, double-handling and convoluted material and information flows, increasing systems uncertainty. Loyal customers were not receiving priority in order fulfilment, and systems were clunky and required manual intervention to do certain key tasks that could assist with product flow. This put the organisations in danger of pushing product on to the customer rather than finding out what the customers wanted. This in turn created a flow on effect, resulting in further supply barriers and increased systems uncertainty.

Supply systems uncertainty was heavily impacted by convoluted material flow relating to supplier inefficiencies. Daily jobs were not being measured by the organisations. KPIs such as delivery DIFOTIS were not being captured. Material errors and problems with orders (such as delayed shipments and faulty goods) were problems for the organisations that lack of measures made it difficult to improve. Similarly, lack of quantifiable data made it difficult to improve in-house operations as well as supplier performance and relationships. Suppliers need to be accountable and such data combined with service level agreements would have assisted in increasing supply efficiency. This combined with the lack of IT interfaces and communication added to the anguish of both organisations. As with demand inefficiencies, supply uncertainty also added to the firefighting efforts required for both organisations and took away from valuable R&D efforts.

Increased inefficiency and missed opportunities related to control system uncertainty could also be attributed to the level of skill and capability (particularly of management) in both organisations. It was discovered that many staff members had years of industry experience, rather than formal qualifications. Those wanting to further their business acumen or other skills had few opportunities to

pursue outside study. Areas such as supplier relationship management and quality management required attention. Management experience in this area was limited compared to others, with roles being covered by those with less capacity to either overhaul or cover the roles in depth (not due to unwillingness but due to other work commitments). The differing levels of experience and knowledge of top management also impacted on the business strategy and visibility throughout the organisations. Strategic goals were not always clearly communicated. Departments often worked independently to achieve different targets. As with suppliers, there was a lack of internal KPI's to guide the workforce, and communication was found to be unclear throughout the sites. Reporting came from different sources and varying templates. Ambiguous communication of targets, growth strategy, core competencies and marketing strategy, for instance, all impacted on understanding the drivers and the state of the organisations overall. Employees, especially those in Operations, expressed their desire for clearer and more regular communications. These barriers all impacted on business performance and increased systems uncertainty, as demonstrated by the EN scores in Table 4.6.

The final source of uncertainty that added to the overall inefficiencies was that of process systems uncertainty. This was heavily affected by a lack of procedures, processes, policies and standards. Knowledge was often tacit, needing to be translated into explicit documents to avoid the risk of valuable knowledge loss. Decisions involving forecasting and planning were often treated as an art more than a calculated decision-making process using systems or specialised tools. As with the previous sources of systems uncertainty, this added to daily firefighting for both organisations, and led to inefficient operations. Departments lacked guidance and tools such as a balanced scorecard (Niven, 2002) and procedures to assist in unifying efforts to achieve targets. This impacted on current performance and providing direction for future endeavours, whilst increasing systems uncertainty overall.

In summary, an exploration of the two case organisations revealed common barriers and major pains. This assisted in addressing research question 2, regarding barriers that obstruct supply chain maturity in the Australian manufacturing sector. It became apparent that these barriers were impacting on business performance and hindering R&D and opportunities for innovation, as more time was needed to fight fires and solve issues each day. Overall, it was evident that the systems uncertainty created instability in the day-to-day operations, resulting in missed R&D opportunities (Böhme et al., 2014c). Table 4.6 highlights common barriers that organisations should be wary of. This can apply to both larger organisations (which may possess many of these barriers) and start-up companies or SMEs, which may be able to reduce or avoid these barriers once they are aware of them.

Identifying the barriers allows for further exploration of the link between SC maturity and innovation. The cause and effect diagrams in Figure 4.4 and Figure 4.6 have been analysed and scrutinised to identify patterns. These findings have been summarised in Figure 4.9, which shows that barriers and high systems uncertainty led to missed opportunities for both Companies 1 and 2. Innovation and solutions were needed in both cases to improve their performance.

Innovation is impacted by various factors such as market changes, demand changes, technology and solution-driven needs, not just the need for products (Kjelberg, Azimont and Reid, 2015; Bossink, 2004; Pantano, 2014). It became evident through analysing Companies 1 and 2 that customer demands and changing needs were not translated into business practices and processes. There was more push onto the market rather than pull in regards to serving customers. This led to the missed opportunities for customer-driven innovation in both organisations.

Beginning downstream with the customer towards the right-hand side oval in Figure 4.9 are the missed innovative value-added opportunities. Customer needs are constantly changing, with demand for solutions (not just products alone) increasing. Companies 1 and 2 needed to listen more to customer feedback instead of pushing products onto customers; this strategy would have helped them deliver solutions that their customers desired, as well as distinguished them in the marketplace. Products can be easily copied (especially by overseas competitors with cheaper imports) (Warren and Gibson, 2013a), but it is through value-adding (Warren and Gibson, 2013b) and value adding solutions that organisations can flourish.

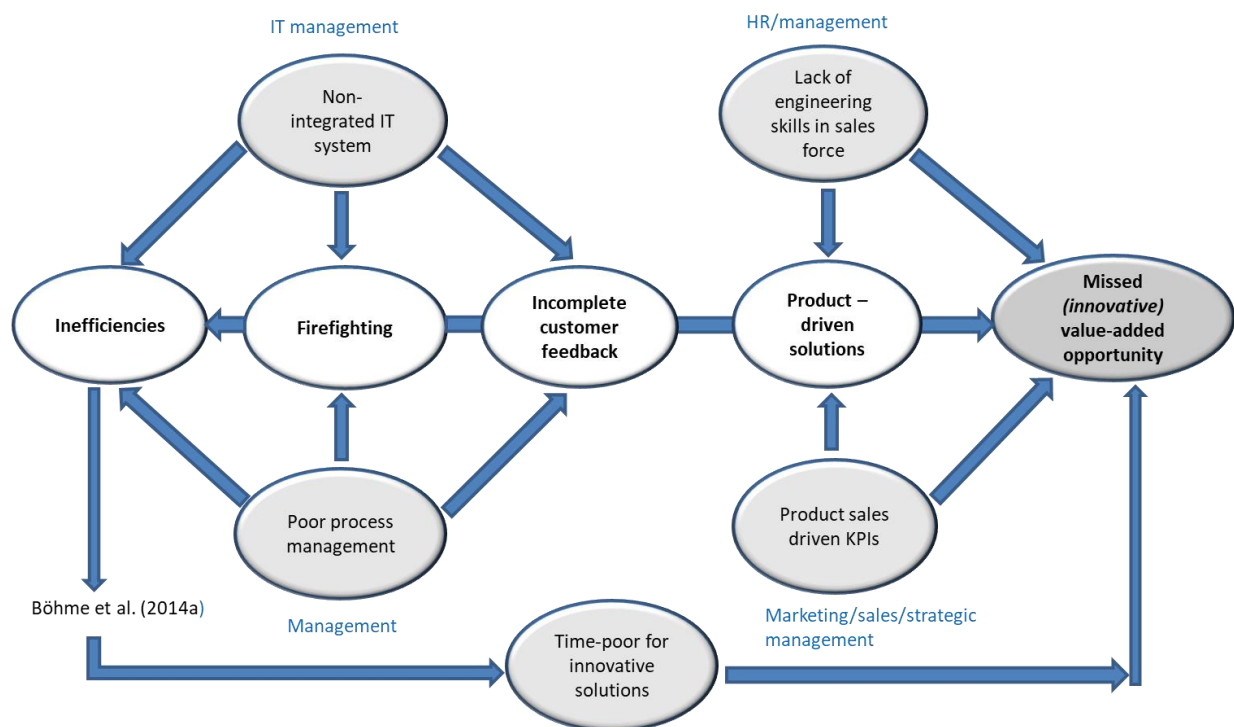
The sales force influenced the reliance on product-driven solutions. Although they were skilled at their jobs and worked hard, they did not have the necessary engineering knowledge or experience required. Engineers' involvement could have assisted in providing more solutions for the customers. Although this was acknowledged within the organisations, the drive to implement this was not evident. Cross-functional teams (particularly including engineering involvement) and KPIs that would encourage a solutions orientation within the organisations could have assisted in driving more innovative solutions into the business.

This then feeds back to the issue of incomplete customer feedback. The organisations were not fully capturing what the customers wanted or needed. Products were being pushed onto customers and poor processes and IT management were not contributing to gaining better feedback or helping the situation. Although the IT was available, it was not being used to its full potential or integrated to reap the benefits of more readily available information for the entire organisation. The multiple systems could have assisted Customer Service in capturing feedback (both positive and negative), which could

have flowed on to operations to either improve performance, avoid repeating mistakes or give praise for a job well done. Non-integrated IT combined with poor processes added to valuable information being lost, leading to convoluted product and information flow, extra work, rework/double-handling and unnecessary firefighting. Ultimately all of this led to higher inefficiencies for both organisations. Influencing all of these barriers to innovation capability was management capability, including a combination of IT, HR, Sales and Marketing; these are shown in Figure 4.9. Better guidance from management could have helped to avoid the major pains of inefficiencies and missed innovative opportunities.

Figure 4.9 conceptualises what the impact of inefficiencies or barriers mean for the organisations overall. Higher inefficiencies upstream are shown to take away from valuable time, resources and energy that organisations could utilise to be more innovative and to provide solutions for customers, rather than to fight fires or produce excess waste in regards to time.

Figure 4.9: The impact of systems uncertainty on innovation capability



Source: Author

Managerial issues, particularly surrounding areas such as skill levels, quality and ISO accreditation, need improvement in Australia. Issues linked to these areas lead to increased inefficiencies and missed opportunities, as shown in Figure 4.9. Skill shortages were noted as a key SC issue, particularly in the Australian automotive industry, scoring 4 out of 5 for its importance to managers (Singh et al., 2005). Jackson and Chapman (2012) noted that this problem is entering the workforce at the graduate level in some cases, which could lead to bigger issues as the people progress through organisations. In an international survey on management practices conducted by Bloom and Van Reenen (2010), Australia was positioned as an average performer, scoring just under 3 out of 5 (with 5 being management best practice). The highest score was the United States of America, scoring almost 3.4 out of 5, with Greece and China at the other end of the spectrum, nearing 2.6 out of 5. Whilst Australia was not the worst performer in that study, it could improve its position.

In summary, Figure 4.9 shows that a lack of understanding and awareness of changes in the market, leads to incomplete customer feedback. This was influenced by the level of management skills/capability, and, in turn influenced organisational performance. Senior management lacked the necessary strategic direction, which resulted in poor translation of processes into value-added processes. Hence, the result was high systems uncertainty, and low SC maturity and innovative opportunities for the organisations (Figure 4.9).

4.6 Discussion

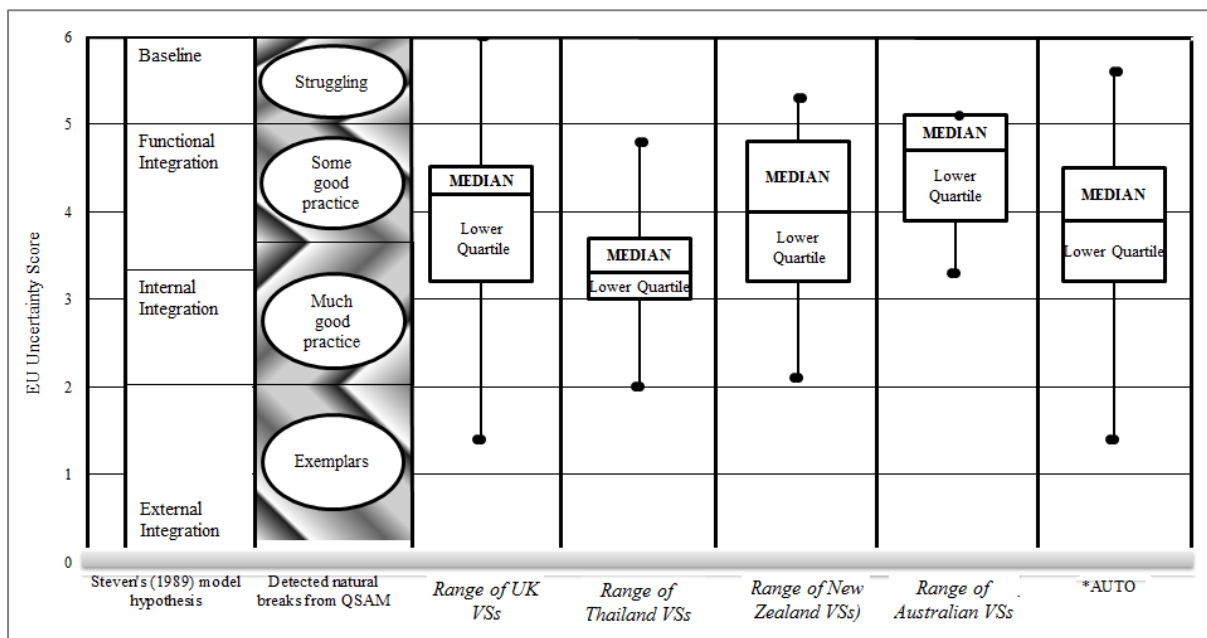
4.6.1 Research question 1 - How mature are Australian supply chains in practice?

According to literature, SCM issues in Australia are not dissimilar to those encountered in other countries. Trust, information sharing, communication, collaboration and the competencies and skill levels of management and other SC professionals (Ariyawardana, Ganegodage and Mortlock, 2017; Ali and Shukran, 2016; Prajogo and Sohal, 2013; Jie et al., 2013; Alfalla-Luque et al., 2013; Bhakoo et al., 2012; Ferrer et al., 2010) are described by many Australian and New Zealand (ANZ) researchers as being key factors in achieving integrated or “seamless supply chains” (Towill and Childerhouse, 2006, p. 757). However, little is known about the level of SC maturity in Australia (Böhme et al., 2014a). Hence, this research identified and provided early insights into the state of SC maturity in Australia through exploring Company 1 and 3, based on the concept of systems uncertainty. Using the Australian data, a cross-case comparison between two case studies was then conducted to provide early insights into common barriers faced in the manufacturing sector, such as firefighting and lack of strategic alignment, and how the barriers to SC maturity are linked to innovative opportunities. Finally, the

Australian uncertainty data was used to provide a benchmark with international studies (Appendix A). This included those from the European automotive sector (Towill et al., 2002; Towill and Childerhouse, 2011; Böhme, et al., 2014b) that are used for benchmarking as they are examples of exemplar cases, that can be compared regardless of factors such as industry and organisational size due to using the context free measure of uncertainty as part of QSAM.

As shown in Figure 4.10, an inclusive view of all QSAMs to date at the time of this research is depicted. As can be seen in the box and whisker graphs in Figure 4.10 (which are based on the EN results for each VS), the findings demonstrate a range of results. The figure comprises of international benchmarking results from Europe, the UK, New Zealand and Australia. The European automotive benchmarks have been included in a separate column due to being an exemplar comparison, as highlighted by Childerhouse (2002), Towill and Childerhouse (2011), Childerhouse and Disney (2002) and Böhme et al., (2010). The level of integration is linked to the maturity of each SC, as identified by Böhme et al. (2016), showing that higher integration levels indicates higher SC maturity. The automotive sector depicts the most mature and integrated SC identified to date, with the exemplar cases achieving external integration. An alternate view of the international results for SC maturity in practice has been included in Appendix item A.

Figure 4.10: Supply chain maturity in practice (including Companies 1 and 2)



Source: Adapted from Böhme et al., 2016

In regards to the Australian benchmarking results, whilst Australia does not demonstrate exemplar cases such as the UK automotive industry (Childerhouse, 2002), it also does not demonstrate the lowest levels of maturity (thus being baseline integration). Australia also has the lowest median internationally. The best performing VS in this case is internally integrated and demonstrating much good practice. Almost half of the Australian VSs showing signs of low SC maturity are baseline and are exhibiting signs of struggle in regards to SC integration. These results indicate that Australian VSs contain high levels of uncertainty. In regards to the uncertainty circle principle model in Figure 4.1, the highest level of uncertainty for 75% of the VSs was due to demand uncertainty; this result has been found in other research, and has been shown to be an issue for other organisations for some time (Davis, 1993). The area demonstrating the lowest level of uncertainty, and therefore the best performing, was process uncertainty. Findings indicate, however, that systems uncertainty reduction is required across all four areas. It would be beneficial to reduce the high systems uncertainty, as it is impacting on organisational opportunities for innovation, with valuable time and resources being consumed by daily problem-solving or firefighting.

Overall, the data shows that the Australian VSs are performing poorly especially compared to international benchmarks of the automotive sector. However, as noted by Towill et al. (2000, p.129) in regards to SC integration, as little as 10% of supply chains were classified as being fully integrated or “seamless” according to international QSAM data. Whilst no exemplar cases are evident in the Australian findings to date, the findings demonstrate an opportunity for further focused studies and improvement opportunities to achieve highly mature SCs with lower levels of uncertainty in Australia. Each organisation has the potential to improve upon their rankings, such as the case study of the New Zealand ETO (Böhme et al. 2014a) through improvements such as business process re-engineering (BPR) (De Felice and Petrillo, 2013), and understanding the state of their SC maturity, and common barriers to innovation, with an improvement in innovation being encouraged by the Australian government.

4.6.2 Research question 2 - How do barriers to supply chain maturity impact on business innovation?

A cross-case comparison and exploration of systems uncertainty led to the identification of common barriers faced by the two Australian case companies (Table 4.6). These barriers were found to be limiting SC maturity and obstructing innovative opportunities. The problems leading to the barriers obstructing SCs include; poor management, poor factual approaches and poor process design understanding. Organisations, regardless of their size, should consider what is obstructing them from achieving a more mature SC. The problem lies in poor management, factual approaches, and poor process design and understanding. By identifying such findings, it creates awareness for academia and

practice not only on the barriers obstructing SC maturity in the Australian manufacturing sector, but it also provides a tool for barrier recognition and reduction.

Benchmarking organisational or SC performance has been highlighted as being important to identifying current performance and future improvements, and as a way to better compete in the marketplace (Dal Forno et al., 2016). SC maturity, including the level of uncertainty in an organisation, cannot be underestimated as a beneficial measure of business performance or as a benchmarking tool. Literature shows that higher levels of maturity and low systems uncertainty can be indicators of an organisation's innovative capability (Böhme et al., 2014a; Parnaby and Towill, 2009; Prajogo and Sohal, 2004). Overall, Australian benchmarking results compared to international standards show that systems uncertainty needs to be reduced and opportunities for innovation increased. In the case of Australian Company 1 and Company 2, high levels of uncertainty were present, particularly for demand and control uncertainty. Whilst these findings correspond to international data, such as findings from a New Zealand ETO example (Böhme et al. 2014a), there is room for significant improvement. Better tools and skills for demand planning could benefit both organisations in this case and assist in decreasing systems uncertainty. Improving demand planning has also been linked to improving forecasting, profit and reducing inventory by up to approximately 30% (Kamal, 2013). Additionally, process improvements, such as BPR (De Felice and Petrillo, 2013) could lead to increased innovative capability, as in the case of the New Zealand organisation that improved its overall uncertainty profile through focusing on re-engineering its processes. This pathway to improving systems uncertainty could be captured and tested via diagrams such as Figure 4.9.

4.6.3 Maturity, uncertainty and Innovation in Australia – beyond Company 1 and 2

Findings from Company 1 and 2 and the relationship between SC maturity, uncertainty and innovation should be considered as part of the wider system, or country. With changes that are being faced in Australia, especially with the next wave of potentially disruptive technologies at the doorstep, understanding uncertainty and innovation and the link between them are increasing in importance. According to the Australian Innovation Systems Report 2015 (Australian Government, 2015), changes have occurred within industry and the economy in Australia over the years that have shifted the focus for growth; “Massive trucks, their trays heavily laden with iron ore and coal, reflect our previous association with the source of economic growth” (Australian Government – Department of Industry, Innovation and Science, 2015, p. III). It has been realised that this reliance on resources such as coal

alone, rather than value adding activities (Kotey and Sorensen, 2014) is not conducive to an economically strong region or country, and such reliance can increase systems uncertainty or risk. To counteract this, a strong focus on innovation enhancement by the Australian government has seen financial support increase from “\$4.2 billion in 2000-01 to \$10.1 billion in 2013-14” (Australian Government, 2015, p. 10), to “between \$26 billion and \$30 billion “in 2014-15 (Australian Government, 2016, p. 1). As well as financial investment, an Australia-wide audit to create a strategic plan for growth was developed, which was planned for late 2016 to provide additional guidance for the Government.

The current state of innovation in Australia has it ranked “fifth out of 30 OECD countries in terms of its overall proportion of innovation-active businesses” (Australian Government, 2016, p. 1), of which SMEs are said to contribute most. There are opportunities for performance improvement by larger organisations and in innovation in areas other than process innovation alone (which the Australian Innovation Systems Report 2016 showed as the most dominant type of innovation in Australia) (Australian Government, 2016). This position presents opportunities for adopting technological innovations that form Industry 4.0, such as AI, robotics or 3D printing/AM, for example. It also presents opportunities for economic improvement resulting from the focus by the Government, educational institutions and industry on increasing innovation capability and lowering reliance on resources alone.

4.6.4 Outlook

As with the Government and other institutions becoming more focused on innovative opportunities, the Australian organisations in this research should also concentrate their attention on R&D/value-adding activities and future endeavours. They need to get their in-house in order (Childerhouse and Towill, 2011a; Böhme et al., 2014a; 2014c) and lower systems uncertainty, as well as focus on improving managerial issues. Figure 4.9 (depicting common barriers) could be used as a guide to assist organisations in determining what to avoid or eliminate to improve efficiencies and innovative opportunities and capability. Investment in technology, such as robotics or the adoption of AM for rapid prototyping or manufacturing (Deradjat and Minshall, 2017), could be used in conjunction with traditional methods to improve agility to market and reduce inventory in some cases.

4.7 Conclusion

In conclusion, understanding an organisation’s SC maturity using benchmarking tools such as QSAM and being able to measure systems uncertainty greatly assists with not only international benchmarking but also improving competitiveness and awareness of improvement prospects, and has the potential to

increase opportunities to add value and innovate. As with Company 1 and Company 2, this knowledge provided an opportunity for improvement for the organisations and context for further study, including innovative opportunity and capability based on SC maturity and uncertainty profiles. This is imperative in countries such as Australia where organisations are seeking alternative ways to compete. This research captured more than just a so-called “laundry list” of problems. It discovered and linked the variables through cause and effect analysis, as well as their impact on performance and innovative opportunities and capability. A greater focus on value-adding activities and possible technological innovations could improve the standing of Australian organisations in future.

This findings chapter contributes to both practice and academia, with the further generalisability of QSAM (extending the international database to include Australian data), the identification and linkage of common cause and effect factors/barriers for academia, as well as providing international benchmarking to organisations (as shown in Figure 4.10 and Appendix A). This gives Australian organisations visibility of other organisations performance in an array of contexts. As with other studies, this research also contains limitations due to generalisability of Australian data (due to the number of case studies selected). It is an early exploration into Australian SC maturity to provide insight and context for this research, however, and is not aiming to dictate nor generalise the maturity of all Australian SCs.

Overall the complete international QSAM database to date is skewed more towards lower levels of SC maturity, as with the Australian cases. Although studies have noted that the organisations have implemented various improvement strategies (Böhme et al., 2014a; Childerhouse et al., 2011) and have applied many enhancements in their SCs, they are still showing signs of struggle with problems similar to those demonstrated in Australia. It would be beneficial for future studies to conduct further QSAMs in a wider range of organisations as well as longitudinal research via QSAM in order to capture progress in Australia towards achieving a more mature and “seamless supply chain” (Towill and Childerhouse, 2006, p. 757).

The next chapter explores the adoption of innovative technology and its impact on VSSs and manufacturing systems through exploring cases of best practice from North West England. The focus on innovative technology is further narrowed to that of 3D printing/AM, as explored in Section 2.9.1.2 due to it being a key enabling technology within Industry 4.0, that is impacting on manufacturing and VSSs worldwide (Rylands et al., 2016; Phillips, 2014; Petrick and Simpson, 2013).

5. Adoption of 3D printing and its impact on manufacturing systems and value streams

The question is not whether manufacturing has a future in the high-cost environment, but rather, what kind of manufacturing has a future...? (de Treville, Ketokivi and Singhal, 2017, p. 1).

5.1 Introduction

The previous chapter explored the level of systems uncertainty and the state of SC maturity in Australia, and benchmarked this with international studies. Through the cross-case comparison of two Australian organisations, it provided early insights into common barriers faced in regards to opportunities for innovation in Australia, particularly for SMEs. This assisted in establishing context for this research and provided an introduction into the state of SC maturity within SMEs in Australia. The rigorous assessment into the common barriers that were found to be linked to innovative opportunities, amongst others, showed that the organisations' daily challenges were detracting from valuable time and resources that could be used more efficiently or effectively in other areas, such as R&D. Understanding and reducing or eliminating these barriers is important as it not only reduces systems uncertainty, but increases opportunities for innovation (Böhme et al., 2014a).

This chapter focuses on 3D printing as a form of innovative manufacturing and its effect on VSs and manufacturing systems. Although 3D printing, also known as additive manufacturing (AM), has been in existence for longer than 25 years (de Jong and de Bruijn, 2013; Petrick and Simpson, 2013), there is still much to learn about its capability and, importantly, its impact on SCs, or more precisely, VSs. VSs can be defined as "all the value-added and non-value-added activities actions required to bring a specific product, service, or combination of products and services, to a customer" (McDonald et al., 2002, p. 214) or as "the special activities required to design, order, and provide a specific product, from concept to launch, from order to delivery, and from raw materials into the hands of the customer" (Womack and Jones, as cited by Childerhouse et al., 2011, p. 537). SCs can be viewed as comprising of more than one or "a bundle" of VSs (Bohme et al, 2014, p. 3). This research will view them as such.

This chapter focuses on 3D Printing and its use in the manufacturing process, and aims to identify the adoption process of 3D printing/AM and the impact that such technology has on the

business and its existing VSs. The significance or full impact of this technology is still largely unknown; however, early indications suggest that it will be an important tool in the manufacturing process when used in conjunction with traditional manufacturing processes (Rylands et al., 2015, Rylands et al., 2016; Sasson & Johnston, 2016, Cotteleer, 2015; Holström et al., 2016). According to Christian and Sandström (2016, p.160) “studies of how industries transition to 3D printing are currently scarce and there is a need for more empirical descriptions of who and why an industry adopts 3D printing for manufacturing purposes”. It is an important area to explore, and researchers such as Goulding, Bonafe and Savell (2013) and D’Aveni (2015) have argued that the use of 3D printing could bring about the next industrial revolution. Whether it is being adopted by an organisation or competitors are using it, business and communities should consider preparing themselves for this wave of technological, social and business change. Cohen et al. (2015, p. 1) used an even more drastic expression, stating that businesses “cannot afford to be complacent” when it comes to this technology (Cohen et al., 2015, p. 1), whilst Sedhom (2015, p. 865) stated that “no one can afford to ignore 3D headlines concerning healthcare, art and even food” for example.

The purpose of this chapter is to investigate and further the knowledge on the impact that 3D printing will have on VSs, particularly in the manufacturing process. This will be done through the use of empirical, case study data, using the business model canvas (Osterwalder and Pigneur, 2010) and value stream mapping (VSM) (Chen et al., 2010; Lacerda et al., 2016; and Childerhouse and Towill; 2004). The business model canvas was chosen because it provides a concise visualisation of a business and combined with VSM, captures multiple parts of the system or business rather than focusing on one area. The business model canvas stems from Osterwalder’s business model ontology (Mäkelä and Pirhonen, 2016), and has theoretical underpinnings in total quality management (TQM), strategic management and transaction cost economics (TCE) (Osterwalder, Pigneur and Tucci, 2005). It provides a systematic and holistic approach to business analysis that can be applied to companies regardless of industry (Mäkelä and Pirhonen, 2016; Osterwalder, Pigneur and Tucci, 2005). According to Fielt (2013, p.93) it is a “shared language for describing, visualizing, assessing and changing business models”. The business model canvas can be defined as “the story that explains how an enterprise works” (Joan Margretta, as cited by Casadesus-Masanell and Ricart, 2011, p. 100). As identified by Fielt (2013) Osterwalder’s business model ontology “synthesizes most other business frameworks and elements at that time” (p. 93). It “identifies essential parts of a business” (Toro – Jarrin et al., 2016, p.1) and is composed of nine essential building blocks, from value propositions to key suppliers and customer segments (Toro-Jarrin et al., 2016; Osterwalder and Pigneur, 2010; Kajanus, et al., 2014). This is combined with VSM, which allows for “all the specific actions required to develop and manufacture a product or deliver a service” (Lacerda et al., 2016, p. 1709) to be represented visually. VSM has been

described as being “a powerful tool that enables the visualisation and understanding of the flow of material and information through the value chain” (Lacerda et al., 2016, p. 1710). It complements the use of the business model canvas as it shows the flow of products and information and the relationship between them. It also provides the benefit of a more focused approach to certain streams or products of interest for analysis, rather than the bigger picture provided by the business model canvas. In summary, these tools of analysis were chosen due to their ability to allow for holistic, visual, systematic research and the comparison of companies independent of industry.

The two questions to be addressed in this chapter are as follows:

- *Research question 3: How do organisations adopt innovative technology into their existing supply chains? Focusing on 3D printing, and;*
- *Research question 4: What is the business impact of innovative technology adoption on the existing value streams/business manufacturing system?*

The structure of this chapter is as follows: it begins by exploring findings from case studies from North West England (focusing on Companies A and B) regarding the technology adoption process and business impact, followed by a discussion of findings and future research opportunities and a conclusion.

5.2 Literature review

5.2.1 From supply chains to value streams

It is SCs that compete today, not individual businesses (Christopher, 2011). Due to the importance of SCs, organisations need to begin by gaining an understanding of them and what they contain, to be able to harness the value of SCs and use them effectively. SCs can be defined as “all activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as associated information flows” (Handfield and Nichols, as cited by Mouritsen et al., 2003, p. 686). SCs, as with businesses, are constantly changing and adapting their structures, titles and focus (Fassoula, 2006; Larson and Halldórsson, 2002) to suit their environments. Such changes are contributing to an increase in industry “clock speed” (Fine, 2000), shorter product lifecycles and an increase in the rate of innovation. SCs were described as being more “product driven”, concerned with cost and the lean philosophy in the 1980s, switching to become more agile, with a focus on speed to market and product quality in the 1990s (Christopher and Towill, 2000, p. 212). This shift to more agile operations is assisted through technologies such as e-enabled (digital) SCs and the rapid information flow that follows (Christopher and Towill, 2000). It can be said to therefore be important for businesses to note and make an effort to understand such important changes, as they have the potential to affect

business strategy, structure and the wider SC. Böhme et al. (2012) describe SCs in practice however, as being convoluted, messy and complex, with many scholars shifting their attention from SCs to the concept of VSs as a way to make sense of this systemic complexity (Böhme et al., 2014; Christopher et al., 2009; Childerhouse and Towill, 2004). VSs can be defined in multiple ways, such as “a value stream consists of all the materials and information required in the manufacturing of a particular product and how they flow through the manufacturing system” (Chen et al., 2010, p. 1072). Womack and Jones (1996) describe SCs as consisting of a bundle of VSs. By shifting the focus to VSs, it allows for greater emphasis on certain products or processes (Childerhouse and Towill, 2004; Matt, 2014). Five aspects to consider regarding VS design include: delivery time, volume, life cycle, variability and variety (Christopher et al. 2009; Christopher and Towill, 2000). Adaptation of VSs to suit changing strategic or market needs, such as with the introduction of new technology or processes, need to be considered by businesses. Tools such as VSM can be used to analyse such impacts (Lacerda et al., 2016; Childerhouse and Towill, 2004), allowing also for comparison between current and future states. VSM has been described as “a powerful tool that enables the visualisation and understanding of the flow of material and information through the value chain” (Lacerda et al., 2016, p. 1710), that assists in “consolidate[ing] the production processes with the help of activities that add value”, and “becomes a living reference to create, redesign or improve business processes for the whole enterprise” (Suarez-Barraza et al., 2016, p. 520). Changes that innovative technology such as 3D printing is introducing, has led to many authors, including those from the social sciences Birtchnell and Urry (2013a) and D’Aveni (2015), predicting disruption to traditional manufacturing methods. This requires increased attention and focus, that can be achieved through tools such as VSM, and may need VS redesign or reconfiguration and BPR efforts to be implemented in practice.

5.2.2 Continuous improvement versus business process re-engineering

Strategies implemented by organisations are constantly being affected by the level of environmental change and challenges faced. Organisations must continuously adapt and consider more than efficiency to compete, as noted by Nag et al. (2014, p. 353), “high speed and cost efficiency alone do not guarantee the competitive advantage”. There are multiple improvement areas that organisations may choose to target with initiatives, such as efficiency (through cost or time savings); improvements in safety and performance; structural changes to the business through continuous improvements (Chapman and Hyland, 2000); or, more radically, BPR (Hooda, 2014).

BPR is the redesign of processes, typically using IT, in order to gain significant improvements in key areas of cost, speed, quality and service (Altinkemer et al., 2011, p. 130). Evidence of the use of BPR in literature and practice began in the 1980s (O’Neill and Sohal, 1998). Systems thinking should be

utilised to understand each of the parts in the overall system in order to benefit from the full advantages that BPR can offer (Cao et al., 2001; Hughes, 2011). Failure to do so could lead to sub-optimal operations, missed opportunities or reduced innovation capability (Parnaby, 1995). As noted by Böhme et al. (2014), in order to be successful BPR requires the consideration of both cultural and technical aspects, or “hard technologies and soft methods” (Parnaby, as cited by Böhme et al., 2014, p. 6519). BPR is particularly relevant to organisations adopting 3D printing/AM, as the introduction of new or altered VSs may require production processes to change also.

5.2.3 Innovative technology – 3D printing/Additive manufacturing (AM)

Introduced in the 1980s by technology pioneer Charles Hull, 3D printing, or AM, began with the use of stereolithography, which uses a laser to cure liquid polymers (Pannett, 2014). Since then, 3D printing has continued to evolve, improving in technology capability, accessibility and applicability, as well as gaining increasing attention from a wide audience (Presswire, 2014). 3D printing/AM can be described as digitally creating an object through computer aided design (CAD), then physically creating the object through the layer-by-layer (or laminating) production technique (Pannett, 2014). Garrett (2014, p. 70) described 3D printing/AM as a “general purpose technology” as it is applicable to a multitude of organisations, products and production techniques. Those adopting this technology range from SMEs or individual hobbyists at home (Petrick and Simpson, 2013), to universities and educational institutions (Pitt, 2015) and large multi-national enterprises such as Boeing (Catalano, 2015). Research has been occurring on 3D printing applications in a range of different industries (CSC, 2012). CSC (2012) summaries this in a report, including examples of industries such as aerospace and retail, and the expected future impact of 3D printing technology, with scenarios that were predicted to occur in the future, beginning to take place already. 3D printing capability has grown beyond rapid prototyping or moulding, and is beginning to be used more so in the manufacturing of end products (Hasan, Rennie and Hasan, 2013; Rylands et al., 2016).

Adoption of 3D printing/AM by business requires multiple aspects to be considered, including business, environmental, social as well as technical (Rylands et al., 2015). It has been noted as particularly important when introducing innovation, whether it is 3D printing or other, that it is supported by the top down, with management support and clear communication throughout the organisation (Dunne et al., 2016), helping the innovation filter throughout. Whilst the technical advantages of 3D printing are important, such as the capability to produce geometrically complex parts (Petrick and Simpson, 2013), Rylands et al. (2015) highlighted that other aspects such as social, business and environmental are also important. The use of this technology for negative purposes, such as producing illegal weapons (Merrill, 2014) is commonly highlighted in the news. Whilst this is an

important social aspect to consider, there are also positives such as the great potential it has for regional rejuvenation or transformation, and the positive impact that it can have on the workforce through skill enhancement (Rylands et al., 2016). Importantly, the strengthening of regions and workforces does not have to be at the detriment to existing traditional methods or VSs (Rylands et al., 2016). As with other technologies, there are risks associated with 3D printing/AM, particularly concerning intellectual property (IP) (Li et al., 2014), and the disruption that it can have to organisations. There are also great opportunities, however, such as the possibility to introduce new VSs and value propositions for the customer (Rylands et al., 2016). It is also influencing manufacturing philosophies, with Patrick and Simpson (2013, p. 13) identifying the shift from “economies of scale” to “economies of one”.

Technological advancements involving 3D printing/AM, have resulted in the occurrence of fast-paced changes regarding multiple aspects, from the types of 3D printers available to raw materials used for printing and its applications (Mellor et al., 2014). There are a range of printers and “ink” or raw materials available. Hobbyist printers, typically fused deposition modelling (FDM) systems, produced by MakerBot and RepRap for example (West and Kuk, 2016), commonly use a range of thermoplastics “that fuse when melted” (Griffey, 2014, p. 8). Larger-scale industrial printers, such as selective laser sintering (SLS) systems are more expensive and use a different technique to produce the finished product, involving a laser to sinter powders (Griffey, 2014). Importantly, both use a layer-by-layer approach to produce the final product. The powders used in 3D printing may include metals such as aluminium and titanium (Griffey, 2014), allowing access to a greater range of products and applications, such as the automotive and aerospace industries, due to the benefits of metal compared to plastic (Reeves and Mendis, 2015). There are options beyond FDM and SLS, including laminated object manufacturing (LOM) (Griffey, 2014), which uses paper and glue, as well as bio-printers and bio-plotters that produce organic materials and structures such as bone and tissue (Soel et al., 2014; Richards et al., 2013; Bose et al., 2013), and Chefjet that prints food (Sun et al., 2015). Although each of these systems vary, they share a common approach to production; thus being the layering of materials, which build up an object rather than subtract from it as with traditional manufacturing methods (Petrick and Simpson, 2013). 3D printing/AM presents a range of benefits and disadvantages, with examples of these summarised in Table 5.1.

Potential opportunities or benefits of 3D printing/AM for the SC include (but are not limited to), lead time compression due to printing at the point of consumption, on-demand printing capability and reduced need for high levels of inventory (Petrick and Simpson, 2013; Tassely, 2014; Rylands et al., 2016). There are also barriers to implementing 3D printing/AM, described as being significant (Rylands et al., 2016), that include technical limitations, such as knowledge and skill to design and create the final

product, the availability of raw material suppliers, cost of machinery, and infrastructure (Rylands et al., 2016). Additionally, there are barriers concerning printable materials and build size of parts or final products due to the capability and size of 3D printers available, as well as IP protection and online-piracy (Moilanen et al., 2015; Appleyard, 2015; Xin and Xiang, 2015), potentially shifting focus to information management (Rylands et al., 2016). Although the capability of this technology is continuing to increase, it has been said that it is not yet at the same level as more traditional or established production methods (Reeves and Mendis, 2015). As with other technologies, the benefits and limitations, as well as trade-offs, must be considered before implementation, as summarised in Table 5.1.

Table 5.1: Benefits and advantages of 3D printing/AM

| Benefits of 3D printing/AM | Disadvantages of 3D printing/AM |
|---|---|
| Creation of complex and unique parts (Cohen et al., 2014; Petrick and Simpson, 2013; Selko, 2015) | Investment in training required in materials, design, infrastructure and specialised software required (Holweg, 2015) |
| Reduced waste material as compared to traditional manufacturing (Khan and Mhor, 2016) | Finishing of final product (Berman, 2012) |
| Ability to create highly customised designs with reduced tooling (Petrick and Simpson, 2013) | Printing speeds and printer capability (Merrill, 2014) |
| Rapid prototype and custom batch creation that can be done economically (Berman, 2012) | Quality control (Reeves and Mendis, 2015) |
| Ability to print on demand and simplify supply chains with shorter lead times and lower inventories (Petrick and Simpson, 2013) | Raw material availability, variety and capability (Mellor et al., 2014) |
| Enabling printing at point of consumption (Tassey, 2014) | Intellectual property and ethical concerns (Li et al., 2014; Moilanen et al., 2015; Appleyard, 2015; Xin and Xiang, 2015) |

Source: Adapted from Rylands et al., 2016, p. 973

In summary, 3D printing/AM technology has great potential for business and consumers, extending beyond the limitations of producing small plastics toys or busts at home or rapid prototypes

in business, to rapid manufacturing (Hasan, Rennie and Hasan, 2013) and the tooling and production of finished products (Rylands et al., 2016). It has been predicted by some in literature as being potentially disruptive to traditional methods, whilst others have discovered that it can complement and enhance traditional manufacturing methods (Rylands et al., 2016). It is receiving increasing attention and investment from around the world, including from countries such as the US, Germany, China, Korea and Singapore. Although it has been predicted that this technology could significantly impact manufacturing systems and VS design (Rylands et al., 2016), researchers have noted that few studies have been conducted into the adoption of 3D printing/AM (Gress and Kalafsky, 2015; Waller and Fawcett, 2013). Due to the scarcity of research into the adoption of 3D printing/AM technology, including how and why industry adopts it, Sandström (2016) has called for more empirical studies describing this in regards to industry adoption for manufacturing purposes.

5.2.3.1 *Industries and countries investing in 3D printing and its applications*

The technology's capability and adaptability, make it applicable to different extents in various industries from the arts, architecture and fashion to the military, manufacturing and medicine. According to Hull (2015, p. 27) "the automotive industry saw the potential first and began to embrace 3D printing to speed up design cycles". It is particularly suited to small runs of customised parts or products (RolandBerger, 2013), such as dental implants, hearing aids (Petrick and Simpson, 2013; Christian and Sandström, 2016), and prosthetics (Prince, 2014) and is receiving attention from many countries, with patents for 3D printing hardware and software increasing from fewer than 90 in 2005 to around 600 in 2013 (D'Aveni, 2015).

Many countries are investing in 3D printing infrastructure and/ or education to prepare themselves for this technological change. The 3D printing industry has been projected to be worth more than \$6 billion in the year 2019 (Kietzmann et al., 2015). Investment by countries include Singapore with \$500 million over five years (3ders, 2013), China with a large scale national initiative (3ders, 2015a), USA with the America Makes initiative (Taylor, 2013), the UK, which is investing £100 million in the aerospace industry (Russon, 2015), New Zealand, with \$12.7 million (Kim and Robb, 2014), and Australia, who are planning to invest \$40 million over seven years (Phillips, 2014). Many other countries are also beginning to realise the potential of this advanced technology, which allows organisations to rethink the placement of their manufacturing hubs, decrease monetary and time costs and even assist countries in potentially re-shoring their activities.

The next section details the methodology chosen to explore the impact of adopting 3D printing.

5.3 Methodology

In this section, the research strategy chosen will be presented. This was influenced by three conditions: the type of research question posed, the extent of control an investigator has over actual behavioural events, and the degree of focus on contemporary, as opposed to historical events (Yin, 1994).

This chapter focuses on the adoption process and the business impact of 3D printing/AM on the manufacturing system and VSs. Due to limited empirical evidence (e.g. Sandström, 2016), this research is exploratory in nature. Using the business model canvas as a lens to analyse findings (Osterwalder and Pigneur, 2010), combined with VSM, case study data from North West England and cross-discipline literature is explored, focusing on findings beyond those of engineering or technical aspects alone (Rylands et al., 2015).

This study began with research taking place in eight different SMEs in North West England. The SMEs ranged from being producers of foldable furniture, textiles and fashion, fishing reels, motorcycle exhausts, bath tubs, springs to wallpaper and filters. Importantly, they were using 3D printing technology, to differing extents, such as for design, mould creation, rapid prototyping, and final product production, to enhance the traditional manufacturing methods available. The raw materials for 3D printing included plastics/polymers and metal, each being suitable for the different industrial applications, such as prototyping an exhaust in plastic and printing the final product in metal. The selection of cases was advantageous for the researcher to gain insight into the 3D opportunities available, however, this research narrowed down the focus to include the SMEs investing in 3D printing/AM for their production processes; thus, Company A and B (as shown in Table 5.2). North West England was chosen due to being geographically significant, for it has a long history in manufacturing which has changed over the centuries, undergoing significant amounts of economic transformation (Rylands et al., 2016). This transformation includes the change in industries, with it originally being a place with a strong history in ship building, furniture and industrial milling, that adapted to changes in the environment, shifting to become a more innovative industrial region specialising in aerospace, biotechnology, telecommunications and pharmaceuticals (European Commission, 2016; European Commission, 2019). According to the European Commission (2016), innovation and advanced manufacturing has played an important role in the transformation of the region, and has positioned it as “the largest concentration of advanced manufacturing and chemicals production in the UK” (European Commission, 2016, no pagination). Whilst manufacturing previously accounted for a large share of output for the economy, this has declined significantly since the 1980s, with services now accounting for approximately 76% of all output (European Commission, 2019), increases in advanced manufacturing and the services industry have impacted on SMEs and the

region's competitiveness. With the changes occurring in industry, both Companies A and B, had been experiencing hardship, and were seeking alternative ways to compete due to increased competition. Due to this, in 2012, both companies began exploring the use of 3D printing/AM in their existing manufacturing processes.

This research chose to include a second case study, Company B, to increase external validity, guard against observer bias and to gain some early insights into companies using 3D printing/AM in their operations (Voss et al., 2002). According to Eisenhardt (1989), case selection is crucial because it defines the limits for generalising the findings. This exploratory research did not use the case study method to describe an average effect, rather to identify a relationship or effect (Stuart et al., 2002), and was exemplary instead of representative (Rylands et al., 2016). Companies A and B were chosen due to being manufacturers that had implemented 3D printing/AM into the production process, instead of using it for mould-making or rapid prototyping. The product that each produced was not a limiting factor for case selection, with Companies A and B manufacturing different and unique products. The raw material was a consideration for selection, with it being limited to the use of plastics/resins and metal, as well as the geographical location of each case study, which was selected due to the maturity of North West England in regards to 3D printing/AM implementation.

Companies A and B are SMEs, each with fewer than 50 employees, as shown in Table 5.2. The products that each produce differ significantly, however, they have strong similarities in that they are both UK-based manufacturers, with fervent customer focus, quality of products, bespoke designs. Importantly, the concern for case selection was not driven by randomness, rather it was guided by the potential for each to assist in contributing to research objectives (Rylands et al., 2016). As noted by Yin (1994), replication logic should be applied when building theory from case studies, rather than sampling logic.

In mid-2015, site visits were conducted by the researcher to establish an initial understanding of industry, products and use of 3D printing/AM. It allowed the researcher to gain valuable insights into the site layouts, production processes and shop-floor design, through observation, interviews and VSM. By conducting the site visits, it allowed the researcher to investigate alongside managers and employees in their natural setting, to study the processes, allowing the phenomena to be observed from the inside (Böhme et al., 2014). Following this, guidelines for semi-structured interviews of managers and shop floor/production employees were developed, and the interviews were conducted with managers and production employees in both organisations. The interviews extended over several days, and ranged from one to three hours. The questions, which explored the 3D printing/AM adoption process within the manufacturing system and its business impact, were aligned with QSAM protocol

and the BPR model developed by Childerhouse et al. (2003), focusing on the interrelated variables of BPR initiatives termed culture, technology, finance and the organisation. The combination of data collection techniques allowed the researcher to establish a more holistic understanding of how 3D printing/AM was adopted by the organisations, as well as the business impact, including the impact on their VSs. An abductive approach was taken overall, as described in Section 3.2, to pursue the aims of this thesis: to extend understandings of adoption and the impact of 3D printing/AM (including VS design), with the initial deductive observations, interviews and analysis providing a solid foundation for an inductive process of identifying patterns and regularities (Eisenhardt and Graebner, 2007; Rylands et al., 2016). Although 3D printing/AM is the focus within Companies A and B, the research also considers the traditional method of production. The following findings from Companies A and B have been analysed using VSM and the business model canvas to explore the impact that 3D printing/AM has had on each case company.

5.4 Findings

5.4.1 Overview of findings from North West England

Research was initially conducted with a group of 8 small to medium sized enterprises (SMEs) in North West England, that were using innovative technology to enhance their traditional businesses. The industries in that region and products produced ranged from textiles, furniture, exhausts and fishing reels to springs, bath tubs and wallpaper. Their use of 3D printing consisted of prototyping, mould creation, and finished products; raw materials for 3D printing/AM consisted of plastics/ polymers and metal.

This research chose to focus on the companies investing in 3D printing/AM in the production process and narrowed the findings to two case companies, Company A and B, as summarised in Table 5.2. 3D printing/AM has grown beyond just plastic busts and rapid prototypes, to being used in tooling and production processes or rapid manufacturing (Hasan, Rennie and Hasan, 2013). While this area is currently attracting growing interest, particularly from business, there is a need to gain further understanding of the actual or potential impacts that it has or can have on business (Felgendher, 2015) and theoretical impacts for academia, as called for by Waller and Fawcett (2014) and Gress and Kalafsky (2015). Within business, as identified in literature, there is a growing interest in understanding the technology not only for creating prototypes, but also for areas such as future mass customisation (Khan & Mohr, 2015;), final parts or rapid tooling (Dippenar and Schreve, 2013), spare-parts production (Burkett, 2014), as well as SC design (Khajavi et al., 2014; Waller and Fawcett, 2013), and business model

design (Bogers et al., 2016) as the capability of the technology increases. The amount of literature in recent times regarding technical knowledge of 3D printing or AM substantially outweighs that of the business applications of 3D printing (Rylands et al., 2015), with constant updates of new materials, designs and capabilities being publicised; thus, there is an opportunity to add to knowledge in the area of business, and more specifically VSs. According to Christian and Sandström (2016, p.160) “studies of how industries transition to 3D printing are currently scarce and there is a need for more empirical descriptions of who and why an industry adopts 3D printing for manufacturing purposes”.

North West England was chosen for this research due to its geographic and historical significance, as mentioned in Section 5.3, transforming over the years from a more traditional manufacturing focus to more advanced manufacturing. Whilst the region contains large global manufacturing companies such as Unilever and BAE Systems (European Commission, 2016), SMEs are important to economic development. Economic studies revealed that SMEs account for over 98% of businesses in the UK (Lancaster University Management School, 2016). According to the European Commission (2016) innovation and advanced manufacturing have played an important role in the transformation of the region and the positioning of North West England. Whilst manufacturing output declined from over 30% in the 1980s to approximately 15% in 2010 (European Commission, 2016), SMEs and the region as a whole have been continuing to transform and adapt to the changes. In this case, both Company A and B were exposed to increasing competition and challenges that required them to investigate alternative methods of competing. Approximately three years ago, both companies began to investigate and invest in the use of 3D printing/AM, with a focus on using the technology for manufacturing processes. The following findings from Companies A and B have been analysed using the business model canvas (Osterwalder and Pigneur, 2010) and VSM to explore the impact of 3D printing technology on both case companies.

Table 5.2: Case company overview

| | Company A: | Company B: |
|---|---|--|
| Industry: | Advanced engineering/manufacturing (metal product) | Advanced engineering/manufacturing (residential and commercial) |
| No. of employees: | 25 | 8 |
| Product categories: | Filters | Wallpaper |
| Market segment: | Chemical, oil and gas; pharmaceutical; power generation; food and beverage manufacturers; adhesives; sealants; waste management; aerospace and hydraulics | Hotels and hospitality; vessels; famous landmarks, offices and homes |
| Application of 3D printing: | Production process | Production process (tooling) |
| Reasoning for adoption of 3D printing: | Design advantages, product customisation, agility and differentiation in the market | Cost-savings, agility, product customisation and increasing the suite of designs/ product portfolio |
| Value proposition: | Customer service excellence, agility, solutions, and expertise in traditional and innovative manufacturing methods | Customer service excellence, traditional products, and manufacturing expertise, agility, customisation |
| Assistance from local university: | Project(s) – computer program and specialist software/ tensile testing conducted on Company A filters/ parts, and design assistance using 3d printing/AM and conventional tooling | Project – Tooling for production/ manufacturing of wallcoverings using 3D printing/AM |
| Impact of 3D printing – did it create new products/processes/ways of working? | Yes – products and processes | Yes - processes |

Source: Adapted from Rylands et al., 2016, p. 975.

5.4.2 Case study Company A

5.4.2.1 Company overview

Company A produces a large range of filters and filtration solutions. The company specialises in a large variety of products from small domestic filters to larger industrial filters used in commercial fishing, factories and aerospace. AM accounts for approximately 2% of Company A's annual turnover (which

the company expects to increase as the use of this technology matures). Company A have a range of machinery in their production facility, including the more traditional large punch presses (hydraulic and pneumatic) to computer numerical control (CNC) and high-tech laser cutters. The production facility is divided into designated areas for different tasks, such as welding, machining and hand folding or cutting of specific filters. In addition to this, there are project-specific work stations, such as those for large filters for the fishery industry and others for small specialised parts for customers in the ink industry, for example. There are also designated areas for customer polymer recycling, operating the mesh tube machine (that was designed and produced in-house), and additional testing facilities. Due to the array of products that Company A produces, they have an extensive punch-press library of designs to choose from. They also use a combination of traditional and innovative technology, including a 3D printer, which is situated near the R&D team, assisting in boosting their operational capability. Company A produce products in small batch runs, usually consisting of under 1,000 items per batch. Approximately 60% of their customer base are repeat customers. In addition to production, Company A execute many tasks in-house, including R&D, sales and marketing. The founding leaders champion innovation and technology, and they have a continuous improvement initiative in place to enhance skills and knowledge in both innovative technology and business acumen. This is assisted by their links with the local university and a nearby fabrication laboratory (“FabLab”).

5.4.2.2 **AM adoption process**

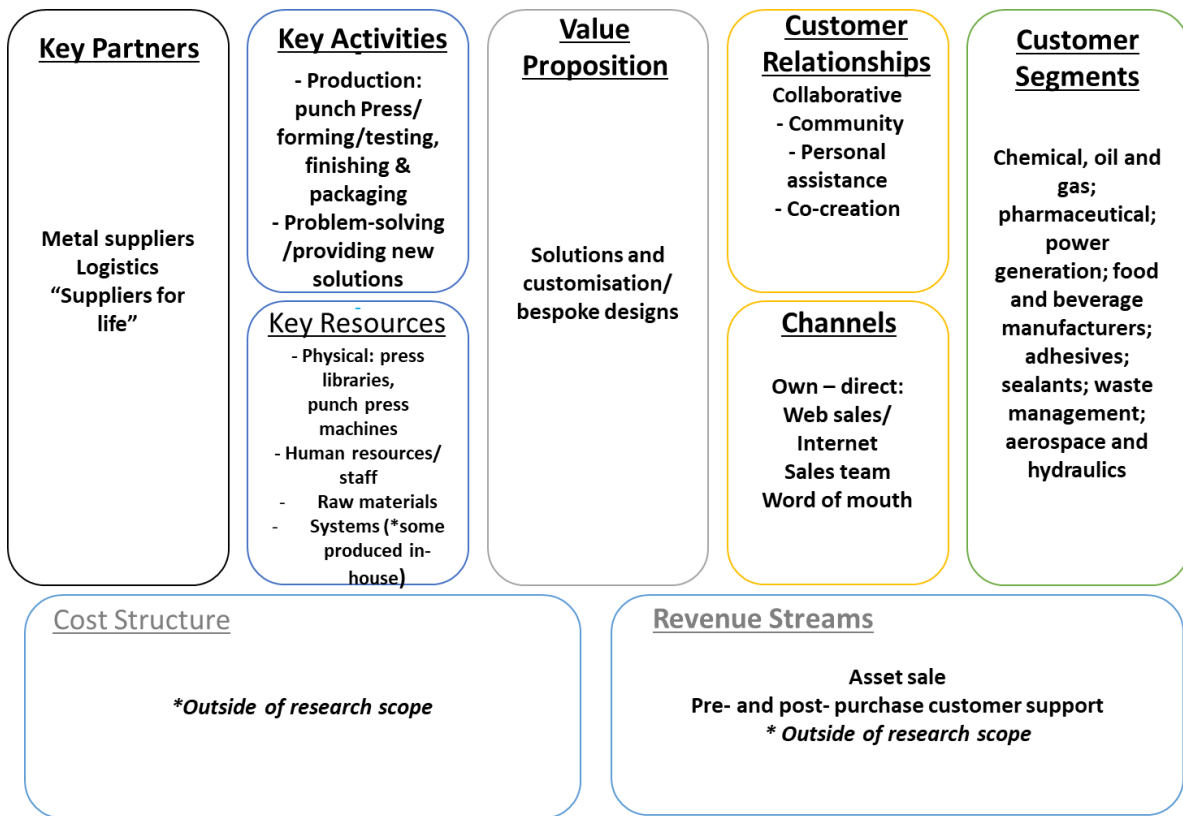
5.4.2.2.1 **Business model canvas**

To gain further insight into Company A and the impact that 3D printing technology has had on their manufacturing processes, data was collected on site through a site tour, observations and semi-structured interviews (as described in Chapter 3). The business model canvas in Figures 5.1 and 5.3 has been used as a lens to analyse the business impact on Company A pre and post the introduction of 3D printing/AM, in conjunction with VSM in Figures 5.2 and 5.4.

Using the business model canvas, key elements of the business have been analysed as summarised in Figure 5.1. Before the adoption of 3D printing/AM, Company A competed predominately on the value proposition of bespoke designs and solutions. With over 30 years of experience in the industry, the company can produce large portfolios of goods, working closely with the customer to produce designs for specific needs. Their customer relationship is collaborative, consisting of community, personal assistance and co-creation (Osterwalder and Pigneur, 2010). Company A established an online community for sharing information and offer customer assistance for before and after purchases. They also interact with the customer during the design phase through to production to differentiate their products from those purchased from off the shelf (and have a

combination of made to order (MTO) and made to stock (MTS) items). Such an approach has allowed Company A to compete against both domestic and off-shore manufacturers. Company A has a worldwide customer base (consisting of many European customers), with approximately 60% of their business being from repeat customers with long-established relationships. They produce and deliver their orders generally within six days, depending on the part. Their customer segment is quite large and consists of chemical, oil and gas, waste management, sealants, adhesives, pharmaceuticals, power generation, food and beverage, aerospace and hydraulics. The key value adding activities (as seen in Figure 5.2) include the sourcing of raw materials (metals); production, involving pneumatic or hydraulic punch pressing, forming and finishing; testing; packaging; and shipping the product to the end user. Company A's key resources include the pneumatic and hydraulic punch presses and library, staff (production and office), raw materials (such as sheet metal) and systems. The database that contains orders, inventory and product information was produced in-house. They have a separate stand-alone system for invoicing. Company A "has close ties with suppliers, where suppliers are seen as suppliers for life" (Director, Company A); these ties are based on longstanding relationships. Suppliers are selected not only for the quality their products and materials, but also for their reliability above cost. Metal suppliers are particularly important to them and local suppliers are used where possible. The channels that Company A uses to promote their business include the Internet, industry events and boards, involvement in the community and word of mouth. Revenue streams consist of asset sales and customer support before and after sales. It must be noted, however, that the revenue streams and cost structure were outside of the scope of this research.

Figure 5.1: Company A – before AM- adoption



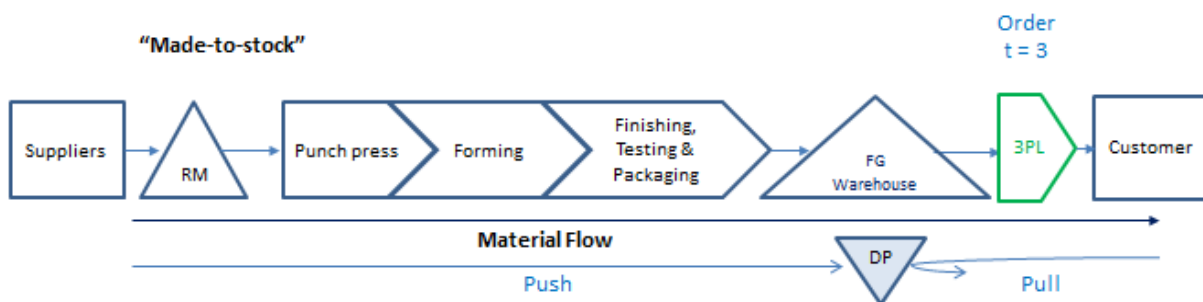
Source: Adapted from Strategizer, 2015

5.4.2.2.2 VSM

The traditional VSs for Company A consist of both made to stock (MTS) and made to order/engineered to order (MTO/ETO) items. Many items are offered online with specific sizes and dimensions; however, there is a section that allows customers to enquire about other sizes or alterations that may be necessary for specific parts. Company A offered a large range of products (with over 15 listed in their product catalogue even before the adoption of 3D printing/AM), not including customised filters, solutions and raw materials such as mesh (which can be supplied formed or as mesh). Figure 5.2 provides an overview of the VS design for a standard filter, MTS, using traditional manufacturing methods. The lead time for a standard product order was short between one to five days according to Company A, whilst a customised product or solution has more variation, and can be between one day to one month, depending on the order. The key activities begin with the sourcing of material (such as sheet metal) from key suppliers, which is then stored on-site in preparation for production. Production begins with punch pressing a sheet of metal to get the desired design and alignment of holes, followed by forming and finishing the filter. The end product is then tested to ensure structural integrity and quality, before

being packaged and stored onsite ready for third-party logistics to deliver it to the end user/customer. The decoupling point in this VS is at the finished goods warehouse. Company A provides standard products and sizes, but also offers customised products for specific uses. A second traditional VS would include the custom filters, which includes an additional step of the engineer engaging with customers to create a design before the filter is pressed and produced using traditional methods (ETO/MTO). The advantages of having both standard and customised items allowed Company A to service a wide range of the market. However, market and environmental challenges have continued to shift since the company was established over 30 years ago, causing Company A to update its manufacturing processes further to adapt to market needs such as increased agility and improved designs. Figure 5.2 provides an overview of the traditional manufacturing VS design.

Figure 5.2: Company A – traditional value stream



Source: Rylands et al., 2016, p. 977.

To remain competitive, Company A adopted 3D printing/AM technology in 2012 in their production process of final products. They first discovered 3D printing technology at the Manchester fabrication laboratory (FabLab). They had access to polymer machines at the lab, where they were able to experiment with designs that could be used as prototypes for their products. By beginning with 3D printing in plastic to experiment with design, Company A were soon able to shift to using metallic powders to produce final products (filters and filtration solutions). This was made possible due to the Fablab granting initial access to the machines and collaboration with the local university. Collaborative projects with the staff and students from the university assisted Company A in their 3D printing/AM implementation, as they provided valuable manufacturing advisory services. For Company A, the main driving force for the adoption of 3D printing/AM was the technical capability that the technology offers. Traditional manufacturing methods could not produce the geometrically complex parts that 3D printing/AM can (Selko, 2015, and Cohen; George and Shaw, 2015). Traditional machinery was having

difficulty with the alignment of holes, which is of paramount importance to filter production, and can be quite complex depending on the filter type (oil filters, for example). Due to the capability of 3D printing technology, this problem could be eliminated. Apart from the technical capability the 3D printing offers, other companies have been more focused on aspects such as the finishing of the final product (the smooth textures, for example) or aesthetics, rather than how to incorporate it into the production process, or operational considerations. Alternatives to 3D printing were tested by Company A to achieve the necessary designs (including hole alignment), such as traditional punch pressing and high-tech laser cutting; though these methods could not achieve the desired outcomes. Company A required the accuracy that only 3D printing/AM is currently capable of (Petrick and Simpson, 2013), and began trialling an array of machines from multiple manufacturers to find the one that best suited their operations. Once decided, Company A then invested in a metal printer for use in the production process of final products. Although technical capability rather than cost reduction was the main driver for using this technology, it can assist with reducing costs associated with tooling and set up time (Cohen, 2014). Benefits for using 3D printing in the production process include not only the advantage of the ability to produce more complex parts, but it also allows for these to be produced in a single piece, reducing weak points that may be introduced by traditional welding or joining. The importance of eliminating these weak points can vary depending on the application, and so bypassing this and producing more robust parts was an advantage of 3D printing/AM. In addition to this, the better alignment of holes and improved production of complex filters was reported to positively impact on energy usage due to the optimised designs, providing benefits to Company A's customers. The speed of design and the manufacturing process made possible by this technology also benefited the customer through more agile customer service offered by Company A. Other important aspects for consideration, including social and environmental aspects (Rylands et al., 2015) were also discussed with Company A. The Director of Company A highlighted that by adopting this technology they had improved their involvement with the community, as well as impacted on their business as shown in Figures 5.2 and 5.4.

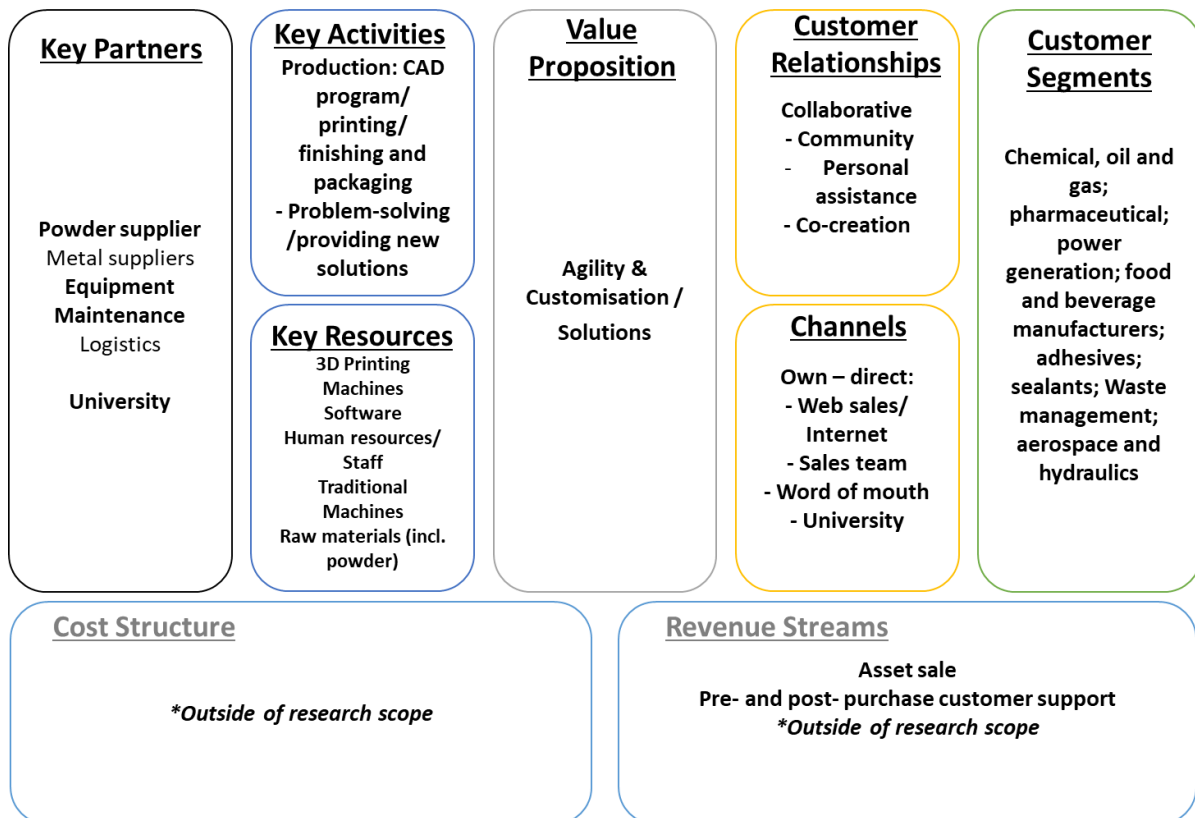
5.4.2.3 **Business impact of 3D printing/AM adoption**

5.4.2.3.1 Business model canvas

Findings post 3D printing implementation in Company A have been captured in Figures 5.3 and 5.4. Using the business model canvas to analyse and compare findings, reveals, first, that the value proposition changed. The value proposition shifted to include that of agility as well as customisation. Agility combined with lean manufacturing practices that are in place assist Company A in reducing waste and serving the market faster than competitors, working to tight deadlines, just in time

(Felgendhreher, 2015; Sharifi, 2006) and lead time compression (Barnes, 2014). It also creates a “leagile” (Naylor et al., 1999; Mason-Jones et al., 2000) environment. The technology has allowed complex parts to be produced much faster and for Company A to more easily switch between designs when using 3D printing. It does not always reduce the cost per part being produced compared to traditional methods, though the difference is minimal at this point. The customer relationships for Company A after adopting 3D printing technology became even more collaborative, as the company was able to offer further solutions and expertise. Sharing of knowledge and community involvement increased (through offering personal assistance, case study examples, and competitions to involve the public). Importantly, co-creation increased with Company A working more closely with customers to create a bigger portfolio of bespoke designs and to educate the market in a technology that has limited understanding in the potential that it offers (Cohen, 2014). Customer segments remained largely unchanged. However, it gave the company the opportunity to expand and increase their attractiveness to the market through increased agility, first-mover advantage and product differentiation (Vecchiato, 2015) assisting with competing against domestic and international competitors with cheaper imports. Whilst it uses 3D printing and has its own in-house research and development team, Company A still uses traditional production methods, such as soldering, which other companies do not do (serving as another point of appeal and differentiation for customers). Key value adding activities were altered to include the involvement of an engineer in building a design database in collaboration with customers through co-creation (as depicted in Figure 5.4). Key resources expanded to include the 3D printing/AM technology (selective laser melting (SLM) machine), software, specialised engineers, and metallic powder for 3D printing. Importantly, an additional key resource that emerged from Company A’s adoption of 3D printing was that of the local university. Company A proactively sought out information on 3D printing technology from the local FabLab and suppliers and then approached the university for guidance and assistance. Their list of key partners also grew to include the local metallic powder supplier, and 3D printer equipment maintenance. Quality, reliability and location remained important factors for the selection of key partners/suppliers. Unlike other companies that have experienced difficulties with suppliers, Company A had not experienced production bottlenecks caused by a lack of raw materials from its metallic powder supplier, due to their high levels of service and close proximity to the company. Channels to market and board involvement grew to include the university and local education institutions. As shown in Figure 5.3, the revenue streams and cost structure are outside of the scope of this research.

Figure 5.3: Company A – after the implementation of 3D printing



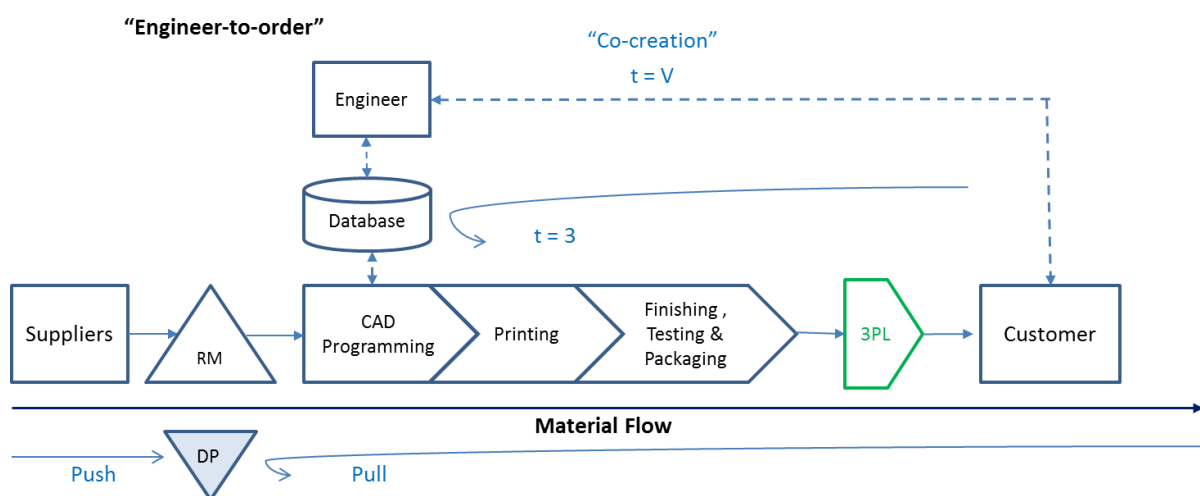
Source: Adapted from Strategizer, 2015

5.4.2.3.2 VSM

Company A discovered more in-house and upstream changes than downstream, following the implementation of 3D printing/AM technology. As Figure 5.4 shows, a new VS formed that co-exists with the traditional VS. It involves co-creation between the customer and the company, including increased customer interaction with the engineering department. The VS begins with suppliers (of raw material such as metallic powder as opposed to sheet metal), located locally, assisting in more reliable supply of powder. This was significant, as Company A had noted that other businesses had issues with other suppliers, particularly of metallic powder. In place of traditional production processes, the next step involves CAD to digitally create the item to be produced. This step involves close collaboration between the engineer and the customer to build a unique database of designs for production using 3D printing/AM. The close collaboration during the design process potentially locks-in customers due to the high investment in time to design the product, building up the database for future use. Waiting

times and the possibility of alternative providers being less reliable act as barriers to change for the customer (positively influencing the ability of Company A to retain customers). Following the design phase, is the production/3D printing of filters. Increases in the 3D printing/AM production costs at this stage as compared to the traditional VS methods of production are described by Company A as minimal, however; savings in tooling and set up costs and design capability outweigh the additional production costs of 3D printing/AM. Once printed, the filter is then finished (as required), tested and inspected before being packaged and shipped to the customer. As compared to the traditional VS, the decoupling point is moved upstream to allow for high levels of customisation which greatly enhances the perceived value by customers (Rylands et al., 2016). Waste is reduced due to the nature of 3D printing being additive rather than subtractive (Petrick and Simpson, 2013), as well as work in progress and the amount of finished goods on site due to the ability to print small quantities on demand. An overview of the new VS design post 3D printing/AM adoption is shown in Figure 5.4.

Figure 5.4: Company A – new value stream



Source: Rylands et al., 2016, p. 978.

Findings revealed that, interestingly, instead of replacing the existing traditional VS, the new VS that was introduced due to the adoption of 3D printing/AM, co-existed and completed it. This has become valuable for Company A, making it possible to offer both methods of production to a customer. There were different advantages or value propositions for the customer, including agility to market to respond to or anticipate change (Sharifi et al., 2006) and the novelty of using a new technology, offered

by 3D printing/AM, and access to knowledge and skill such as soldering and other traditional methods that becoming more difficult to find in other businesses. As noted by Company A's Director, "most other companies don't solder anymore. They see it as old fashioned". Overall, the addition of 3D printing technology was significant as it not only resulted in the creation of a new VS, it also changed the value proposition to the customer to allow for more customised products and solutions, and agile responses to changing market conditions.

Company A conducted multiple case studies, with documentation provided to the researcher during this study, of an example of how lead time compression was possible due to having 3D printing/AM capability. This case demonstrated a significant example of agility by Company A, whereby a critical part required by a customer was designed and produced in approximately one week, as compared to larger competitors using traditional methods and taking more than 12 weeks to attempt produce the same part. These larger competitors were unsuccessful, where Company A was triumphant due to their adoption of 3D printing/AM. This example of agility offered by the newly formed VS provides the platform to service existing customers more effectively and opens up the market to other customers and opportunities (Rylands et al., 2016).

Following the adoption of 3D printing/AM, the Director of Company A expressed that "We are now seen as cutting edge, adventurous go-getters who make time to innovate", not just as traditional filter manufacturers. Prior to the introduction of 3D printing/AM, Company A had a history of innovation, from inventing specialised mesh machines in-house, to implementing newest presses in the past. The leadership's enthusiasm towards new technology adoption was significant, and it was evident during the site visit and site tours that it permeated throughout the entire organisation. Company A had a positive culture, accepting of new technology and change. The founders each focus on specific business areas, with one promoting the company, new ideas and public relations (PR), and the other focused on innovation and technology. Company A are driven by their enthusiasm for innovation and educating the market, and are open to working with other companies and knowledge centres to promote their work and the general use of 3D printing/AM. This open and driven culture and positive PR has assisted Company A with the acceptance of 3D printing/AM and has assisted in improving business performance, through offering new value propositions to customers, more customised innovative products, solutions and agility to market.

Overall, the adoption of this technology has had a positive impact on Company A through providing increased manufacturing opportunities and further opening up the market. When referring to Darwinism and SC design, Fawcett and Waller (2014, p. 162) wrote that "only the adaptable survive",

which is being demonstrated by Company A. Company A is continuing to improve its products and have rebranded and positioned itself not only for the current market, but future markets as well.

5.4.3 Case study Company B

5.4.3.1 Company overview

Established 100 years ago, Company B is a producer of unique wallpapers. The company is historically known to be innovative in product design, development and application. Prior to the implementation of innovative technology, Company B were known for their innovative applications of their products, with wallpaper being used for unique ceiling and wall decorations, as well as table runners, to name a few. Company B's products go beyond having aesthetic or design appeal, and incorporate hygienic and practical properties (in that they are hardwearing, durable and cleanable). Company B displayed resilience throughout the years, experiencing great hardship during war, which impacted heavily on their business and design portfolio, as rollers and other equipment were ordered to be melted down for ammunition. Following this, there were various changes in ownership over the years, with the company experiencing a downturn for several years. In more recent times, business for Company B has been improving, with interest from international customers growing, particularly from markets in Eastern Europe due to the lifestyle appeal and product range (which is manufactured in the England). Improvements in business and the attainment of additional product certification, attracted what Company B described as "much needed investment" to support and grow. Company B sell their products through distributors, online partners and exclusive distributors per country, to international and domestic customers, with the customer base being 25% domestic.

5.4.3.2 3D printing/AM adoption process

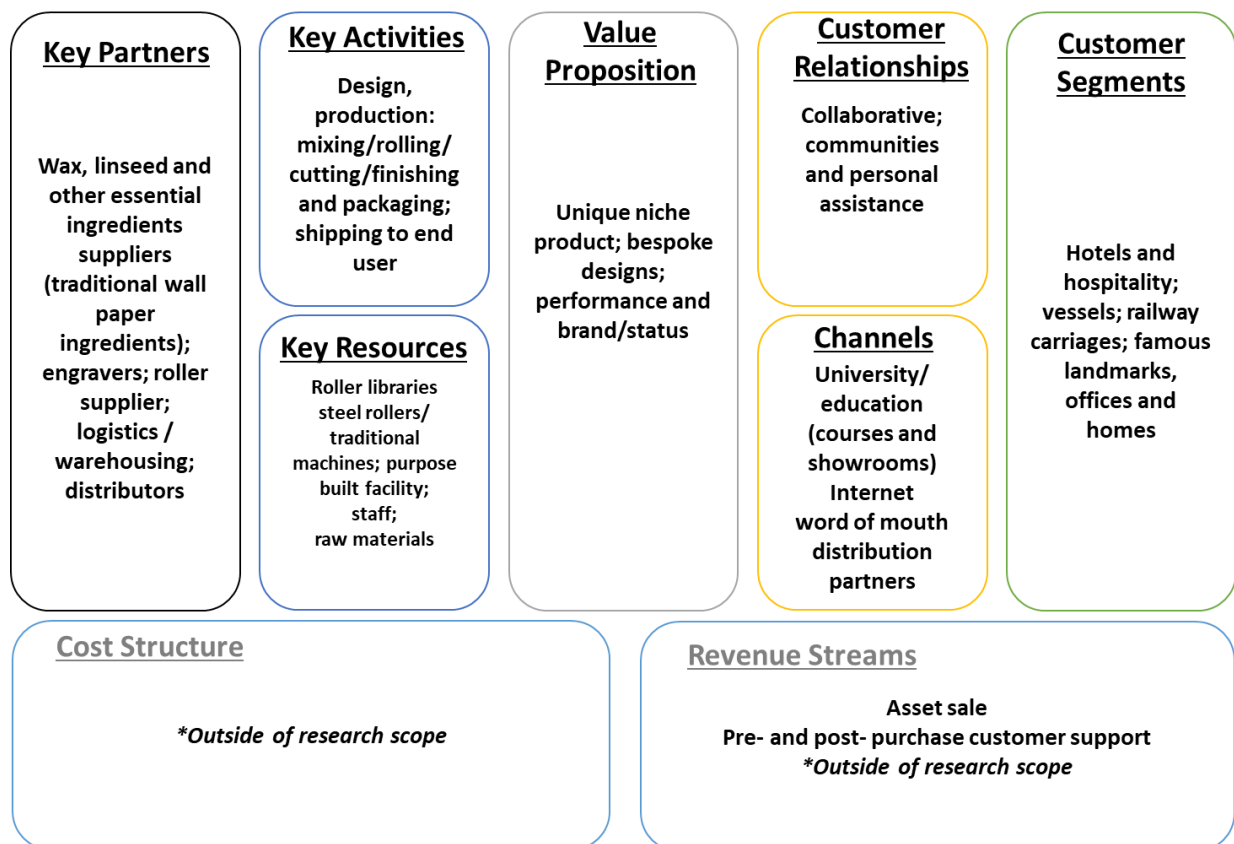
Company B began the process of 3D printing/AM adoption in 2012, focusing on the use of this technology for printing tooling (roller sleeves) for the production process. This started with the investigation of the design process using CAD to create designs that could be 3D printed to produce the sleeves, instead of printing the final product (wallpaper). This required the trialling of different materials and sleeve sizes, which was a complex task due to the design complexity, the materials available (with some causing adhesion to the wallpaper during rolling) and the size and capability of 3D printers (to produce the correct size sleeves), that was made possible due to collaboration with the local university. The openness of Company B for exploration during this research was assisted by the

new ownership and culture of the management and employees. Increased investment by the new owner also assisted Company B to begin investigating 3D printing, with the importance of growing their design portfolio (through producing rollers) recognised. By doing so, it would increase their agility to market and potential for product customisation, as well as their suit of designs offered to the customer. Trials were still taking place to perfect and finalise the use of 3D printed sleeves in the production process at the time of this research. The small team at Company B however, were determined to implement this technology, with the Commercial Manager saying “AM is the way forward for getting more designs to the market, quicker and bespoke manufacturing”. Company B demonstrated a pull to adopt the technology and in contacting the local university/knowledge centre for help. 3D printing presented Company B with an opportunity to be more agile to market demands and product customisation to compete against other wall coverings.

5.4.3.2.1 Business model canvas

As with Company A, the business model canvas has been used to evaluate the company before and after (expected state) 3D printing implementation, as shown in Figures 5.5 and 5.7.

Figure 5.5: Company B – before the implementation of 3D printing



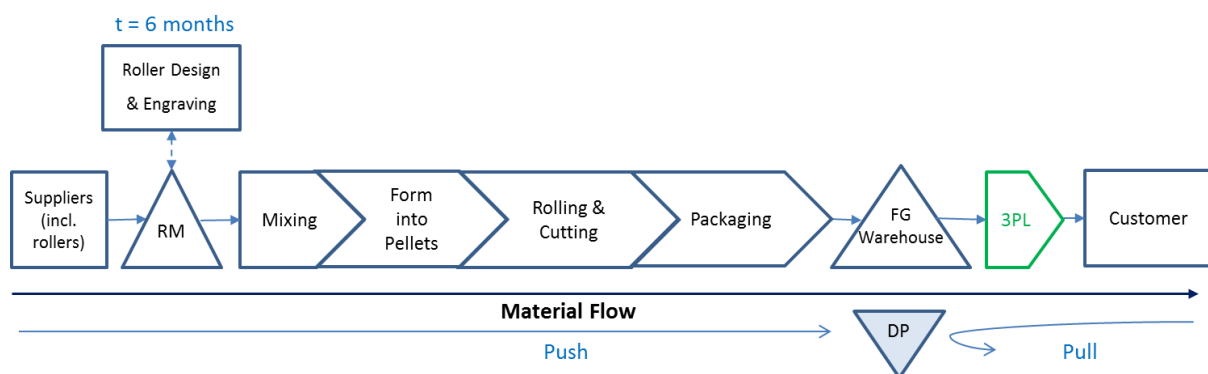
Source: Adapted from Strategizer, 2015

Company B consists of a small team of fewer than 10 people who manufacture in a purpose-built facility in England. The company has been using the same recipe of natural raw materials that they used when they were established a century ago. Traditional methods of production with mixers, rollers and cutters are still used; however, it is in the process of updating part of its equipment in this process to expand its capabilities and product range. Their value proposition before adopting 3D printing/AM was based on a niche product offering, product performance and brand/status. Even before exploring the use of 3D printing/AM they had a wide customer segment predominantly based on business to business relationships. Customers included businesses such as hotels and hospitality, vessels, railway carriages, famous landmarks, offices and homes. Company B collaborates with its customers and offers personal assistance before and after purchase, as well as an online community (though forums, news stories, installation advice and training). The product competes with other wall coverings and decoration, from paint and tiles to other types of wallpaper. Their key activities (as seen in Figures 5.6 and 5.6) include design of the wallpaper, procuring steel rollers within the UK (which are then engraved in Germany), mixing key ingredients to form pellets, rolling, cutting and finishing the product, after which it is packaged, warehoused and shipped to the customer. Company B uses an in-house system for forecasting and managing the product. Company B at the time of this research had 36 designs in their collection and produce one or two new designs per year, and four to six mixed designs per year (which is a significant investment in both time and resources for the company). Key resources for the company include their designs, roller library and production machinery, production and office staff, the purpose-built production facility, and raw materials. Company B's key partners include the key suppliers of raw materials and other ingredients, steel roller producers, engravers, logistics and warehousing. Their relationship with their key partners is described as being contractual due to their size in the marketplace. Company B chooses their key partners based on quality, reliability and location above cost. They purchase from local suppliers where possible; for example, from base paper suppliers in Leeds to Sales & Marketing assistance in rebranding and repositioning in Manchester. Channels to market are based mostly on word of mouth and through local educational institutions (where training show rooms have been established), the Company's website, and distributors. Their revenue stream is based on asset sale and before and after sales customer support and cost structure. Due to its revenue stream and cost structure information being outside of the scope of this research, it has not been included for either Company A or Company B.

5.4.3.2.2 VSM

VSM was used to explore the traditional VS of Company B before the adoption of 3D printing/AM, as can be seen in Figure 5.6. It begins with suppliers of raw materials (such as gum, linseed and chalk) and importantly steel rollers. Company B had a good relationship with suppliers, which they described as being commercial (due to their size) but positive in terms of performance, including the high service level and reliability, as well as high quality raw materials supplied. Company B used local suppliers where possible, including raw materials (gum and chalk), cardboard packaging and marketing expertise. The steel rollers, which were made in England, were shipped overseas to undergo an engraving process in Germany. This was said by Company B to be a costly and time-consuming process that costs approximately £15,000 per roller and has a six-month lead time. Once the roller is ready, the other raw materials supplied can be mixed and processed using traditional methods. The product is produced to stock (with the customer being able to choose from over 30 possible designs). The production process comprises of six key ingredients being mixed together by Company B to create a cake-like mixture, which is rolled into pellets 1-2mm thick. Conveyor belts carry the pellets to the rollers to be rolled into a specific design, producing 10m rolls. Company B the inspects the rolls and cuts them to size, with any overhanging wallpaper removed. The wallpaper is then rolled, and the rolls are then put aside for approximately one week to cure. Batches of 20 to 30 rolls per design are produced from each batch of mixture. All rolls produced are natural in colour, allowing for the customer to customise the product. Inventory is kept onsite or in a centrally located warehouse. Stock is managed, with staff keeping track of product location and age. It was noted by Company B that the product lasts approximately 2 years in a roll (as it continues to get harder and stronger as time goes on, making it ideal for when it is applied to walls).

Figure 5.6: Company B – traditional value stream



Source: Rylands et al., 2016, p. 980.

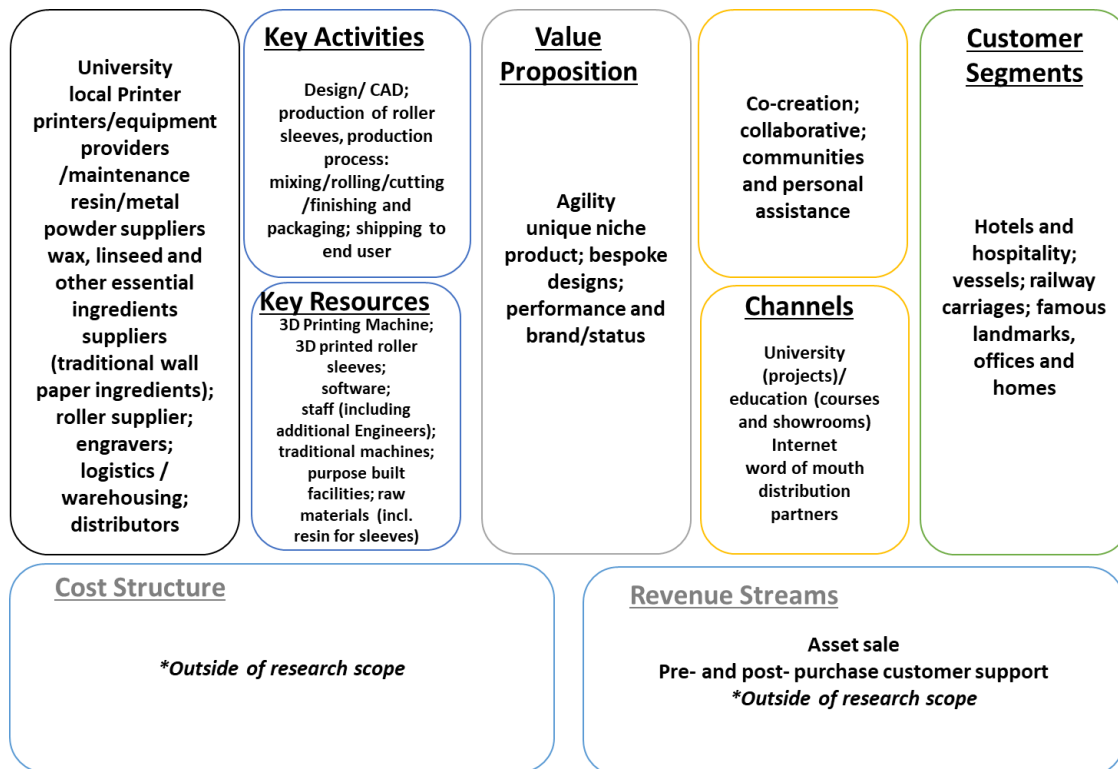
Though traditional methods of production have been positive, improvements to the VS are being sought through advanced technology to improve the value proposition of Company B, which is explored further in the next section.

5.4.3.3 **Business impact of 3D printing/AM adoption**

5.4.3.3.1 Business model canvas

To continue with their innovative tradition and to continue to compete globally, Company B began researching the use of 3D printing in their business. Opportunities that exist for Company B in using such technology are not in radically changing their VS design, production process or raw material mixture of the wallpaper, but in the production tooling: the design and construction of the rollers. Company B began investigating 3D printing over two years ago with the assistance of the local university, focusing their attention on roller sleeves (metal and plastic). Company B was required to invest substantial amounts of time into this investigation due to the 3D design process that the wallpaper requires (such as creating the required depth in CAD that can successfully be produced) and the size of the roller sleeves that are needed in the production process. Company B also explored different materials for producing the sleeves (as the wallpaper mixture being rolled can stick to certain surfaces). By creating sleeves locally (through a 3D printing company) or in-house (by acquiring a 3D printer), this would allow Company B to significantly speed up the new design process (from six months to less than one month or possibly even one week according to Company B), reduce costs such as logistics and transportation by using suppliers within the UK, saving thousands of pounds. This could enable Company B to build up its design portfolio to the size of its original portfolio offering (which had included between 1500–2,500 designs). The technology could also enable more customised products rather than just made to stock, and assist in reducing procurement, logistics and management costs. By customising designs, more exclusive products could be made available to customers also.

Figure 5.7: Company B – after the implementation of 3D printing



Source: Adapted from Strategizer, 2015

As Company B being was in the process of transitioning to 3D printing roller sleeves for use in the production process at the time of this research, Figure 5.7 shows the expected changes using the business model canvas after the implementation of this technology. Investment in this technology will have slight effect on the VS structure and value proposition. The value proposition is expected to shift to include agility and customisation without jeopardising the existing product offering. The speed in design and time to market will greatly benefit Company B's ability to serve the market more efficiently and effectively (as the roller sleeves will be produced either locally or in-house). 3D printing will reduce the time and cost substantially from six months and thousands of pounds to a few hundred pounds and a lead time of less than one-month to produce customised rollers. Logistics costs of getting the parts from overseas (where they are currently being hand-engraved) will be reduced as the task will either be done locally or in-house. Recent investments have increased the market presence and brand opportunities for Company B. The collaborative customer relationship is anticipated to be strengthened, with the offering of further solutions, products and designs being engineered to order rather than made to stock. The database for 3D printing and in-house expertise could be of value to

customers, both in retaining current clients and attracting new ones. This includes the unique designs and faster production. Company B's market has expanded into Russia and the UAE, among others, with the product being highly sought after by customers due to the prestige associated with its brand and country of manufacture. The customer segments are expected to expand to include a larger audience, though the market segments may be similar before the adoption of 3D printing/AM. As in Figure 5.6, the key activities in production will expand to include CAD and engineering involvement to build up a database before printing roller sleeves which are used to produce wallpaper. Key resources for Company B would include additional 3D printing machinery (if produced in-house), software, engineers, and raw materials such as resins for 3D printing/AM. Key partners would expand to include the university, which was proactively approached by the company for 3D printing/AM expertise, particularly in making and testing roller sleeve prototypes. It is also expected that the group of key partners will grow to include local 3D printers (if 3D printing is outsourced), raw materials (resin and/or powder suppliers) and 3D printing machine maintenance (depending on whether 3D printing will be outsourced or performed in-house), as well as those mentioned in Figure 5.7. before the implementation of 3D printing technology. Channels for the product are expected to expand to include a stronger internet and market presence. Overall it is anticipated that it would increase Company B's potential will increase without encroaching on its traditional offerings or radically changing the VS design.

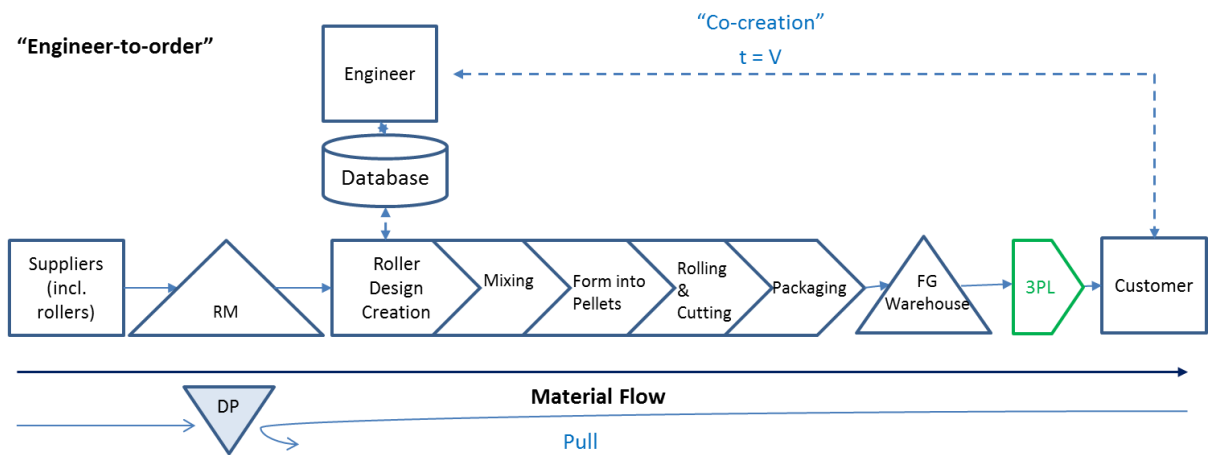
5.4.3.3.2 VSM

3D printing/AM adoption was in progress at the time of this research. The technology was being trialled and tested, showing progress towards implementation. Due to this, the expected VS following the adoption of 3D printing/AM has been depicted in Figure 5.8, using data collected, including observing trials and prototypes. The focus of the expected VS is on the roller creation and design.

The process begins with orders being received and the raw materials being procured from suppliers of gum, chalk and metal rollers, for example, and includes additional raw materials such as plastics for the 3D printer (which are kept in stock). CAD is then used to design sleeves and create files to be used in the production process. This step includes the in-house collaboration between the customer and engineer to create designs, which are kept in a database.

Trial data at the time of this research showed that by 3D printing the roller sleeve, time compression could be possible, reducing the lead time of getting a new product to market to one week, at the cost of only a few hundred pounds instead of £15,000 and a six-month lead time. The production steps following this are similar to those shown in Figure 5.6, before 3D printing/AM adoption.

Figure 5.8: Company B - new value stream



Source: Rylands et al., 2016, p. 981.

In this case, 3D printing is being introduced as part of the production process through creating the roller sleeve. This is a key part of the existing tooling process for production rather than printing the end product. Although Company B is not printing the final product, Figure 5.8 shows how using 3D printing/AM for tooling can create opportunities and affect VS design. Co-creation has been introduced into the expected VS, as well as potential for the value proposition to shift to include agility and customisation, without impacting on their existing VS or value propositions offered. There is great potential for Company B to achieve greater speed to market and lead time compression through the adoption of 3D printing/AM also, as well as repositioning in the market and positive PR.

Overall, for Company A and B, AM technology has been an enabler to enhancing value propositions and introduced new VSs whilst having limited impact on traditional VS design.

5.5 Discussion

5.5.1 Research questions 3 and 4 - How do organisations adopt innovative technology into their existing supply chain? What is the business impact of innovative technology adoption on the existing VSs/business manufacturing system?

The aim of this exploratory research was to investigate the adoption process of 3D printing/AM within manufacturing systems and its business impact on two SMEs in North West England. The findings revealed learnings that could be cautiously suggested as being generalisable to other post-industrial regions such as the Australia. Knowledge centres worked closely with the SMEs in this research, to assist with the experimentation, prototypes and trials involved in the adoption process of 3D printing/AM technology, with the aim to create products that could bypass the barriers faced by traditional manufacturing (Cohen, George and Shaw, 2015). In the case of both SMEs, this research found that the introduction of 3D printing/AM has (or is expected to) enable both the ability to offer additional value propositions to customers, as well as introduce additional VSs into their business to assist with their competitive ability.

Traditional VSs and manufacturing processes were not negatively impacted by the introduction of 3D printing/AM. Instead, Company A and B were able to increase their capabilities and presence in the market, and strengthen their business offerings to customers through offering both traditional and innovative production methods and solutions. Thus, this research is in alignment with the findings of Birtchnell and Urry (2016), that contradicts current studies that highlight the replacement of traditional manufacturing methods with 3D printing/AM, instead of co-existence.

Importantly, in addition to the benefits mentioned, the adoption of 3D printing/AM led to the introduction of a key partner or knowledge provider, termed knowledge centre. This included the local university and fabrication laboratories, which the organisations contacted for their expertise and advice on 3D printing/AM. The university in particular, was a significant knowledge centre for both Company A and B throughout the process of investigation and adoption, as it offered insight into the technology, assistance with experiments and additional help that the organisations would not have otherwise had access to (or if so, it could have been costly). Importantly, the adoption of 3D printing/AM allowed both organisations to develop new skills, whilst retaining and enhancing traditional skills, it resulted in adding or expanding VSs, instead of replacing them, and it allowed for products that were not possible to produce with traditional methods to be manufactured. Whilst Company B was not adopting 3D printing/AM for the production of final products, it provided insight into how 3D printing critical tooling can positively impact on the business, including increased agility. The positive PR and increased opportunities in the market for Companies A and B, outweighed the current revenue attributed to 3D printing, however this is anticipated to increase. The increased agility, capability and co-creation production process were positive in both cases. Company A and B were accepting of innovation and had positive cultures, which filtered throughout the organisations.

Unlike other studies that have stated that “SMEs that are already employing traditional manufacturing processes fail to recognise full potential of modern technologies” (Achillas et al., 2015, p. 300), this research disagrees. Early findings suggest that the SMEs already using traditional manufacturing processes do have the capability to recognise the full potential of modern technologies such as 3D printing, as demonstrated by Company A and B. Although other research and literature appear to focus more heavily on advanced markets, such as medical, prosthetics, and dental implants (Bogers et al., 2016), this study demonstrates that those companies whom appear to be less technologically advanced are also either implementing 3D printing technology in their production processes, or are exploring it to compete and improve the value propositions that they offer to end users. The technology may still be in its infancy, however, the importance of considering its adoption or impact is increasing, regardless of industry. It is expected to significantly impact on manufacturing, particularly mass production even of standardized products, within the next 5 years (D’Aveni, 2015).

Findings from this research have been summarised in Figure 5.9, showing key elements of the adoption process and business impact. According to Rylands et al., (2016, p. 983), the impact that the adoption of 3D printing/AM technology has had leads to the following hypotheses;

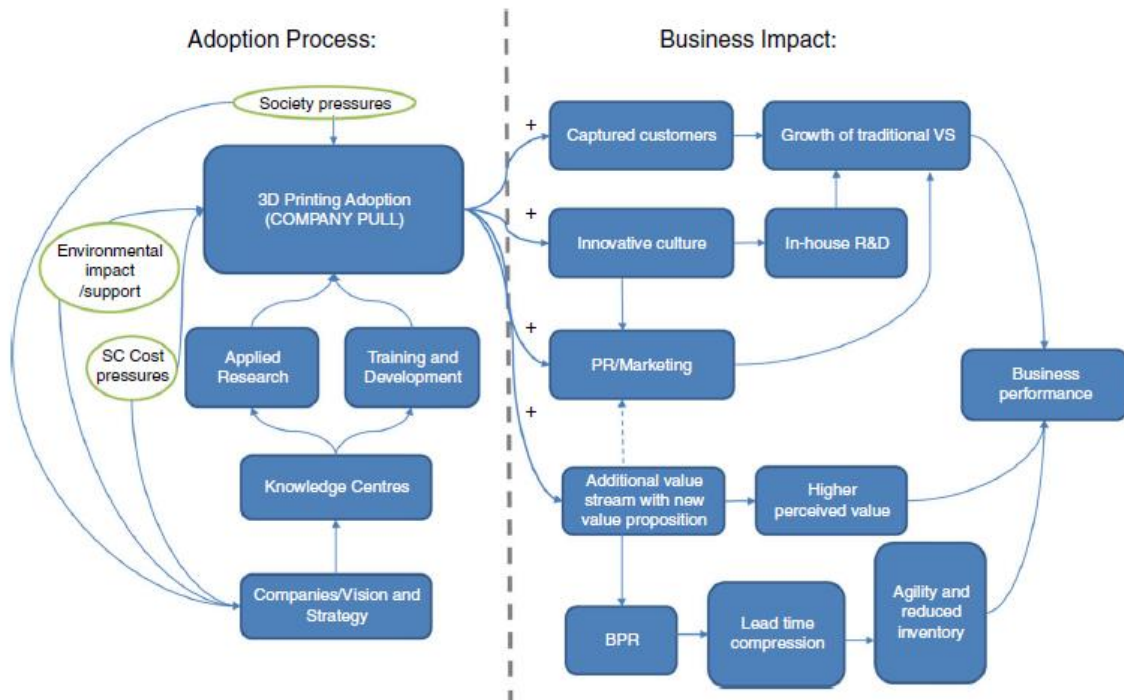
Hypothesis 1. Incorporating AM into the manufacturing system results in growth across value streams due to close client engagement during the co-creation process.

Hypothesis 2. AM is not replacing existing manufacturing/VS, rather it is complementing a company’s offerings.

Hypothesis 3. Unless the value proposition changes, the business impact is limited (engineering solutions versus business solutions).

Hypothesis 4: AM knowledge centres are critical supply chain nodes for a company pull-driven implementation process.

Figure 5.9: Incorporating 3D printing into the manufacturing process



Source: Rylands et al. (2016)

In summary, from reviewing the available literature, areas within SC and 3D printing literature that are becoming increasingly popular include SC mapping to analyse time compression, cost analysis and agility. To the author's knowledge, elements that do not appear to have been as largely covered in literature include that of the effects on organisational culture, human resources, impact on value propositions, and the potential to lock in customers through creating the 3D printed database and expertise offered (as depicted in the top section of Figure 5.9). Positively, Company A and B demonstrated a culture accepting of change and innovation throughout all levels of the organisation, particularly the founders and leadership team. They also enjoyed the pursuit of educational advancement and sharing their knowledge with the community. Currently, Company A are openly engaging with customers, businesses and educational institutions like Universities to increase awareness and educate others around them. Company B is also engaging with local educational facilities and the University to deliver training courses and materials on their products. Both companies demonstrated that they are accepting of change and have a positive culture, particularly the owners/leaders who showed enthusiasm for the use of 3D printing/AM.

5.5.2 Future outlook

From reducing the cost of logistics, improving speed to market and increasing co-creation (Rayna et al., 2015), to consumer production or creating “prosumers” (Petrick and Simpson, 2013), it is anticipated that the SC and VNs within them will experience further changes as the adoption of AM increases and technology develops. Education in this area is increasing in importance, with countries such as China (Krassenstein, 2015), Korea (Yeol, 2015) and the USA (Goulding, Bonafe & Savell, 2013) to name a few, investing heavily in educating the workforce in 3D printing and advanced manufacturing (not just in purchasing or producing the necessary hardware and software). The Australian Government has also begun to target advanced manufacturing (NSW Government - Department of Industry, 2018), with the “how” of production being highlighted as more important than the ‘what’ or the final product that is produced. It has been recognised that the impacts of Industry 4.0 (Xu, Xu and Li, 2018) are widespread and the need to keep up with the changes is important to nations all over the world. The future of 3D printing/AM may see the focus shift to the raw materials or cartridges needed for the machines, or networks of “prosumers” (Petrick and Simpson, 2013) expand, further linking those producing in home settings. It could impact on the manufacturing, retailing and dispensing of medications, the transportation of organs through the 3D printing of specialized ice cubes, and the need to increase education in material engineering. Due to the creativity in this field, the future of advanced technologies such as 3D printing/AM hold almost endless possibilities for practice and academia.

5.6 Conclusion

There are a number of reasons for businesses to adopt 3D printing/AM technology. In the case of this research, it was to assist with geometric complexity that traditional methods could not achieve in Company A (Cohen, George & Shaw, 2015; and Cozmei and Caloian, 2012), and critical tooling, design portfolio in Company B. Other reasons for adoption may include localised production (Birtchnell and Urry, 2013b; and Petrick and Simpson, 2013) and waste reduction. In both Companies A and B, agility enhancement was made possible due to 3D printing/AM. According to Rylands et al. (2016), there is great potential for 3D printing technology/AM, combined with strong SC and SCM, particularly in manufacturing, to help companies compete in today’s challenging environment. According to Allen (as cited by Rose-Anderssen et al., 2009, p. 241), “[i]t is the communities with the ability to learn that will prevail rather than communities with optimal, but fixed behaviour” (Allen, as cited by Rose-Anderssen et al., 2009, p. 241). The focus of this research was on two case studies that adopted 3D printing/AM in their manufacturing process in North West England for quite different products (wallpaper and filters). Importantly, both Companies A and B demonstrated the ability to learn and

adapt with their adoption of AM, despite the existence of their traditional methods, size and history in business and the region. This introduced additional VSs that co-existed with traditional manufacturing methods and VS, also introducing additional value propositions for the customer. Traditional manufacturing was strengthened and skills increased, with innovative technology introduced without compromising traditional methods. Both companies were provided with the opportunity and ability to further grow their business and capabilities to compete, positively impacting on the local region with the spill over of skill, knowledge and economic benefit.

This research is one of the early field explorations focusing on the adoption of 3D printing/AM and the impact that it has on business manufacturing systems and VSs. By conducting this research, new insight was developed regarding the growth of existing and new VSs due to co-creation engagement. The research also showed that AM can complement traditional VSs rather than needing to replace it. As with other studies, this research has limitations. Due to the number of case studies chosen for this research and their location, generalisability is a limitation. There is an opportunity to expand the number sample of cases and location, as well as further test findings in Figure 5.9. As AM technology continues to evolve, improve and adapt to suit new industries and uses, so too must businesses and their VSs. With such evolution are future opportunities for research.

The next chapter investigates the evolving SC and rate of innovation in a start-up SME, through exploring the products, processes and supply chain design as it progresses through its journey to becoming more mature.

6. Product, manufacturing process and supply chain design innovation

There is general consensus that manufacturing strengthens the economy in which it is carried out...It is also generally agreed that innovation follows manufacturing... (de Treville, Ketokivi and Singhal, 2017, p. 1).

6.1 Introduction

The previous chapter explored the adoption process and impact that an innovation manufacturing, in this case 3D printing, has on manufacturing systems. Cases from North West of England were used as examples of best practice that could benefit others, such as Australian manufacturers. It was discovered that such technology was being adopted not only by high-tech organisations, but also by more traditional SMEs. Traditional manufacturing was being complemented by 3D printing and re-engineered VSs were implemented by the focal manufacturing companies. Customer service and value propositions were improved which positively affected business performance. It was accepted by many organisations and knowledge centres in the region as a way to revive local manufacturing and a potential way forward for other regions and/or countries facing the decline or changes in manufacturing. This leads to the current chapter, where further exploration of manufacturing in Australia, and the possible rejuvenation of organisations through technology and innovative products, as well as supply chain design are investigated.

This chapter focuses on exploring innovative niche manufacturing in Australia. As stated in the opening quote, manufacturing is of great importance, as it impacts on the overall economy (de Treville, Ketokivi and Singhal, 2017; Gray et al., 2017). It can improve economic strength and resilience (Spring et al., 2017), as well as foster innovative technology development and capability (de Treville, Ketokivi and Singhal, 2017; Spring et al., 2017), quality of life/create higher living standards (Gold, 2014; Wu, 1992), and security (Gray et al., 2017), among other benefits. Although the service industry is also important, manufacturing capabilities have been described as being “an indispensable source of competitive advantage” (Soosay et al., 2016, p.9) for businesses that cannot be ignored. Indicators that have shown the impacts of manufacturing and innovation vary, from an increasing number of patents (Autor et al., 2016), to more noticeable improvements in transport, such as in the automotive industry (Wu, 1992), to improved education for the community (Wu, 1992). Spring et al. (2017, p. 7) noted that “manufacturing has higher levels of innovation, productivity growth and export intensity than other sectors, which improves the balance of economic trade and provides economic resilience”.

Ten years ago, manufacturing was the second largest employer of over 1 million people in Australia (Australian Bureau of Statistics, 2017b). In 2015-2016, manufacturing declined to sixth place (ABS, 2017b), and was also overtaken by construction, with regards to sales and service income of \$373 billion versus manufacturing's \$371.5 billion (Australian Bureau of Statistics, 2017b). Although manufacturing has been experiencing change, with the manufacturing landscape transforming in Australia (Anderson, 2017; Baffour et al., 2016), the Australian Bureau of Statistics (2017a) published data showing that 58.3% of the manufacturing sector in 2015-2016 were actively involved in innovation, followed closely by retail and the arts. Manufacturing displayed the highest percentage in innovation activity of any sector. Also of note is that businesses with five to 19 employees and 20 to 199 employees were active in innovation (Australian Bureau of Statistics, 2017a), showing activity rates of 59.7% and 71.5% respectively. Manufacturing and the positive flow-on effects, such as innovation, are important to the economy and economic resilience (Spring et al., 2017). Therefore, it can be said that understanding and preserving manufacturing and innovation in Australia is of high importance.

A common source of innovative capability and economic growth is in start-ups (Universities Australia, 2017; Australian Bureau of Statistics, 2017a). Like SMEs however, they have been facing an array of barriers. Early findings from Chapter 4 indicated that existing SMEs in Australia have encountered issues due to high levels of uncertainty, which in turn constrain innovation capabilities. Learning from best practices in other organisations and getting ones in-house in order could assist in improving business performance, including the state of their SC. To further understand the product innovation process and issues or common pitfalls which can result in high uncertainty before an organisation grows larger, the focus of this chapter has shifted to the Australian start-up space. As noted by MacCarthy et al. (2016, p. 1696), "[u]nderstanding the supply chain life cycle and how supply chains evolve provides new perspectives for contemporary supply chain design and management". A focus on start-up organisations could assist in improving the organisational journey of growth, avoiding barriers and possibly reducing the number of iteration cycles faced when developing new products and/or services. In a recent report on start-ups in Australia (Startup Muster, 2017, p. 1), Government official Laundry proclaimed that "[s]tartups play a critically important role in Australia's innovation ecosystem. They punch well above their weight in terms of contribution they make to growth in jobs, sales and exports compared with other types of firms". Start-ups in Australia between 2004 and 2011 accounted for 1.2 million new jobs and \$164 billion in economic growth (Australian Bureau of Statistics as cited by Australian Government – Department of Industry, Innovation and Science, 2016, p. 27), and provide substantial benefit to the economy. According to Scaringella (2017, p. 3), "further qualitative studies to better understand the complex phenomenon of start-up survival and growth" are required. This research focuses on exploring growth, innovation, product development

and processes in a local, innovative manufacturer in the start-up space. Learnings from this findings chapter will address the fifth research question:

- *Research question 5: How do manufacturing start-up SMEs upscale production of innovative products over time?*

The structure of this chapter is as follows: it begins with a literature review of manufacturing systems, innovation and product development processes, followed by a methodology section, an overview and findings from Company X, including a timeline of significant events, application of product development processes, discussion, future outlook and conclusion.

6.2 Literature review

6.2.1 Manufacturing/manufacturing systems and innovation

“In an industrialised economy, manufacturing industries may be viewed as the backbone of the nation’s economy, because it is mainly through their activities that the real wealth is created” (Wu, 1992, p. 6). Manufacturing and manufacturing systems have been an important part of many economies throughout history. The concept of manufacturing systems, anchored in systems engineering (Parnaby and Towill, 2009a), has been in existence for many years, with reference being made to them even before the Industrial Revolution (Wu, 1992). A manufacturing system can be described as being a “system in which raw materials are processed from one form into another, known as a product, gaining a higher or added value in the process” (Parnaby, 1979, p. 123). Manufacturing systems can differ depending on industrial context (Parnaby, 1979) or functional needs (Suh, Cochran and Lima, 1998) and according to Parnaby (1979, p. 130), they must be “adaptive...in order to survive”. As well as this, manufacturing systems should not be considered in isolation, as a manufacturing system or its outputs may provide inputs for another (Parnaby, 1979; Wu, 1992). Manufacturing system design can impact on various parts of a business, as per Böhme et al.’s (2014) impact table, from productivity and cost, to product improvement and SC configuration to name a few (Böhme et al, 2014; Suh, Cochran and Lima, 1998); thus it is important for organisations to be aware of their processes. Parnaby and Towill (2009b, p. 1053) consolidated business processes involved in the manufacturing system into the four main areas: marketing and sales processes (MSP), which acquires orders for goods and services; product induction processes (PIP), which designs new services and products to meet market needs; product delivery process (PDP), which are for delivering the requisite products and services; and support and control process (SCP), which provide and operate the infrastructure that enables the business to function as

intended. This categorisation allows for the use of a systems approach (Parnaby and Towill, 2009b) to study how a business is performing and create a plan for future growth and improvement.

Examples of each of the key business processes have been provided in Table 6.1, which range from product inception to getting the product to market.

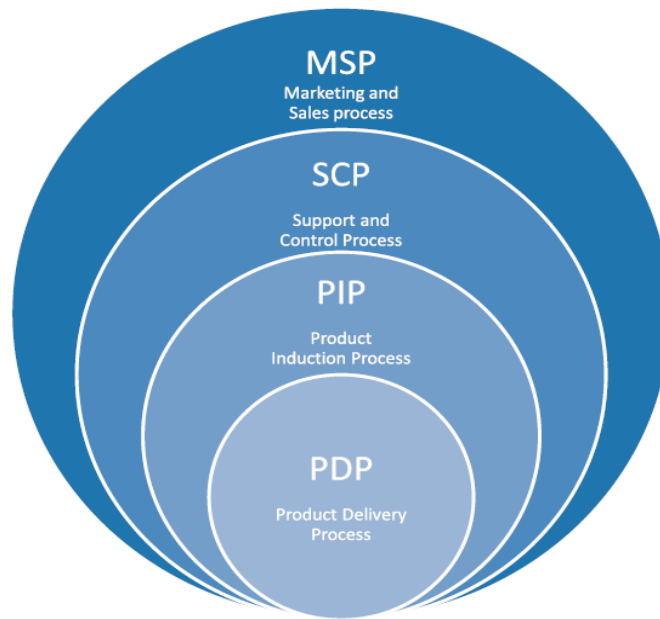
Table 6.1: Key business process examples

| Key business process: | Example: |
|-----------------------------------|--|
| Product delivery process (PDP) | Logistics/transportation, production/manufacturing process |
| Product induction process (PIP) | Brainstorming, R&D, prototypes |
| Support and control process (SCP) | IT systems, databases, document controls, management controls |
| Marketing and sales process (MSP) | Marketing, campaigns, advertising, websites, social media, salesforce |

Source: Author

Each of the four processes was reconfigured by Böhme et al. (2014) into an onion-like figure as shown in Figure 6.1. Figure 6.1 originates from a case study by Böhme et al. (2014) and depicts the best practice adoption of ETO main processes, which has been adapted from Parnaby and Towill (2009b). This figure provides a holistic or systematic view of an organisation, in which all areas not only exist but interact. Using key business processes in Figure 6.1 as part of their investigation, Böhme et al. (2014) were able to assess an organisation, the application of best practices learnt from other organisations and the impact of BPR systematically, using a longitudinal case study methodology. It was discovered that ultimately PDP and uncertainty reduction were linked to innovation and improving innovative capability. According to Böhme et al. (2014, p. 6533) Figure 6.1 could be viewed as “a possible roadmap to enhanced innovation capability”.

Figure 6.1: Relative effect of PDP best practice adoption on ETO main processes



Source : Böhme et al., 2014a, p. 6532

Using Figure 6.1 as a guide, starting at the core of PDP, and moving outwards towards MSP, there may be paths that an organisation can take that are linear and others that require multiple iteration cycles in order to reach set goals. Importantly, to go through each step or phase effectively, organisations generally need to get their in-house processes in line first before embarking on new products or extending integration beyond their organisation (Stevens, 1989; Childerhouse and Towill, 2011a). By doing so, this could reduce the number of iteration cycles and process uncertainty (Böhme et al. 2014) that an organisation would have to go through to get from the core of the “onion” (product delivery and induction processes) to MSP. Improved processes and reduced systems uncertainties may need to be addressed before organisations can become more innovative, so that valuable time spent “fire-fighting” or double-handling can be better invested into efficient management practices, R&D and value-adding processes, as indicated by Böhme et al. (2014) and Rylands et al. (2015).

Being an innovative organisation has been deemed as “essential” (Parnaby and Towill, 2009b, p. 1054). Additionally, PDP or products and services have been described as being “a fundamental operational core competence” (Parnaby, 1995, p. 338) that needs to be constantly reviewed and released to the market in order to remain competitive. The key focus is therefore products, processes, and innovation.

In summary, manufacturing and manufacturing systems are an important part of many economies around the world. Remaining competitive requires innovative products and services, and an understanding of the key business processes, specifically regarding the processes of PDP and PIP. The next section focuses on product development. This is central to the “onion” model, which will be referred to as the PDP model going forward.

6.2.2 Product development, failures and innovation

It is important to understand product development and innovations in organisations, as they provide a means for organisations to compete and of differentiate themselves from others in the market. The product lies at the heart of the organisation and all other business processes (refer to Figure 6.1). Product innovation and development has been described as being the “key to survival and growth of firms” (D’Este, Amara and Olmos-Peñuela, 2016, p. 280). The process can involve radical, incremental (Garcia and Calatone, 2002; Trott, 2017) and really new product innovations (Garcia and Calantone, 2002) to name a few, such as the steam engine or World Wide Web, through to less disruptive products such as a new car model (Garcia and Calantone, 2002). Such products arise to serve existing markets or to create new ones (Sok and O’Cass, 2015). There is much literature regarding successful product innovation and its strategic importance (Parnaby, 1995; John and Snelson, 1990; Cheng, Chang and Li, 2013; Hanaysha and Hilman, 2015) to support the significance of this area in business research. However, product development failures and the reasons for them are also important (Khanna, Gulfer and Nerkar, 2016; Scaringella, 2017; Sheppard and Chowdhury, 2005; Whetten, 1980). As stated by Scaringella (2017, p. 1), who drew on research by Nonaka and Takeu (1995) and Sheppard and Chowdhury (2005), “failures should be studied with the same energy that successes are scrutinized”.

Surprisingly, there is a large discrepancy regarding new product innovation/development failures in both academic and practitioner literature. Many report, or have referenced others who claim, that the failure rate is approximately 80% or above (Crawford, 1977; Crawford, 1987; Miller, 1993; Kocina, 2017), which is high. However, other studies (using empirical evidence), argue that the failure rate is approximately 40% on average (Stevens and Burley, 2013; Crawford, 1987; Castellion and Markham, 2013) across multiple industries (Castellion and Markham, 2013; Stevens and Burley, 2013). It has been identified that this large discrepancy could be due to an array of factors (Castellion and Markham, 2013), such as influential papers and figures, such as Stevens and Burley’s (2003, p.17) universal success curve, which showed that for every three thousand raw ideas, only one would reach commercial success; a difference in definitions of what constitutes product innovation success and failure (Castellion and Markham, 2013); or what Castellion and Markham (2013, p. 976) identified as

being “argumentum ad populum”, the popular belief of the people that causes an assumption that something is true even if it is not.

Even if the success rate of product innovations is approximately 60%, there is still an opportunity for organisations to investigate their business and improve their processes to obtain further efficiencies and a better product success rate. To aid in design and decision making and to increase the probability of a successful product, various studies (Bhuiyan, Thomson and Gerwin, 2006; Hambali et al., 2009; Ellram, Tate and Carter, 2007; Fine, Golany and Naseraldin, 2005) have linked products and processes using concurrent engineering (CE) and the SC using three-dimensional concurrent engineering (3-DCE) to improve. Both CE and 3-DCE allow the researcher to take a systematic approach to business processes (Ellram, Tate and Carter, 2007) and design (Hambali et al., 2009) to explore possible pitfalls as well as measure performance and implement improvement and change initiatives. Hambali et al. (2009, p. 9) even argue that “to produce excellent products, the concept of Concurrent Engineering must be implemented”. CE and 3-DCE are explored further in Section 6.2.3.

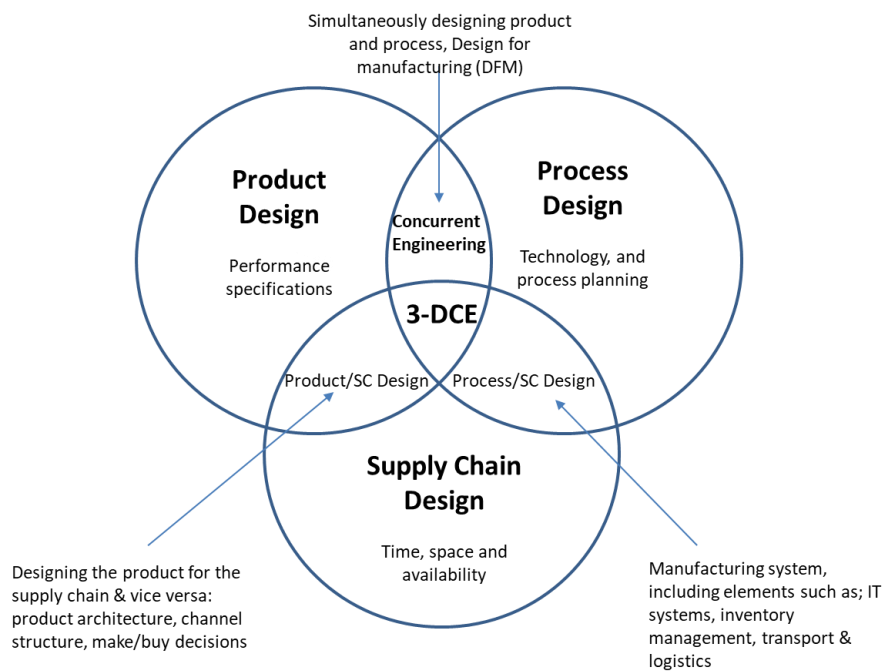
6.2.3 Concurrent engineering and three-dimensional concurrent engineering

CE is a manufacturing philosophy (Singhry, Rhaman and Imm, 2016), also known as simultaneous engineering (Nategh, 2009; Zhang and Zhang, 1995), design for manufacture (DFM) and design for assembly (DFA) (Smith, 1997) among others. It can be defined as “a systematic approach to integrated concurrent design of product and their related processes, including manufacturing and support” (Pullan, Bhasi and Madhu, 2010, p. 425). The concept of CE has been implemented in business longer than its title has existed (Smith, 1997), and although it has been said that it is difficult to “trace the very original source of the idea” (Zhang and Zhang, 1995, p. 222) practices including the fundamentals of CE have been mentioned in literature from the 1950’s onwards (Smith, 1997). The literature has mentioned multiple benefits of CE, such as improving product innovation (Koufteros et al., 2002) and innovative ideas (Li, Zhao and Li, 2017), reducing uncertainty (Koufteros et al., 2002), assisting with competitiveness (Meybodi, 2013) and redesign reduction (Fine, Golany and Naseraldin, 2005), improvements in quality, customer satisfaction (Pullan, Bhasi and Madhu, 2010), lead time and time to market compression (Zidane et al., 2015; Fukuda, 2015; Zhang and Zhang, 1995; Smith, 1997), cost reduction (Zhang and Zhang, 1995) and increased flexibility (Fukuda, 2015). Further benefits of CE are that it does not require the “adoption of a radically new set of ideas” (Smith, 1997, p. 67) and it is not limited by an organisations’ “size, product, or level of technical sophistication” (Thorpe, 1995, p. 10).

Anchored in concurrent engineering (CE) is three-dimensional concurrent engineering (3-DCE). 3-DCE introduces a third dimension to be considered; that of the SC. According to Shidpour, Shakrokhi and Bernard (2013, p. 875), 3-DCE “tries to consider, simultaneously, different aspects of design, process and supply chain in the early stages of product development”. Incorporating this third dimension of SC is important, as highlighted by Fine (2000, p. 213) who declared that “the ultimate core competency of an organization is supply chain design”. The combination of the three elements or core competencies has been linked to increasing competitive advantage (Mombeshora, Dekoninck and Cayzer, 2014), as well as to other benefits such as reducing waste and redesign (Fine, Golany and Naseraldin, 2005), and those associated with CE. Fine (1998) introduced 3-DCE in the 1990s, and although it has since been gaining attention in the literature (Fine, Golany and Naseraldin, 2005), further studies are required (Rungtusanatham and Forza, 2005; Blackhurst, Wu and O’Grady, 2005; Ellram, Tate and Carter, 2007; Shidpour, Sharokhi and Bernard, 2013). Ellram, Tate and Carter (2007, p. 305) describe 3-DCE research as “being in its infancy”. To the author’s knowledge, gaps identified in 3-DCE literature until approximately 2013 have since lessened, although the findings of researchers’, such as Ellram, Tate and Carter (2007), and Rungtusanatham and Forza (2005) are still significant to investigate. Rungtusanatham and Forza (2005, p. 257) argue that understanding 3-DCE is of importance as “very little is known about how to do so to maximise operational, supply chain and firm performance”. Additionally, simultaneously or concurrently producing products and services has also been linked to reducing uncertainty (Koufteros et al., 2002) and providing a systematic lens for observing/studying organisational performance (Ellram, Tate and Carter, 2007), which aligns with this research.

Before applying 3-DCE to a case organisation, as in this research, it is important to note the elements that constitute 3D-CE. Figure 6.2 shows a simplified representation of the major elements for consideration: product, process and supply chain design (adapted from Fine, 1998; Ellram, Tate and Carter, 2007). Each element is important individually; however, when combined, they result in further benefits to organisations (Mombeshora, Dekoninck and Cayzer, 2014; Fine, Golany and Naseraldin, 2005).

Figure 6.2: Elements of 3-DCE



Source: Adapted from Fine, 1998, and Ellram, Tate and Carter, 2007

Each element has been included in Table 6.2, which summarises the CE and 3-DCE literature. It is not an exhaustive list; however, it provides insights into key themes/topics within the literature. A key word search was carried out, limiting the search only by full-text journal articles and key words. Over 80 journal articles were reviewed in total. Many journal articles in particular (including, but not limited to: Fine, Golany and Naseraldin, 2005; Müller, Narasimhan and Gopalswamy, 2016; Zadnik, Starbek and Duhovnik, 2012; Fatchurrohman et al., 2012; Huang, Zhang and Liang, 2005) explored quantitative methods as ways to improve or model the implementation and performance for instance of CE and/or 3-DCE. Overall, the topics varied; Table 6.2 groups them by theme, including models and simulation, SC design (Fine, 2000; Balasubramian, 2001), organisational culture/characteristics (Zhu et al., 2016; De Sousa Mendes and De Toldeo, 2015) and the environment/sustainability (Abbasi and Nilsson, 2016; Ellram, Tate and Carter, 2008; Karaosman, Morales-Alonso and Brun, 2016). The industries that were explored were diverse, with CE and 3-DCE being studied in SMEs in the medical industry in Brazil (De Sousa Mendes and De Toledo, 2015), in the larger automotive industry (Sapuan, Osman and Nukman, 2006), printers and IT in Japan and the United States (Umemoto, Endo and Machado, 2004; Liker et al, 1996), in oil, gas and construction in Norway (Zidane et al., 2015) and in fashion operations (Karaosman, Morales-Alonso and Brun, 2016) in Sweden (Pal and Torstensson, 2011). The literature showed that the lens of CE and 3-DCE can apply to many organisational contexts

(Thorpe, 1995) using qualitative, quantitative and mixed method research. It also highlighted an opportunity to further research start-up companies in the Australian context, as to the best of the authors knowledge at the time of this research, there is a gap in this area of the 3-DCE literature.

Table 6.2: Summary of the literature on 3-DCE concepts

| Key 3D-CE Concept: | Definition: | Key themes/topics: | | | | | | | | Contributing authors: |
|---|---|---|--|--|--|---|---|---|------------------------------|---|
| | | Models/ modelling, simulation, testing: | Frameworks, tools for decision-making, exploration, theory advancement, benchmarking, tutorials: | Barriers, challenges, adoption issues, motivation, uncertainty, and risk analysis: | Product complexity, design, innovation, continuous change, adaptation, safety: | Supply chain: design, supplier selection, network, logistics providers, customer, procurement, cross-industry, extended SCs, manufacturing system, value streams: | Strategy and manufacturing philosophies (lean and agile): | Organisational culture, teams/teamwork, characteristics, capabilities and change: | Environment, sustainability: | |
| Concurrent engineering (CE): Product-process design | "CE dictates that product and process decisions are made in parallel as much as possible and that production considerations be incorporated into the early stages of product design" (Fine, Golany and Naseraldin, 2005, p. 390). | X | X | X | X | X | X | X | X | Wu and O'Grady (1999), Li, Zhao and Li (2017), Zadnick, Starkbek and Duhovnik (2012), Bogus et al. (2011), Pullan, Bhasi and Madhu (2010), Wu et al. (2010), Müller, Narasimhan and Gopalswamy (2016), Gopalswamy (2016), Fatchurrohman et al. (2012), Aleisha, Suresh and Lin (2011), uz Zaman et al. (2017), Ganapathy and Goh (1997), Koufteros et al. (2002), Zidane et al. (2015), Tseng and El-Ganzoury (2012), Fine (1998), Zhu et al. (2016), Maulana et al. (2017), Arnette and Brewer (2017), Meybodi (2013), Harding and Popplewell (1996), De Sousa Mendes and De Toledo (2015), Aleisa, Suresh and Lin (2011), Nategh (2009) Swink (1998), Balasubramian (2001), Youssef (1994), Bhuiyan, Thomson and Gerwin (2006), Umamoto, Endo and Machado (2004), Liker et al (1996), Sapuan, Osman and Nakman (2006), Hambali et al. (2009). |
| Product design | "A product is a structure of interconnected components and subsystems" (Masmoudi et al., 2017, p. 175). Product design is when "designers improve, adapt or upgrade a product by changing some of its components and/or functions" (Masmoudi et al., 2017, p. 175). | X | | X | X | | X | X | | Masmoudi et al. (2017), Eisenhardt and Tabrizi (1995), Brown and Eisenhardt (1995), Brown and Eisenhardt (1997), Eisenhardt and Martin (2000), Koufteros et al. (2002). |
| Process design | Process design includes the steps, decisions and methods involved in creating a product and/or service from raw materials to the finished product. | | X | | | | X | | | Anantasarn, Suriyapraphadilok, and Babi (2017), Safizadeh et al. (1996) |
| SC-process design | Aligning SC design (from raw materials to finished product) and processes, with the potential to optimise operations. | | | | X | X | X | | | Simatupang and Sridharan (2008), Hammami, Frein and Bahli (2017), Pan and Nagi (2010), Christopher and Towill (2001), Christopher and Towill (2002). |
| Supply chain design | Supply chain design incorporates many elements such as raw materials, | X | X | X | X | X | X | | | Potter, Towill and Christopher (2015), Towill et al. (2015), Christopher et al. (2009), Pan and Nagi (2010), Inman and |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|--|
| | insourcing/outsourcing, supplier location, relationships, logistics, facility function/location (e.g. consolidation), product complexity (Inman and Blumenfeld, 2014), operations, and customers, among others. | | | | | | | | | Blumenfeld (2014), Payne and Peters (2004), Choi and Hong (2002), Mason et al. (2002), Parker and Anderson (2002), Gosling et al. (2015), Christopher and Towill (2001), Christopher and Towill (2002). |
| SC-product design | Aligning SC design (from raw materials to finished product) with product design/ design the product to suit the SC and vice versa. | | X | | X | X | | | | Gan and Grunow (2016), Singhry, Rahman and Imm (2016), Simatupang and Sridharan (2008), Hammami, Frein and Bahli (2017). |
| Three-dimensional concurrent engineering (3-DCE): SC-product-process design | "This approach considers supply chain design together with traditional concurrent engineering. 3D-CE tries to consider simultaneously, different aspects of design, process and supply chain in the early stages of new product development" (Shidpour, Shahrokhi and Bernard, 2013, p. 875). | X | X | X | X | X | X | X | X | Fine, Golany and Naseraldin (2005), Shidpour, Shahrokhi and Bernard (2013), Blackhurst, Wu and O'Grady (2005), Ellram, Tate and Carter (2007), Fixon (2005), Forza, Salvador and Rungtusanatham (2005), Rungtusanatham and Forza (2005), Marsillac and Roh (2014), Singhal and Singhal (2002), Abbasi and Nilsson (2016), Huang, Zhang and Liang (2005), Fine (2000), Boardman and Clegg (2001), Fine (1998), Petersen, Handfield and Ragatz (2005), Ellram and Stanley (2008), Ellram, Tate and Carter (2008), Mombeshora, Dekoninck and Cayzer (2014), Pal and Torstensson, (2011); Karaosman, Morales-Alonso and Brun (2016). |
| Beyond 3-DCE | Beyond 3D-CE includes additional dimensions to that of product, process, and supply chain design. | | | | | X | | | | Pal and Torstensson (2011), Fukuda (2015), Schonberger and Brown (2017) |

Source: Author

Overall, the literature shows that research opportunities are available in the area of 3-DCE, specifically for start-ups. To the author's knowledge, research regarding this topic has not been conducted in Australia. Understanding the application of 3-DCE further in this area could assist start-ups to progress through the stages/phases of organisational growth faster and potentially with greater success (as will be explored in Section 6.4). As with the practice of 3-DCE, the findings may not be limited by organisational size (Thorpe, 1995) and could also be applied to larger organisations wanting to expand into new areas and/or to improve their competitiveness or capabilities. Using 3-DCE in the early stages of business growth could therefore be an opportunity to further boost the areas of innovation and manufacturing in Australia.

In summary, the topics of innovative manufacturing systems, product innovation and 3D-CE are important areas to consider, particularly for start-ups in the competitive Australian context. Whilst product innovation is significant (D'Este, Amara and Olmos-Peñuela, 2016), taking a holistic approach beyond the product alone allows the focus on innovation to broaden to other processes in the manufacturing system. In particular, the literature presents opportunities for further exploration of 3-DCE in the Australian start-up space, as well as the adaptation of the PDP model in Figure 6.1, to benchmark or plan future growth, to answer research question 5 – How do manufacturing start-up SMEs upscale the production of innovative products overtime?

To add to knowledge in this area, case study research was performed with an Australian start-up company, Company X.

6.3 Methodology

This chapter aims to explore innovative manufacturing in the start-up space in Australia, to gain a further understanding of product innovation development and start-up growth. This section, in addition to the broader methodology in Chapter 3, describes more specifically the methods of data collection with regards to Company X. A single in-depth case study was used to investigate a "how" question:

- Research question 5: *How do manufacturing start-up SMEs upscale the production of innovative products over time?*

As highlighted by Yin (2014) such questions as "how" or "why" are appropriate for case study research such as this.

At the time of this research, Company X was in the early stages of growth and was discovered to be continuously adapting their supply chain, processes and product to meet market needs. Due to this, this research explores the journey of Company X through the application of Figure 6.1, the PDP model, and the concept of three-dimensional concurrent engineering (3-DCE) (Fine, 1998). As with research by other scholars (Parente and Geleilate, 2016) the focus is on a single organisation or firm level rather than an entire industry.

6.3.1 Case selection

This research used a single in-depth longitudinal case study to explore Company X, an Australian start-up organisation that manufactures 3D printers. Company X was selected due to their size, industry and location, as well as its employees' and leaders' ability to assist with research objectives, rather than randomness (Yin, 1994). Company X needed to be agile and continue to differentiate themselves in a market that is continuing to grow in popularity and accessibility (Beauman et al., 2014); thus the timing and importance of this research were significant not only to the researcher, but also to Company X.

As with Fine (1998) and his "industrial fruit flies" such as IBM and Intel, Company X (due to its size and agility) was more suitable for this research than larger organisations commonly characterised as being more bureaucratic, complex (Davis, 1993) and slower to change. Company X is small in size and located in a region where there are three larger organisations – including a hospital, university and steel manufacturer – that dominate. Due to changes in the economic environment however (particularly for the steel manufacturer), start-ups and SMEs have become even more important to preserve and encourage in order to possibly rejuvenate the region, as demonstrated by knowledge centres and innovation hubs. Interest in the importance of start-ups and impact of entrepreneurship was evident in literature for multiple countries and regions, such as those in Spain, USA, and The Netherlands (Albert, 2017; Koster, van Stel and Folkeringa, 2012; Gries and Naude, 2009; Friar and Meyer, 2003), reinforcing the importance of exploring this area in Australia also. Company X allowed this research access to study their entire supply chain. This included the constant and swift changes that were initiated (often daily) and the element of technological innovation that demanded that Company X not remain complacent about their products, services or customer needs. As summarised by Fine (1998, p.11), "No capability is unassailable, no lead is uncatchable, no kingdom is unbreachable". 3D printers are gaining increasing attention, and they are becoming accessible at an increasing rate due to factors such as the expiration of patents and falling prices (Beaman, Bourell and Wallace, 2014; Presswire, 2014; Balletti, Ballarin and Guerra, 2017). 3D printers have even begun appearing in local supermarkets in Australia. Company X recognised that it may not be enough to have the most elite hardware in a market that is becoming increasingly competitive.

The use of a single in-depth longitudinal case study was appropriate for this research due to it being exploratory, with a goal of gaining an in-depth understanding rather than a broad view or study of relationships between a series of cases. Limitations include generalisability, as only one case study is used (Voss, Tsikriktsis and Frolich, 2000; Steinberg, 2015), however, a strength of this research is that the single case of Company X allowed an in-depth exploration (Voss, Tsikriktsis and Frolich, 2000) to further understand the process of product innovation and growth within a start-up organisation. According to Mariotto, Zani and de Moraes (2014), single case studies may even lead to producing more complex theories due to focusing on one case and theory application rather than many. Moreover, this single case study allowed for the verification and extension of the PDP model (Böhme et al., 2014a), which presents future research opportunities for further testing in other case studies and the potential of improved generalisability. The findings combined with what was learnt from the UK SME case studies in Chapter 5 could provide guidance to both practitioners and academia in future studies, as well as provide assistance to start-ups during their growth phase; they could potentially provide assistance to larger more mature organisations exploring new business endeavours or expansion.

6.3.2 Research design and data collection

According to Yin (2014, p. 16), case studies allow for the in-depth investigation of a “contemporary phenomenon...within its real-world context”. Case studies are said to not only support the development and explication of theory, but also support the aims of those performing the research (Voss, Tsikriktsis and Frolich, 2000). Researchers are able to immerse themselves in the case and explore the reasons for/causality of certain phenomena and the environment for example, rather than just the results (McCutcheon and Meredith, 1993; Benbasat, Goldstein and Mead, 1987).

Before conducting research on the selected case organisation, a research protocol was developed (Yin, 2016), guided by the findings in Chapters 4 and 5. This included interview questions based on QSAM (Appendix B), which provided guidance for the research, as well as the phases of the PDP model which structured the data collection. Ethics approval for data collection was also sought and granted, with the intention of studying the evolution of the SC and journey of Company X from 2013 to 2017. Engagement with the case organisation, Company X, began in September 2016 and research was conducted over a period of approximately 16 months. Data collection took place in the form of semi-structured interviews, observations and archival data collection, both on and off-site, increasing rigour due to the triangulation of data (Böhme et al., 2012), as shown in Figure 6.3.

Figure 6.3: Data collection summary

| Year: | 2016 | 2017 to early 2018 | | | | | | |
|---------------------------------|---|--|---|--|--|---|--|--|
| Topic: | Business Overview / Scoping exercises | Exploration phases | | | | Other - Next steps and clarification | | |
| | | PDP | PIP | SCP | MSP | | | |
| Timeframe: | Approximately 2 months | Approximately 11 months | | | | Approximately 3 months | | |
| Data Collection method/sources: | <ul style="list-style-type: none"> * Scoping interviews with senior staff (off-site and on-site) * SC mapping | <ul style="list-style-type: none"> * Document collection (e.g. archival order and demand planning data, order management process, customer feedback/experiences data) | <ul style="list-style-type: none"> * Interviews with senior staff and operational team * Observations (process and layout mapping of outsourced assembly facility) * SC mapping * Email correspondence /archival data/quantitative operational data | <ul style="list-style-type: none"> * Interview * Observations (Head Office) (e.g. new printed products, accessories and marketing aids) * Document collection | <ul style="list-style-type: none"> * Data - recording received via email focusing on product and SC development (a review of the business overview with additional information) | <ul style="list-style-type: none"> * Interview (including updates on new products and services) * Observations (Head Office - e.g. new raw materials and product designs) | <ul style="list-style-type: none"> * Email correspondence - questions regarding the journey and clarification * Phone correspondence - clarification | <ul style="list-style-type: none"> * Verification of findings |

Source: Author

Figure 6.3 shows a summary of the data collection process that occurred during the exploration of Company X. Data collection took place in stages, as shown by year and topics covered. This included an initial scoping phase to get an understanding of the business, which took place over approximately two months in late 2016. Key senior staff were engaged during this period. It must be noted, however, that due to the size of Company X, there were only three key senior staff at the time and one of them had been travelling internationally for business, so their availability was limited. This was followed by an exploration stage in 2017, which was broken down into phases (following the PDP model for guidance). During this stage, the data collection was the most intense, especially during the first three months, with multiple interviews, observations, site visits, and data collection taking place. New employees, such as an Operational Manager and junior staff were employed and the team continued to grow throughout the data collection period. Individual interviews and group meetings took place in order to keep the researcher up to date with changes across the business. Following this was the final stage including next steps or new developments, clarification and verification during late 2017 to early 2018. Contact with Company X occurred at regular intervals throughout the data collection process, for example by with email in between interviews, to keep up to date with the business. This caused less distraction, particularly for minor questions, than further interviews or meetings. Company X is small (beginning with three Founders and growing to fewer than 10 people in total), so this was taken into consideration when organising interviews.

Data sources varied. Observations of operations were conducted in Company X's head office and in the facility of the outsourced assembler (Company G, a local non-profit organisation), with the supervision of Company X's Operations Manager. This allowed for the researcher to produce flow charts and map VSS for the 3D printers and services that Company X offers. The overall SC for Company X was also mapped following interviews (Appendix H). Over 10 interviews were conducted in total, ranging from approximately one to one-and-a-half hours each, with research targeting all employees of Company X as potential interviewees. This was facilitated by Company X's size and the researcher's access to the different departments, as it would help the researcher to gain an understanding of the organisation as a whole. Also of interest was Company X's outsourced assemblers at Company G, in particular the foreman, who was the most experienced, and whom the Operations Manager described as critical to all stages of assembly and testing. Semi-structured interviews were conducted both individually and in groups on-site, as well as by phone to individuals, to capture further data and verify findings. Multiple channels of communication were used including email, which Company X used to provide answers to outstanding questions, verify information and provide recorded data. Data collected ranged from archival data on Company X's demand planning and orders

for example, to operational procedures and customer feedback regarding Company X's products and customer experiences

Analysis of the data occurred during and post data collection. Data analysis can take multiple forms and consists of "examining, sorting, categorizing, evaluating, comparing, synthesizing" (Neuman, 2011, p. 517) "tabulating, testing" (Yin, 2014, p. 133) and questioning data to make sense of findings. Yin (2014, p. 133) encourages researchers to "play" with their data to identify patterns and concepts that may or may not have appeared obvious when data collection began. In the case of this research, it followed one of Yin's (2014) four general strategies of theoretical propositions, which Saunders, Lewis and Thornhill (2012) state can provide a connection to the literature and direction for the research. Using an abductive approach, as described in Section 3.2, a framework was developed following the literature review, which guided the data collection and analysis (as shown in Figure 6.3). Interviews were transcribed and additional researcher notes (including observations) were recorded within 24 hours of the data collection taking place during the research process, following the "24 hour" rule (Eisenhardt, 1988, p. 741). Findings were then used to produce an initial representation of the journey of Company X (as shown in Appendix H), with data analysed using the PDP model and 3-DCE lens from the literature review.

6.4 Findings

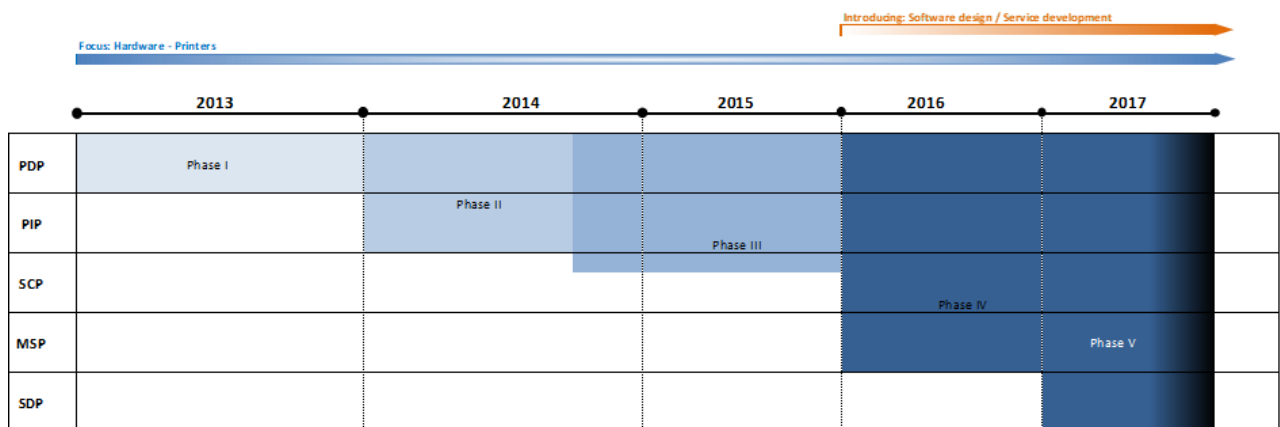
6.4.1 Overview of Company X

Company X is an innovative Australian start-up company. The organisation was established in 2013 by three founders, each specialising in different disciplinary backgrounds: a mechanical/industrial engineer with industry experience in various companies, government/Defence and university; a SC and operations professional with industry experience; and a mechatronic engineer working in academia with an expertise in 3D printing. Since its founding, Company X has continued to grow: seeking new team members, designing new product offerings and more recently extending into services surrounding 3D printing. Company X now includes operations, sales and marketing, product development and software design, and employs eight employees (Chief Executive Officer, Chief Financial Officer, Chief Technology Officer, Operations Manager, Sales and Marketing Managers, Product developer and Software Developer). This section explores the product development and innovation within Company X from its establishment in 2013 to the end of 2017 to answer the fifth research question:

- *Research question 5: How do manufacturing start-up SMEs upscale the production of innovative products over time?*

The detailed journey of Company X has been captured in Appendix H, including key milestones such as the number of printers sold, team growth, investor funding, and the development of new designs. The timeline has been configured using a modified swim-lane approach. Swim lane models are activity diagrams (Hause, 2006) depicting organisational activities via lines drawn across the various sections (Dumas, van der Aalst and Hofstede, 2005). Typically, they would show “the name of the organizational unit that is responsible for the execution of actions” (Dumas, van der Aalst and Hofstede, 2005) in each section. In this case, instead of assigning certain processes, tasks or activities to organisational units or individuals, each step has been categorised using the key elements of business processes, as shown in Figure 6.4. This is to show the growth throughout the stages of the PDP model (Figure 6.1) over a five-year period for Company X, rather than a model of who is responsible for certain tasks or processes. By tracking the growth phases of Company X in such a manner, the intention is for the extension and verification of Böhme et al.’s (2014) PDP model. By bringing together the two concepts of the PDP model and CE/3-DCE, the pathway of growth is enriched.

Figure 6.4: Summary of phases in Company X’s timeline



Source: Author

The timeline (Appendix H) has been further summarised in Figure 6.4 to more clearly show the phases of growth for Company X. Further detail surrounding each activity has been captured in Table 6.3 and text in the following sections. The journey displayed elements of both the PDP best practice model and CE/3D-CE as Company X developed; therefore, the phases have been combined to investigate the start-up’s growth and product innovation/development. The findings from Company

X's journey have been divided into five phases: phase I: PDP, phase II: PIP and CE, phase III: 3-DCE, phase IV: design and market exploration (SCP and MSP), and phase V: service delivery process (SDP) and 4-DCE.

Table 6.3: Summary table – Activities in Company X's journey

| Phase: | Year: | Activity: |
|--|--------------|--|
| Phase I: Product Delivery Process (PDP) | 2013 | <ol style="list-style-type: none"> 1. Company X is founded and ideas are developed 2. 3D printer parts are developed, beginning with off the shelf components for prototype development 3. Off the shelf parts are then refined 4. Redesigned parts are 3D printed 5. Parts are laser-cut and hand-made 6. Prototype is developed 7. * Some controls are in place |
| Phase II: Product Induction Process (PIP) & CE | 2014 | <ol style="list-style-type: none"> 8. "Minimum viable product" FDM 3D printer available using off the shelf parts (mainly from Australian suppliers) 9. Third party shipping is used to ship the product to the customer 10. *Some marketing takes place |
| Phase III: 3-DCE | 2014-2015 | <ol style="list-style-type: none"> 11. New suppliers are engaged as not all parts were available in Australia as well as there being quality and time issues with Australian suppliers (Company X began sourcing from overseas) 12. Production needs increased and assembly was outsourced to a local company (assemble to order) |
| Phase IV: Support and Control Process (SCP), and Marketing and Sales Process (MSP) – Design and Market Exploration | 2015-2016 | <ol style="list-style-type: none"> 13. New team members hired (interns, consultant, Operations Manager, Marketing Manager, Product Developer) 14. More controls are put into place and captured in procedures (e.g. processes for outsourced assembly, order management, request-tickets and trouble tree support) 15. Product quality and testing: investigating batch tracking, inspections and quality control 16. Investigating improved shipping agreements and providers 17. New projects (spread across the team): developing website/ online tool for designing "makerspaces", pre-commercialisation of new bio printer, investigation of European hub for overseas markets, designing new flat pack printers for educational facilities (with a potential new market overseas), designing curriculum for schools (introduction/integration of 3D printing in subjects, and software development for printers to avoid current constraints for customers) 18. Part revision and sourcing of new parts/suppliers (e.g. for a critical part, the extruder and wire connectors) 19. Streamlining assembly process and plant layout of outsourced assemblers 20. Developing tool for improved printer assembly 21. Part revision (e.g. wire connectors) 22. Exploring and promoting new business models (e.g. subscriptions) 23. Revising supplier agreements (e.g. for quality) 24. Expansion of digital marketing campaign, implementation and management. Additional marketing introduced (in addition to social media and face-to-face), including school project competitions for students 25. Expansion of online content (due to Company X and their customers collaborating) 26. Development of 3D printer software for schools 27. New material for 3D printers is introduced – "silk" |
| Phase V: Service Delivery Process and Four-Dimensional Concurrent Engineering (4-DCE) | 2016-2017 | <ol style="list-style-type: none"> 28. New team members hired (Sales Manager and Software Developer) 29. Online tool development (e.g. for creating "makerspaces") 30. Solutions and packages developed for customers (with the focus expanding to include more services) 31. Preparation for the introduction of the next generation 3D printer (for release early 2018) 32. Introduction of more support in the product |

Source: Author

Whilst each stage of the journey has been separated clearly into different phases, as simplified in Figure 6.4, the phases were not independent of each other. Each phase shares elements of previous stages and showed growth as Company X developed (Appendix H). There may be outliers in each stage such as marketing and less formalised or ad-hoc controls; however, the majority of activities by year fit inside each of the different shaded areas in Figure 6.4. The journey has been highlighted as such to show these stages of growth and product development, which will be explored in further detail in the following sections.

6.4.1.1 **Phase I: Product delivery process**

Company X began manufacturing fused deposition modelling (FDM) 3D printers at home. According to the CEO, in the beginning *“we wanted to produce the greatest thing [3D printer] ever created”* and worked on developing ideas for approximately one year. The CEO developed a design, which the CFO noted *“it could do 95% of what \$5,000 printers could do, but for a fraction of the price”*. The founders began using parts for production that were readily available that they could purchase off the shelf, such as eccentric spacer assembly and belts. Almost all of the parts were sourced from suppliers in New South Wales, Australia and the designs were based on the available components. Next, the parts were refined. Parts that Company X redesigned were then 3D printed (for prototype parts), laser cut and handmade. In some cases, the laser-cut parts were superglued together to create a new design, and in others, parts were purchased that required alteration by hand. To give an example of the cumbersome process, the CFO discussed the belt process. According to the CFO, in the beginning the CEO had an idea to create a minimalist axis driver for the 3D printer using a pulley system instead of threaded rods (that were more expensive and being used by other companies). Although Company X were able to 3D print successfully with their wire pulley system, the CFO stated that *“we very quickly realised that there was an art to getting adhesion between the fishing wire and the drivers”* and that they needed to move to a belt and pulley system. The belts that were available however were 6mm wide, and so the founders had to use a blade to hand-cut them to 5mm for their original design. This was soon acknowledged as not being viable and so new parts were sourced. 3D printing was also considered by the founders for production in the beginning of their journey. After exploring examples of this and failure rates in other companies however, the founders decided that 3D printing would not be viable for manufacturing, with the CFO exclaiming that *“it’s (3D printing) for mass customisation, not mass production”*.

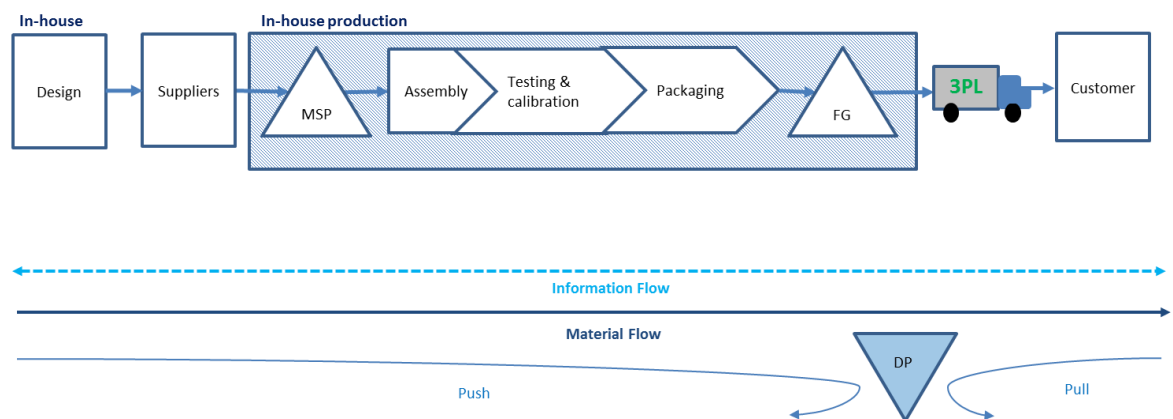
After performing further market research and revising their designs, Company X decided to produce an open-design printer that was described by the CEO as being *“small and accessible”*. Company X produced a prototype within two months and then decided to approach a local school to be their

audience for their product. During this phase, developing a product idea and modes of getting it to market were key. This phase was the foundation for Company X's journey and the following layers of the PDP model.

6.4.1.2 Phase II: Product induction process and CE

Following the prototype development, Company X produced a Fused Deposition Modelling (FDM) printer that they called the "minimum viable product" (MVP). According to the CFO, "the MVP was basically assembled by hand and didn't really need a lot of tooling". Unlike other printers, the open-design did not have an ABS microwave design, which allowed users to observe the inner-workings of the 3D printer without getting hurt. Due to the open design, the users could gain an understanding of the process, plastics, coding and geometry for example. The 3D printers were produced using mainly off-the-shelf Australian parts at the founders' homes. The first stage of the 3D printer VS has been captured in Figure 6.5, which summarises the early years of Company X (2013-2014) during Phases I and II of their journey.

Figure 6.5: Company X's 3D printer value stream in the early stages of the journey



Source: Author

Figure 6.5 depicts a simplified VS for Company X's 3D printer production. Once the original FDM printer design was confirmed, a combination of various parts and packaging materials were procured. The materials, which were sourced mainly from Australia, were originally off-the shelf, then modified. These materials were shipped to the founder's homes where an in-house assembly/production process took place. Printers were assembled-to-order (ATO) and packaged on-site. The finished goods were then shipped from the founder's homes to the customers using a third-

party logistics provider. During this phase, the parts that were available for assembly influenced the design of the printer, which the founders would modify depending on the available parts.

In regards to their customers, Company X identified a niche target market early in their journey. Company X decided to focus on the Australian education market, and to actively target the use of 3D printing in schools. The founders focused on design and process, not just the hardware itself, and consciously developed the open-design printer for this market. The open-design allowed for teachers and students to see how the 3D printers worked. The 3D printers were designed to not be easily damaged if the students wanted to touch them, nor dangerous for the user. Company X's CFO described the education target market as being important noting that *"in five years, the kids will leave school and change our global supply chains"*. As well as this, the educational focus provided differentiation in the market, which is valuable as 3D printing becomes more widely accepted and accessible (Kerns, 2018; Balletti, Ballarin and Guerra, 2017). According to the CFO, the use of the printers in schools *"allows you to delve deeper into design and constructs"*, helping students to improve their understanding of subjects such as engineering and maths. It allowed students to produce more than just a bust or toy, and to discover the coding and background to creating the final 3D printed products. Others have also begun to discover the importance of using this technology to educate and create interest in subjects. In one example, this has been done through the use of different materials such as Vegemite (an Australian food spread) used in 3D printing, to create edible circuit boards for teaching children about science (Hamilton, Alici and in het Panhuis, 2018).

In addition to producing the 3D printers, marketing for Company X in the early stages was mainly through social media and face-to-face. Company X would conduct demonstrations at schools and various events, and post about their product on social media platforms. The marketing and controls during this phase were evident, however they were not prominent until later (during phase IV) in the journey. The focus for Company X during phase II was on the product and processes, or CE, where available parts and processes influenced the 3D printer design, as well as the 3d printer design influencing the assembly process.

6.4.1.3 **Phase III: 3D-CE**

The foundation of CE in Phase II set the stage for the next phase. This began with a reiteration of the production/assembly process and parts. Company X originally sourced local parts for production; however, due to poor DIFOTIS and supplier performance (including receiving faulty parts) and the fact that certain techniques (such as anodising parts) were not available in Australia, they eventually had

to source some parts from overseas suppliers. According to the CFO regarding Australian suppliers, *“it took 10 months to get samples done, and then when we finally sorted that, the manufacturer just wasn’t interested in our volumes...If it’s not mining then they are not interested”*. Due to this, the CEO stated that *“So at that point we made a couple of critical design choices”*. Certain parts were only available overseas. According to the CFO *“so once we were doing these parts overseas, we started to get a bit more creative with what else we could do...but it threw up its own challenges in that we didn’t want to put all of our eggs in one basket...And so we literally broke down the design to capabilities”*. The CFO also shared that as well as being concerned about process and capability, *“we broke down our design as much as possible because we wanted to protect ourselves from mimicry”*. Company X was taking into consideration the product design and processes in regards to the capability of the SC during this phase.

As Company X continued to expand as demand increased during 2015, the assembly process also required revision. Whilst the initial in-house assembly process could keep up with market demand at the time, the CEO stated that *“the process was fiddly and inconsistent”*. Due to this, *“every unit ended up being slightly different”* (CFO). Company X was quickly outgrowing their production space (which began in garages at founders’ homes) and needed to find a solution in order to gain product consistency and a process that could prepare them for growing market demand. The process was therefore reviewed and the assembly was outsourced to a local organisation. Outsourcing allowed Company X to focus on their core competency of design and value-adding through R&D. It assisted Company X in creating value-add through the supply chain by being close to the product. Company X noted that the product was still under development and so being able to bring the units back to base to upgrade or repair them was important. Company X also noted that their longer-term vision was to keep value-add in Australia, and to support the product, market and customer. As well as benefiting the organisation, engaging the outsourced assembler (Company G) also allowed Company X to contribute to the local economy in generating employment opportunities.

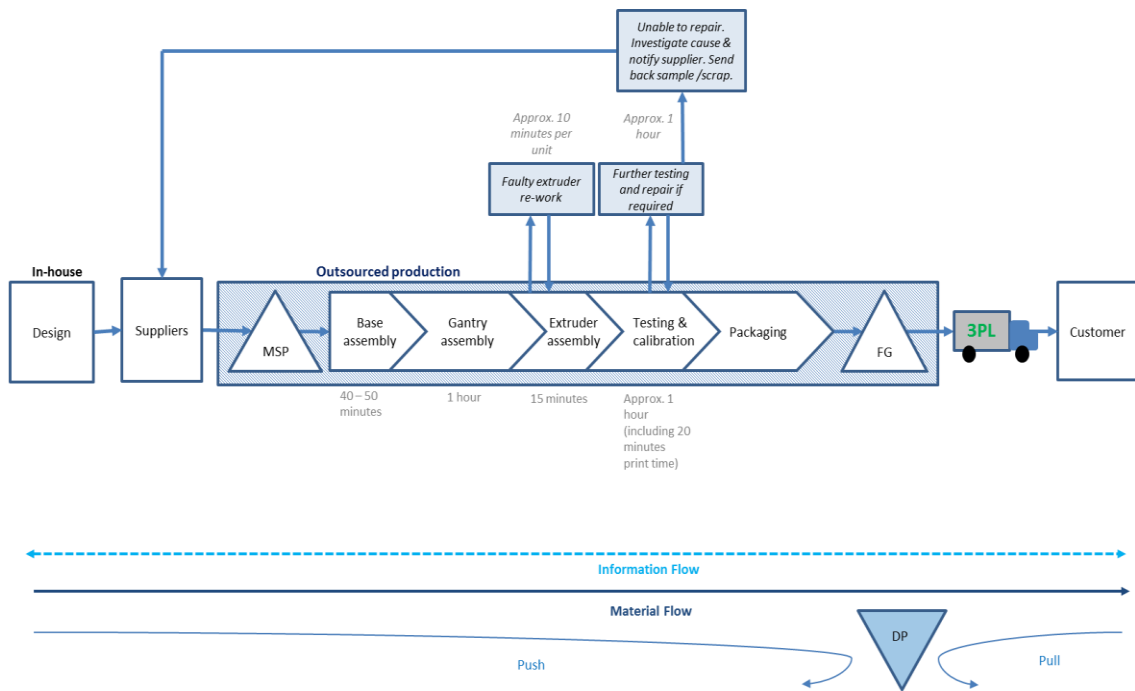
The assemblers were a local ISO-accredited organisation that was in close proximity to Company X’s headquarters. Company G assisted the community not only by creating employment opportunities, but by offering employment to workers with disabilities. Company X acknowledged the capability of the assemblers and incorporated this into the product design and procurement of parts. Company X would *“design for complexity for IP, not for putting it (the 3D printer) together”* (CFO). For example, when starting with Company G, Company X acknowledged that they could not keep using acrylic bodies/chassis. As the aluminium chassis that were available in Australia at the time were not

suitable, Company X needed to go to an overseas supplier. Company X would also select or design parts based on assembly complexity, so that workers with disabilities could assemble the 3D printers.

During the exploration of phase III and the product, process and SC reiterations that were evident, it became apparent that using the lens of 3-DCE (Fine, 1998) during this phase was applicable. From the team members with mixed backgrounds and experience (such as engineering, supply chain and operations) openly working together day-to-day to the continuous changes and improvements occurring, 3-DCE was evident. With each interview that was conducted and meeting that was held, from product design, to the manufacturing process and supply chain design, it was clear that each dimension would change often to assist another part of the business. Company X was aware of their environment and the need to constantly change and adapt. For example, certain parts of the printer such as the gantry were designed with not only the end-user in mind, but also what the supplier could produce most effectively as well as what was most suited to the assembly process of Company G. Throughout this phase, Company X not only considered price, but also the capability of their supply chain to deliver the end product to the customer. Process changes, procedure implementation, new recruitments, tool implementation, part and process modifications and production layout changes are just a few of many adjustments that Company X made; they have been captured in Appendix H.

Following on-site observations and data collection, Company X's updated 3D printer VS was captured, as shown in Figure 6.6. This was done so to understand the changes occurring during Phase III, such as processes related to Company X producing their product off-site and possible bottlenecks that impacted on production efficiency.

Figure 6.6: Stage II: Company X's 3D printer value stream



Source: Author

Figure 6.6 demonstrates the second stage of the 3D printer VS for Company X, including outsourced production. As with stage I in Figure 6.5, the VS begins with the product (3D printer) being designed by Company X. Company X then sources the necessary parts and packaging suppliers from Australia and abroad, which are sent directly to Company G for storage and production. This includes multiple parts, from anodised bases and gantries, to nuts, bolts and packaging received from multiple suppliers. Details are then sent to Company G for assembly. Once the stock is received, it is then picked by operators or foremen and taken to the first station, where the bases are assembled and prepared for the next station. Following this, the gantry is then assembled and attached. This step was described by Company X as requiring experience and precision as there is important belt tensioning and wheel spacing that takes place. The foreman is particularly valuable at this stage due to having the experience and confidence in tensioning, as it is a skill that the operators cannot learn just by reading instructions. According to the Operations Manager this step *“requires feel”*. The foreman also added that *“it’s hard to put in writing how to put the belt on. It takes experience to know how to tension the belts and there are more than one”*. Also, with regards to attaching the gantry, the Foreman included that *“it’s not very technical, but it is particular”*. Once the gantry is applied, the next step is to assemble the extruder. This step was noted to be particularly important by the Operations Manager at the time of interviews due to the

gantries being prone to faults. The fault was not due to the assembly process, but manufacture and/or shipping (where the product could be damaged during transport due to its fragility). An additional step was incorporated into their VS to check faulty extruders and re-work them as required by the Foreman. Once complete, the 3D Printer was then sent through to the next stage of testing and calibration. Batches of 10 - 25 units a week were being produced at the time of this research and each were tested and calibrated by the Foreman before being packaged. This included printing test items on each printer, which would take approximately 20 minutes. If there were faults present, further testing by the CTO would take place. If the issues could be rectified, the 3D printer would then be packaged ready for delivery to the customer. 3D printers that passed initial testing and calibration would also be packaged and put into the finished goods area. The box would be left open until the customer confirmed their order, so that the accompanying filament and accessories could be included with the 3D printer (postponing order customisation).

Overall, it was evident especially during Phase III that Company X was constantly reviewing their product, processes and supply chain (3-DCE) to optimise their performance. In reflection of the processes, the CFO commented that *“Some design choices we made all hang together in terms of the actual assembly or production of the 3D printer, the support of the printer and then the supply chain of the printer”*.

6.4.1.4 **Phase IV: Marketing and sales processes and supply and control processes – product and service VSs**

Phase IV, continued to build upon the 3D-CE evident in the previous phase and was a time of much growth for Company X. This included the team expanding, process documentation and a greater focus on sales, marketing and controls (MSP and SCP). It also showed Company X progressing through to the outer layers of the PDP model (Böhme et al., 2014).

Company X had established a design, product and processes at this stage. Over 200 3D printers had been sold early in 2016. Demand however was increasing and Company X identified the need to evolve in order to progress. In order to increase the support and control process during Phase IV, team growth was important. This included bringing on new interns who were then promoted, consultants and new hires. The company employed an Operations Manager assisted with overseeing the production process (from stock acceptance to having finished product ready to ship to the customer). This allowed the founders to focus on other projects and tasks at head office, whilst the Operations Manager could perform regular production site visits (often multiple visits per day) to ensure processes

were as efficient as possible and quality was consistent and of a high standard. The Operations Manager would perform multiple tasks such as collecting feedback from the foremen regarding the production/assembly process, perform incoming inspections, batch tracking, quality/stock checks and deliver shipping labels (which the founders had done previously). Having an Operations Manager also allowed for the outsourced assembly processes to be fully documented. Procedures were co-developed with the outsourced assembling organisation, Company G, and controls such as: assembly, testing and calibration were defined. Capturing this tacit knowledge assisted not only in quality control, but also in process visibility, transferability (if new or additional assemblers were to be engaged), and consistency of production. It also allowed for more focus on improving efficiency in the production process through bottleneck identification and possible project implementation.

Some of the possible bottlenecks identified during VS mapping, as shown in Figure 6.7 in Phase III, were discussed during meetings with the Operations Manager. This included the belt tensioning and extruder assembly process, which were critical to the production process and would be especially important if demand increased. It was discovered that possible improvement areas, such as tools for tensioning, instructional videos, and different extruder designs for example had either already been identified and/or had a solution in progress by Company X at the time of the research. Identifying them as part of the VSM, however, assisted in the validation of the processes with both the researcher and Company X. Procedures and educational material was under development, new suppliers for the extruders were being sourced and the production area being streamlined to improve efficiency. It demonstrated that Company X's managers were aware of their environment and were agile in adapting to change.

Company X hired additional team members, including a Product Developer and Marketing Manager, during Phase IV. This allowed more focus and time to be allocated to controls and marketing, which further added to the SCP and MSP stages of the journey. For example, a dedicated person (the Product Developer) was available to manage certain product improvements and developments, such as a new bio printer that the team were developing. As well as this, Company X was able to expand their digital marketing campaign, implementation and management due to hiring a Marketing Manager. In reflection, the CFO stated *"When we started, we knew a lot about product development and supply chain, some about process, but not a lot about marketing and sales, which would have helped reduce the iteration processes from the start."* This was an important phase for Company X's managers, who identified that in order to continue serving the market effectively, greater focus on marketing or the MSP stage was needed. Company X needed more than just the bare minimum social marketing and an evolving website to showcase their products to the market as they were being developed.

During this phase additional team projects were introduced. This was possible due to the team growth and investor involvement. Being able to introduce new projects was important, as identified by Company X. *“The market expectation grows and changes. Competitors have sophisticated printers and needs grow”* (CFO). Therefore, to combat the changing customer and market needs, multiple projects were introduced. Cross- discipline projects included the pre-commercialisation of a bio-printer, investigation of flat-pack 3D printers for educational markets (including overseas), a European hub for expansion into overseas markets, development of a website or online tool for establishing “makerspaces”, and curriculum and software for schools to introduce 3D printing and to bypass possible IT constraints.

In addition to these projects, other important updates during Phase IV, including those in the PDP and PIP stages were implemented. Day-to-day operations, such as the production process and site layout improvement, was able to be streamlined. There were product improvements, with new suppliers of a critical part (the extruder) sourced, helping to reduce failure rates. The importance of this was highlighted by the foreman, who declared that *“[a]pproximately 95% of all failures are due to this part”*. A tool was developed to assist with belt tensioning during 3D printer assembly (which had been highlighted in the previous phase as problematic). Revision of parts, such as the wiring, was occurring. Customised name plates (based on cartoon characters) were being developed for the printers, offering both personalisation and assistance with troubleshooting (as the printer could be more easily identified). As well as this, a new raw material named “Silk” was released. This material had a smooth finish, eliminating the need for post-processing of the final printed product and was helping to sell units. Company X declared that they sold eight units in the week that “Silk” was introduced, just by customers viewing items printed from the material.

Company X was working predominantly on product development in the initial phases of their journey, and began moving towards service offerings as the team and capability expanded during Phases IV and V. Services became more prominent towards the end of 2017 in Phase V, which will be explored in the following section.

6.4.1.5 **Phase V: Service delivery process and 4-DCE**

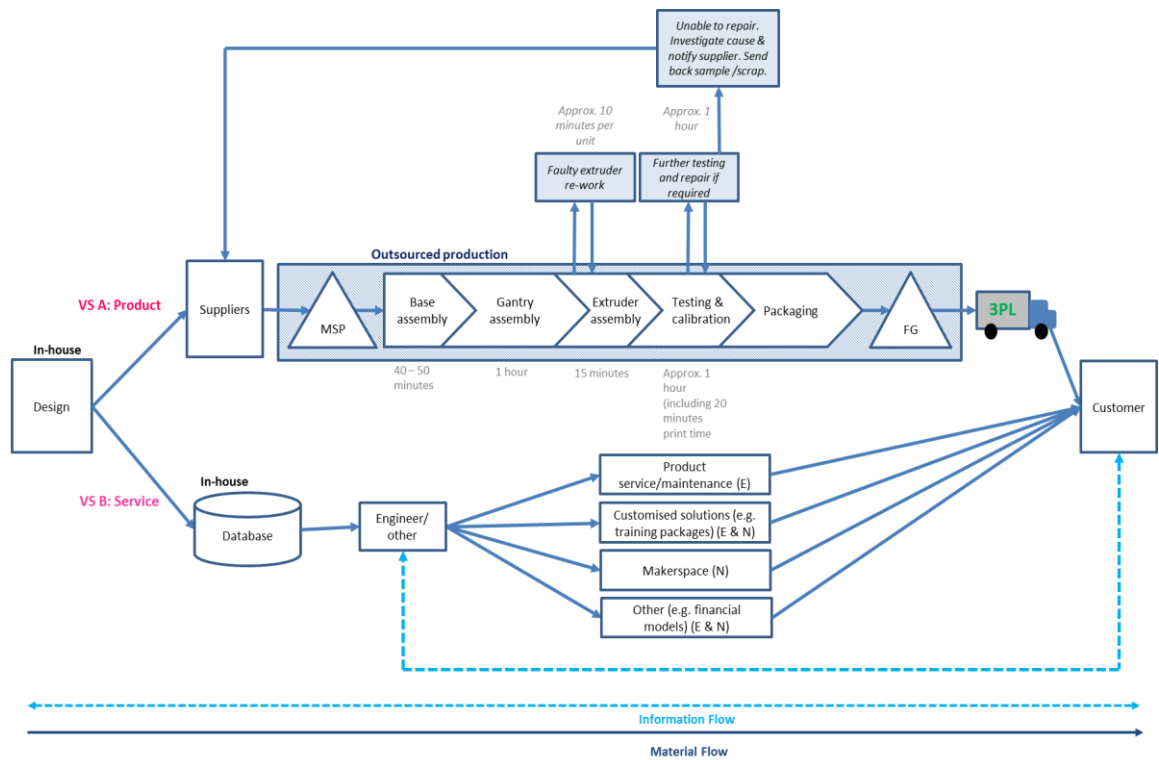
During the final phase, Phase V, the attention of Company X was beginning to shift more towards service to accompany the product offerings. Company X had sold 322 units by the end of 2017 and had

12 new external investors on board. Additional team members, including a Software Developer and Sales Manager, were hired and there was a focus on creating more value for the product through different services. For example, an online tool for developing “makerspaces”, which according to Niaros, Kostakis and Drechsler (2017, p. 1144) can be used as a broad term for “community-run physical places where people can utilize local manufacturing technologies” such as 3D printers and laser cutters. In the case of Company X, the target market was schools/educational facilities for the online “makerspace” planning tool. This was an innovative service to also drive their products. As well as this, turnkey solutions were being developed, such as software packages for teachers to accompany Company X’s 3D printers (which were in line with the educational curriculum), and different financial models, such as subscriptions and printer leasing. This gave the option for schools and students to subscribe or lease units for a period of time (with an option for the units to become the customers’ property after a certain amount of time), and to take pressure off customers’ budgets (such as capital expenditure for schools).

Printers were also being designed to drive service, with a new design being developed to include a camera and wireless internet capability, among other features. By including such features, Company X could bypass IT constraints in schools and gather error data and even video footage of the print job directly from the printer. The design would assist with reducing support lead-time. It could also potentially assist Company X in building up a database of common and potential issues and solutions to use during troubleshooting of other printers. This design was under development at the time of this research, with engineers seeking feedback from educators/teachers on which features would benefit them most with the product due for release early 2018.

The focus on products and services resulted in Company X developing a second complementary VS, as shown in Figure 6.7. VS A, as discussed in Phase III, shows the product design, production process and delivery to the customer. VS B however comprises of service offerings, for both new and existing customers (as denoted by “E” or “N” in Figure 6.7). This includes but is not limited to offering customers 3D printer services/maintenance (such as trouble tickets support), customised solutions such as training packages/software for teachers (e.g. tools for students to teach them about how to design and build an object), and different financial models such as subscriptions and leasing of printers.

Figure 6.7: Stage III: Company X's product and service value streams



Source: Author

In summary, Company X displayed a journey largely representative of Böhme et al.'s (2014) PDP model during the five years of the journey that was explored in this research. It became evident in the final two phases (IV and V) that Company X identified that they are product focused and that there is further untapped value in the service offerings. The activities of Company X during 2017 in particular highlighted this shift in focus towards services, which indicated that there may be an extension to the PDP model, with an additional phase of service delivery process (SDP) being added. This phase was observed to involve quick iterations of the previous four phases (PDP, PIP, SCP and MSP) that took place, resulting in SDP. Service was helping to sell 3D printers, and printers were being designed to drive services also. The findings also revealed a possible fourth dimension to concurrent engineering: product, process, SC and, now, service. A summary diagram of the model expansion can be seen in Figure 6.8 in the discussion section.

6.5 Discussion

6.5.1 Research question 5 - How do manufacturing start-up SMEs upscale the production of innovative products over time?

...[o]bserving fruit fly industries gives us the next best thing: an opportunity to see how one's future may play out based on the experiences of others – who happen to be travelling in a lane of faster traffic (Fine, 1998, p. 12).

Manufacturing in Australia is important to the economy, from having competitive and strategic value, to improving living standards (Gold, 2014), and increasing innovation capability (de Treville, Ketokivi and Singhal, 2017). Start-up organisations in particular play an important role within Australia, especially regarding their innovation capability, agility and insight that one can gain from the rate of change that they experience. Researchers such as Scaringella (2017) have highlighted the need for further qualitative studies surrounding start-up survival and growth to gain further understanding of this area.

As with Fine (1998, p. 12) and his “fruit fly industries”, Company X were small, agile and continuously adapting to their environment. Company X was “in a faster lane of traffic” (Fine, 1998, p. 12) as compared to larger more mature organisations and provided insight into the growth and innovation process within a start-up organisation. Using Company X, a start-up niche manufacturer of 3D printers, this research aimed to add to knowledge by addressing the fifth research question:

- *Research question 5: How do manufacturing start-up SMEs upscale the production of innovative products over time?*

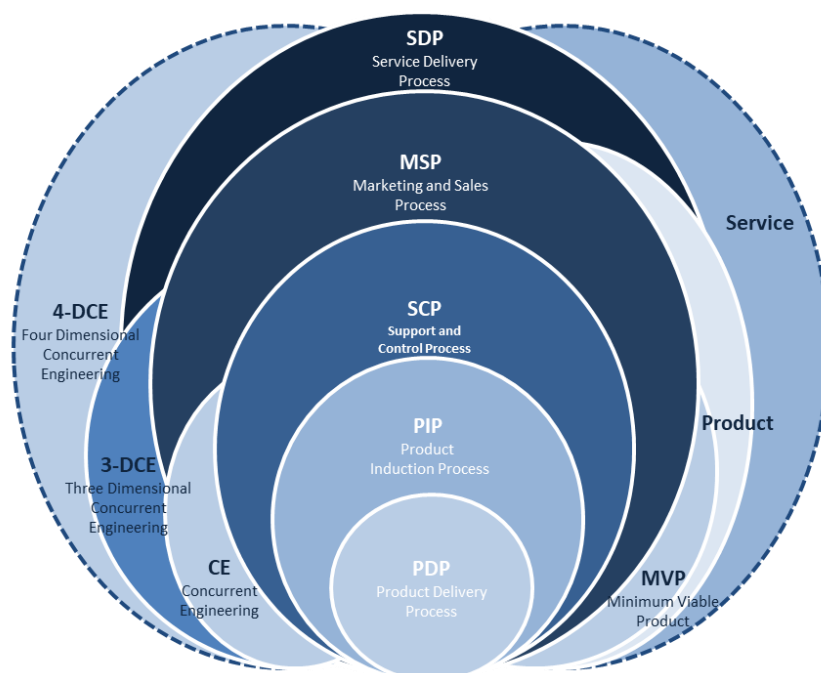
This exploratory research provided early insights into the role of CE/3-DCE and the pathway of development regarding upscaling and commercialising product innovation in the start-up space. The results therefore could contribute to practice, in providing guidance for other manufacturers in the start-up space, and academia, through the application and combination of concepts (such as CE/3-DCE and the PDP model) to further understand start-up organisations, as well as verification and extension of the PDP model (as per Figure 6.8) for start-up organisations.

The application of CE/3-DCE to Company X was significant, as it was noted as playing an important role in Company X from the beginning of their journey in 2013, including having experts in different fields working together, to continuously adapting processes and designs (both product and SC) throughout their journey to meet market needs. Interestingly, at the beginning of the journey, Company X used the expertise of each founder to look beyond simply developing products. It began with a focus on process and product design and re-design, with multiple iterations to get to the MVP. Company X was mindful of internal and external abilities and built the products and processes to suit them. It began with their suppliers’ (followed by their customers and assemblers) abilities and concern with protecting their intellectual property. Company X exercised a degree of corporate consciousness, whereby “collectively its individual members are in a state of awareness and mindfulness” (Lavine and

Moore, 1996, p. 403). Printer parts were modified to suit processes and vice versa. When parts were being sourced from overseas, Company X was mindful of their product and processes also. Company X purposely split their designs and sourced parts from multiple suppliers to aid in avoiding reverse engineering and pirated copies and imitation products. Suppliers would only see their part and not the entire design, which could be likened to a magician only letting stage hands know a piece of the puzzle/trick each so that they could not reconstruct the act themselves. Using a 3-DCE lens throughout the exploration of Company X's journey, it was clear that Company X were concurrently engineering in their early years during the PDP and PIP stages. This soon evolved to 3D-CE (Fine, 1998) and 4-DCE as Company X progressed through their journey. Although Company X was aware of their actions and had demonstrated the use of CE initially, they had not realised or labelled it as CE or 3-DCE. The nature of being a start-up organisation combined with the founders' knowledge had created an environment in which they were constantly seeking new ideas and designs as a way of operating, rather than applying theory or naming it 3-DCE.

The case demonstrated that whilst CE is something that may or may not be consciously implemented, it may be something that can be learnt overtime. This means that for other cases embarking on a similar journey to that of Company X, they may still implement CE/3-DCE (Fine, 1998) to enhance their journey part-way through or at a later stage. They may even add further dimensions to CE, 3-DCE and beyond, depending on their journey.

Figure 6.8: PDP model and CE expansion

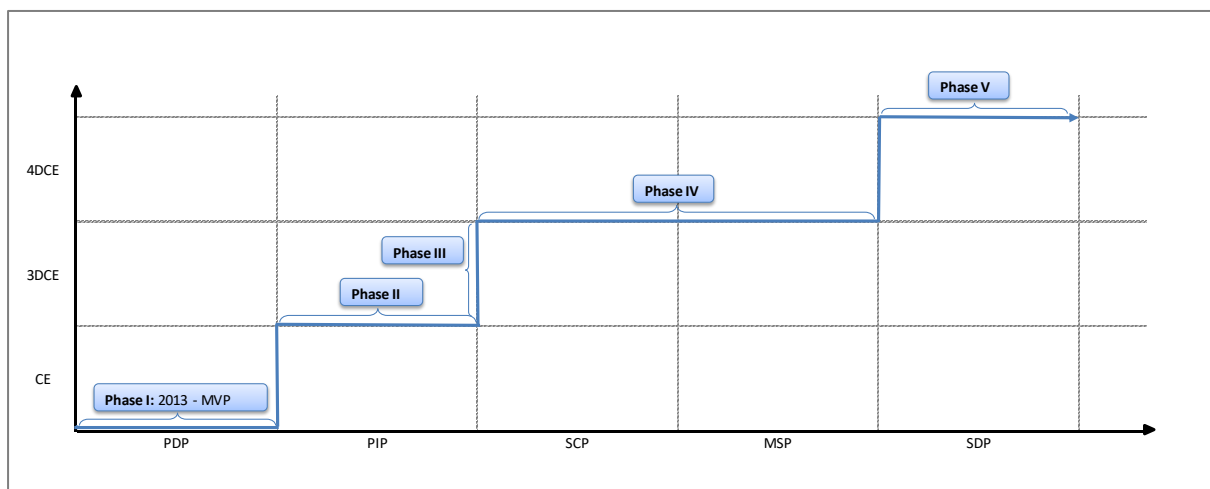


Source: Adapted from Böhme et al., 2014a, p. 6532

Figure 6.8 combines the original PDP model (Böhme et al., 2014a), with the CE manufacturing philosophy. Evidence during testing of the original PDP model however, revealed that there were additional phases/dimensions in the journey of Company X. The extension into further dimensions, such as four-dimensional concurrent engineering (4-DCE) and service delivery process (SDP), shows growth of the service elements of the business journey (as shown in Figure 6.8). It is almost a learning trajectory, showing steps that may be taken in both the product focused and serviced focused phases of growth, as well as operationalising business proposals, in addition to other models such as the lean/business model canvas utilised in Chapter 5. Tools such as these tend to stop prior to the operationalisation of ideas, and so Figure 6.8 may complement other models/canvases. In reviewing the model in Figure 6.8, Company X's managers also commented that providing such figures during key business interactions could also be of value to potential investors.

An alternative view of Company X's journey using the PDP model and CE expansion is shown in Figure 6.9. This shows the progression throughout the different stages of growth, and their applicability to CE, which could be used by other organisations to capture and investigate changes in their businesses.

Figure 6.9: Company X's journey



Source: Author

6.5.2 Future Outlook

The value-adding operational and organisational methodologies finely honed and applied via a well-trained workforce will provide protection and competitive advantage. After all this is now a world where the same

standard modern machinery, associated equipment and software can be purchased by any competitor. Its possession no longer generates competitive advantages as of right. Management must ensure best practices are used to ensure efficient and effective utilisation (Parnaby and Towill, 2009, p. 1053-1054).

As per the quote by Parnaby and Towill (2009) asserts, it is no longer enough to just have the necessary equipment in order to remain competitive. Competitive advantage can be fleeting rather than sustainable (Fine, 1998). This has been linked to the quickly changing business environment organisations operate within today (Fine, 1998). In the case of Company X, they operate within the fast growing, technically innovative, increasingly accessible, competitive environment of 3D printing, and according to the CEO, have realised that having the best printer is not enough. There needs to be another offering or differentiation in the market to remain competitive. Perhaps additional dimensions to that which are offered in Figure 6.8 will develop, in which products, processes, SC design and services can be coordinated to offer optimal competitive advantage. Innovation through education in CE/3-DCE may be focused upon with more intensity to create competitive advantage that is harder to imitate than finished products.

6.6 Conclusion

Innovation takes many forms, from technologically advanced products, to management techniques, processes and SC design. It has been acknowledged by many researchers (D'Este, Amara and Olmos-Peñuela, 2016; Parnaby, 1995; Cheng, Chang and Li, 2013; Hanaysha and Hilman, 2015), practitioners and even the government (NSW Government - Department of Industry, 2018) as being important to compete in the today's business environment. In the case of this research, concentrating on a single longitudinal case study in the niche manufacturing start-up space allowed for the exploration and further understanding of growth of start-up organisations. This is significant as it was identified as a gap in literature, particularly for Australia. Start-ups have been identified as sources of innovation, with potential to positively impact on regions. Focusing on businesses before they grow could assist in avoiding barriers faced by SMEs (as in Chapter 4) or larger more mature organisations.

This chapter aimed to answer research question 5: How do manufacturing start-up SMEs the production of innovative products over time? It also aimed to contribute to knowledge in both academia and practice through the application/testing, verification and extension of the PDP model in conjunction with the lens of CE/3-DCE, as well as developing a guide that could be used by practitioners in providing direction during the upscaling of their business and products or services offered (as summarised in Figure 6.8).

The following chapter includes a discussion of the thesis, covering each of the three findings areas relevant to Chapters 4, 5 and 6.

7. Discussion

7.1 Introduction

The field of supply chain management is broad, from the multiple definitions available that researchers have not yet reached a consensus on (Halldórsson, Larson and Poist, 2008; LeMay et al., 2017; Croxton et al., 2001), the different classifications of the relationship between logistics and SC (Larson and Halldórsson, 2002), to the different configurations of SCs, and the strategies that exist to manage them. Even so, despite the lack of a common definition or consensus on the best management approach, the enigmatic field of SC continues to be an area of opportunity, increasing in importance in both academic literature and practice as they continue to evolve. From the optimal seamless or externally integrated SCs originally presented by Stevens (1989), to the future of SC networks and clusters (Stevens and Johnson, 2016), understanding SCs and their evolution is of importance. Supply chains are timeless. They are almost like old majestic oak trees that have lived through the ages, with a strong core and an abundance of sturdy branches reaching out in all directions, providing different options from shade and shelter, to an anchor point. Some branches are sturdy and load bearing, whilst others are weathered and serve more decorative purposes. The various branches could almost be likened to the multiple VVs that supply chains offer, with some being there for many years and other 'shoots' appearing as the environment changes, such as with the introduction of new products, processes or innovation. They, both the old oak tree and supply chains, may exist for many years without being noticed or tended to until changes take place within the environment and the need for them is realised. It is only then when one truly looks close enough that the details and opportunities present themselves.

This research aimed to look closer, to explore the current state and future opportunities that are possible. This occurred through the exploration of supply chains and VVs, largely in Australian manufacturing SMEs, and the potential to enhance their innovative capability. Manufacturing in Australia has been changing. Although there has been debate by some in regards to the current state of manufacturing (Milne, 2010; Lannin, 2018; Commonwealth of Australia, 2003; Murphy, 2016; Ruthven, 2018; Georgeson and Harrison, 2015), there is no denying that it is far from its peak in the late 1950s/1960s, when manufacturing accounted for approximately 29% of Gross Domestic Product (GDP), as opposed to less than 10% approximately 40 years later (Milne, 2010). In terms of the total workforce, employment in manufacturing was approximately 8% in late 2013, down 8.8% from that of 1984 (Georgeson and Harrison, 2015), and down 22.5% from that of 1965 (Baffour et al., 2016), with future declines predicted within the next 20 years for certain Australian states (Mincer, as cited by Georgeson

and Harrison, 2015). Employment in manufacturing has been decreasing, with over 100,000 jobs lost Australia-wide during 2008 and 2012 (Commonwealth of Australia, 2012).

Government driven changes in Australian manufacturing have been occurring, that has seen the focus shift from traditional manufacturing to advanced manufacturing, influenced by the introduction of Industry 4.0 (NSW Government - Department of Industry, 2018). In a recent Government report, focus was placed on the production process instead of on the final product (NSW Government - Department of Industry, 2018) as a source of innovation. The introduction of innovative technology, such as 3D printing, is allowing organisations to innovate through both processes and final products. Such changes in the industry are providing further opportunities for Australian organisations to remain competitive and possibly rejuvenate manufacturing and the communities in which they are situated (as with the cases in the UK from Chapter 5).

Manufacturing has been linked to innovation (de Treville, Ketokivi and Singhal, 2017; Spring et al., 2017), higher living standards for the nation in which it is situated (Gold, 2014; Wu, 1992), as well as education opportunities, and competitive advantage (Soosay et al., 2016) to name a few. Due to the importance of manufacturing in Australia, as well as SMEs who account for over 95% of all businesses in Australia (AiGroup, 2017; Gilfillan, 2015), the focus of this study was narrowed to Australian manufacturing SMEs, to provide early insight through case study investigation. An overall research question was presented to guide the research;

- ❖ What is the current state of SC maturity and innovation within Australian manufacturing SMEs and how can this be enhanced through the adoption of innovative technology and/or processes?

This question was then divided into five research questions, separated into three distinct findings Chapters (4,5, and 6). Chapter 4 provided early insight into the current state of SC maturity within two Australian manufacturing SMEs, and underlying issues or barriers to SC maturity and the link to innovative capability. Next, Chapter 5 presented two cases of best practice from the UK, where clear pathways of innovative technology adoption were evident (providing insight into implementation pathways). Finally, Chapter 6 presented insight into a vibrant, agile Australian start-up SME through conducting a longitudinal case study that investigated the evolving SC, influence of innovation (including the rate of change and CE), providing insight into what other manufacturing SMEs can expect. They were considered agile due to their speed to market, rate of change and information flow for example (Christopher and Towill, 2000; Fine, 2000). Next, a discussion based on each of the three findings areas is presented.

7.2 The current state of supply chain maturity and innovation in Australia

7.2.1 How mature are Australian supply chains in practice?

Although there is much in SC literature that has not yet been agreed upon, one such important view or belief that has been agreed is that it is SCs that compete today rather than individual businesses (Christopher, 2011). This research recognised and agreed with this viewpoint, and sought to establish an understanding of the Australian SC landscape, providing context for this research. Researchers such as Böhme (2012) and Childerhouse (2011b) called for further applied SC diagnostics to take place in order to gain further insight into good practices and challenges in real-world SCs. Therefore, this research chose to utilise the QSAM diagnostic to do so, gaining insight into SCs and adding to the further generalisability of QSAM.

Through the investigation of two Australian case studies using the diagnostic tool, QSAM, it was discovered that there were lower levels of SC maturity evident, with approximately half of the VSSs being closer to 'baseline' integration or displaying high uncertainty and low maturity levels in the two cases. Systems uncertainty was high across all four categories (demand, supply, control and process) for both case studies. Business strategies were not made clear by top management or translated into achievable KPIs, making it difficult for the employees to meet appropriate goals. Business was more reactionary as compared to proactive, resulting in rush orders, quick fixes and higher levels of 'firefighting' than usual, which were more costly to each SME as compared to better planned operations. There were IT systems in both businesses, but the correct data was not always available due to issues such as limited systems access, IT issues and obsolete data being kept in the system. Having the IT or tools available to perform powerful reporting and record keeping but not being able to utilise them fully was frustrating to the employees. Some employees would resort to an 'art vs science' approach of using their 'gut feeling' or experience for sales forecasting or making important decisions, rather than relying on the available IT. High amounts of experience and tacit knowledge across the two SMEs was extremely valuable to the businesses, however it was not being adequately captured. Both were at high risk of knowledge loss as employees retired or resigned. Overall, better planning and procedures were needed to assist in managing this uncertainty. Employees were often time poor and were expected to manage multiple areas/projects, such as quality. This resulted in certain areas being neglected due to lack of time and knowledge on the topic, and increased employee fatigue and impacting on organisational culture.

Both SMEs demonstrated passion for innovation and improving their innovative capability, however the high systems uncertainty was a barrier to being able to pursue innovative initiatives and

make contributions in this area. Issues from organisational culture, management experience, and the adoption of appropriate manufacturing philosophies, through to the physical site location and production layout were all adding to the lower maturity results for both SMEs. Daily issues and 'firefighting' were reducing the time and effort available for value-adding innovative opportunities.

These findings revealed that there are some big issues in both the Australian SME. If these issues are widespread, they will need to be addressed in order to get the sector innovation ready. The lower maturity and higher systems uncertainty present an area of opportunity to discover the 'why', or the root causes behind these results, and how they could be improved. Innovation would then be more easily adoptable once more mature practices are in place. The results were not dissimilar to those discovered by researchers in other countries, with only approximately 10% displaying exemplar SCs (Towill et al., 2000) in investigations of over 120 VSs internationally (Aitken et al., 2016). It is also not uncommon for SMEs to have fewer employees to cover higher workloads, as compared to larger organisations. SMEs can be better managed however to balance this, such as through the identification of root causes as in this research. By using QSAM to investigate the Australian cases studies, this research provided early insight into the current state of SC maturity in Australia. These findings were significant to this research as this area had been identified as a gap in the literature, and it provided an important foundation for this thesis.

QSAM is a well-rounded, robust diagnostic tool that allows for multiple forms of triangulation, including data, researcher and method (Böhme et al., 2014a). Anchored in systems theory, it allows the researcher to focus on the entire system or SC, not just parts (Maani and Cavana, 2007). As discovered in both academic and practitioner research, having a transferrable method such as QSAM, that allows for the comparison or benchmarking of multiple industries is desirable (Childerhouse and Towill, 2011a). Unlike consultation that commonly occurs in practice, researchers conducting QSAM are able to present unbiased views and recommendations that the organisation may or may not choose to implement. The researcher offers practitioners insight into multiple applicable theories depending on the case, without having one specific theory or 'product' to sell. The researcher is able to get to the core or root causes of the issues faced that increase systems uncertainty, leading to not only developing a list of barriers to SC maturity, but also discovering the relationship between them and the link to innovation, as discussed in the next section. This research contributed to the further generalisability of QSAM, through utilising it in new contextual settings, as prior to this research, QSAM had not been applied in the Australian context.

7.2.2 How do barriers to supply chain maturity impact on business innovation?

Barriers to SC maturity and innovation capability are not restricted to physical limitations such as site location or size, or even strictly monetary limitations, as discovered through conducting QSAMs in Company 1 and 2. Organisational culture, tacit knowledge and management skills play an important role in the level of maturity, SC integration and decreased “muda” (Behnam, Ayough and Mirghaderi, 2018, p. 64) or waste, that can influence systems uncertainty. Organisational barriers linked to people, such as issues surrounding management capability, knowledge, trust and skill, as well as influence from top management are not restricted to the QSAM findings within this thesis. It was found that these results corresponded with other existing studies that also found these barriers to be common (Böhme et al., 2014a; Childerhouse et al., 2011). The identification of barriers in the Australian context was a contribution of this research.

Importantly, barriers were not just listed in this research. By conducting cause and effect analysis, the link between the barriers was established. Through exploring the relationship between the barriers to SC maturity and linking them to innovation, a contribution was made by the researcher in developing a model (see Figure 4.9) to conceptualise findings and also to show the extension of QSAM to examine the link between system uncertainty/barriers and business innovation further. QSAM provided an important platform in which additions such as this, to investigate innovative capability, could be achieved. QSAM has also been improved and extended in other studies, such as to examine longitudinal case studies (Böhme, 2012), with the likelihood of further evolution of QSAM expected.

By conceptualising findings, such as in Figure 4.9, this research provided a contribution that could act as a guide to assist practice in what barriers to pre-emphasise, avoid, and what areas to target in continuous improvement initiatives (such as training initiatives or consolidation of IT systems), further improving SC maturity and organisational performance. For academia, this research provided further insight into the overall state of SCs and reasons behind why they are facing high systems uncertainty and low SC maturity, which is impacting on their capability and ability to pursue more innovative contributions.

Innovation has been highlighted by the Australian Government as needing attention in order for Australian organisations to compete on the world’s stage (Australian Government, 2016; NSW Government-Department of Industry, 2018). SMEs have been attributed with the highest contribution to the innovation effort in regards to being actively involved in innovation (Australian Government, 2016), and so further research into this field that could assist in improving the current state can be said to be beneficial to academia, practice and policy makers. Exemplar cases could be possible in Australian SCs, with further research and exploration, including by academia providing the insight into theory

and QSAM international database of knowledge, and by practice letting research explore real-world cases, allowing research questions and theories to evolve to suit the setting/changing environment to remain practice relevant. Next, examples of best practice of SMEs adopting innovative technology are discussed.

7.3 The impact of the adoption of innovative technology on manufacturing systems/value streams

7.3.1 How do organisations adopt innovative technology into their existing supply chain?

Innovation and the pursuit of improving innovative capability is applicable to many organisations as well as scholarly endeavours (Cheng, Chang and Li, 2013; Hanaysha and Hilman, 2015). This research, through focusing on the adoption process and impact that it has on VVs and manufacturing systems, is relevant to both practice and academia. With the technological advancements of Industry 4.0 becoming more widespread, this research was one of the early studies that focused on how innovative technology (3D printing/AM) is adopted by SMEs as well as the impact that it has (Rylands et al., 2016; Rylands et al., 2015). Literature revealed that many other studies focused on the technical aspects of 3D printing technology and engineering aspects (Rylands et al., 2015), rather than impacts on business and the SC.

This research investigated the adoption of 3D printing/AM in two cases of best practice from SMEs in North West England, that began with experimentation and working with knowledge centres, through to using the technology for tooling as part the production process and the production of finished products. This research is practice relevant, with the Australian Government (NSW Government-Department of Industry, 2018) highlighting the improvement of process innovation through advanced manufacturing. It is also relevant to academia in providing insight into pathways of implementation and business impact that could be applicable to other businesses or contexts. The two case studies contributed to findings revealing that traditional manufacturing methods could co-exist alongside the new advanced methods, introducing additional VVs and value propositions for the customer. Contributions were made by the researcher through identifying the co-existence of traditional and advanced manufacturing methods, and by capturing findings through VS mapping, combined with the application of the business model canvas (Strategizer, 2015; Osterwalder and Pigneur, 2010) to SMEs adopting 3D printing/AM and the business impact.

Due to the insight gained through conducting this investigation, this research disagreed with other research that traditional manufacturers cannot recognise the value of advanced/modern manufacturing methods or would not be willing to implement advanced technology (Achillas et al., 2015), and agreed with Birchnell and Urry (2016) that traditional methods of manufacturing do not have to disappear to

make way for the implementation of new, innovative manufacturing processes such as 3D printing/AM. Next, the business impact of 3D printing/AM is discussed.

7.3.2 What is the business impact of innovative technology adoption on the existing value streams/business manufacturing system?

The adoption of 3D printing/AM importantly resulted in the introduction of additional VVs and value propositions for the customer. It also led to partnerships and close working relationships with knowledge centres, customers (through co-creation) and the community (including other businesses). The SMEs that adopted the innovative technology were able to extend their product offerings and increase the attraction of additional customers through marketing and positive PR (as captured in Figure 5.9), that went beyond time compression or product design advantages captured in other studies (Petrick and Simpson, 2013; Barnes, 2014; Tasse, 2014; Rylands et al., 2016).

The introduction of knowledge centres, allowed access to further knowledge, machinery/technology, prototypes, cost savings and opportunities that many SMEs would not have access to. In turn, the knowledge centre, including the local University, had access to real-world SCs. Educational opportunities were being provided by the SMEs to other businesses, those in the community and knowledge centres, who wanted to learn about 3D printing/AM. As well as this, the University was open to providing training to assist in upskilling employees within the SMEs and access to educational conferences. This is significant, as various studies have highlighted the manufacturing industry as having the least educated workforce in Australia (Georgeson and Harrison, 2015), and so advancing skills of the workforce is of importance. This area of research regarding the adoption process and impact of 3D printing/AM was also identified by Christian and Sandström (2016, p. 160) as being of importance as “studies of how industries transition to 3D printing are currently scarce and there is a need for more empirical descriptions of who and why an industry adopts 3D printing for manufacturing purposes”. Contributions from this research adding to the knowledge in this area include; providing insight into a technology from a SC perspective (3D printing/AM) (Rylands et al., 2015), the types of organisations adopting the technology (for example SMEs in manufacturing), why they are adopting it (including tooling and the production of finished products), pathways of adoption of 3D printing technology, the impact on VVs/manufacturing systems (Rylands et al., 2016), and the link to knowledge centres and positive PR from the adoption of 3D printing/AM, as captured in Figure 5.9.

Next, the journey of an innovative start-up SME is discussed.

7.4 Product, manufacturing and supply chain design innovation

7.4.1 How do manufacturing start-up SMEs upscale the production of innovative products over time?

As with the research by Fine (1998, p. 12) on “fruit fly industries”, this research also recognised the value of studying an agile, start-up SME experiencing higher levels of change or faster clockspeed than many larger organisations. This area is important to the Australian Government and research, with start-ups in Australia attributed as major sources of innovation and economic value (Startup Muster, 2017), and research calling for more qualitative studies to investigate the growth and survival of start-ups (Scaringella, 2017), especially due to the high level of start-up failure as compared to larger organisations.

This research used the manufacturing philosophy of CE (Singhry, Rhaman and Imm, 2016), to begin the investigation of product and process design within the selected case SME, Company X. The origins of CE have been said to be difficult to trace (Smith, 1997; Zhang and Zhang, 1995), however, the fundamentals appeared in literature during the 1950s (Smith, 1997). Although this concept is not relatively new, according to literature, it is still a very relevant concept that could offer benefits to organisations through the wider adoption of it in practice. It does not require radical mindset changes and it is applicable to organisations of all sizes, technical ability and products (Thorpe, 1995; Smith, 1997). This provided a starting point for the research, in conjunction with the PDP model (Böhme et al., 2014a) to map the growth phases or journey of a start-up SME. Research soon revealed that the SME’s journey had taken it beyond CE and the PDP model (Böhme et al., 2014a), and included 3D-CE, which includes SC design along with product and process.

As the journey continued, findings revealed that there was a need to expand the investigation further to include the application of 4D-CE. This was due to the increase in product and addition of service offerings. This is topical and important, as the growth in services sector in Australia has been far larger than that of the manufacturing industry (Heath, 2017). It is not only those in the service industry, but those within manufacturing that are offering services as another value proposition to customers and point of differentiation to compete, particularly against cheaper imports. Shorter lead times from local manufacturers might not be as appealing to most customers if an imported product is cheaper, however additional service elements and after-sales care that an organisation can offer, such as Company X (and even Company 1 and 2 in Chapter 4) could be of value to the customer and a business winning point of difference.

Exploring Company X's journey through a longitudinal study provided the researcher with insight and the ability to conceptualise the growth into a model that other organisations could use. To capture this journey, the findings were compiled into an expanded model (see Figure 6.8). The expansion of the PDP model and CE philosophy provided insight into the journey of SMEs and different phases of growth. This could be beneficial to practice in providing a guide as to what to expect during growth stages or for planning, such as what barriers to avoid, that could be applicable to start-up SMEs and larger organisations. By combining the elements of product, process, SC design and services, it could assist organisations in developing their businesses, to be able to progress through the growth stages presented in Chapter 6. It could also assist with developing a point of differentiation and competitive advantage that is more difficult to copy or imitate than a product. An example of this are 3D printers, which are becoming more available to the market (particularly every day consumers) as prices decrease and more options become available (particularly for the FDM printers).

Organisations need another point of differentiation to compete in addition to the equipment that they have (Parnaby and Towill, 2009), such as Company X with their link to education and service offerings, as well as software and technological innovations that were built into the printers that competitors had not yet developed. Company X's journey showed that through the application of CE/3D-CE thinking, other forms of innovation could be used to compete, including product, process and SC design. Gaining insight into a young, agile, fast paced SME provided an opportunity to assist those in practice with the journey, as discussed, and provide insight for researchers into how relative models and philosophies can be expanded and applied in industry. Contributions from this research include; insight into the growth and journey of start-ups through a longitudinal case study (including VS mapping, timelines and model development), application, testing and extension of the PDP model (Böhme et al., 2014a) in a different context, application and extension of theory (CE/3D-CE) (Fine, 1998), and model development (Figure 6.8) to guide practice and academia throughout the growth phases (or assisting in the improvement of more mature organisations).

7.5 Overall Discussion

Much can be said to be uncertain in the world today, except for the presence of change. Change is constantly occurring, sometimes rapidly and at other times it is incremental and less noticeable. Technological change however, is rapidly occurring, with the rate of disruption increasing as the impact of Industry 4.0 becomes more widespread. Since the First Industrial Revolution, significant changes have been occurring, where technological advancements assisted in the development of mass production, forms of alternate energy and additional modes of transportation, reducing the strict reliance on environmental elements such as wind power only, improvement in the speed of certain

modes of travel, and the reduction in artisan craftsmanship. Since then, throughout the various revolutions, through to the introduction of Industry 4.0, some of these changes have come full circle, such as the return to alternate energy types, such as wind, and a focus on the economies of scope or more artisan, small-scale, customised production that technology such as 3D printing/AM currently provides, rather than just economies of scale. With the evolution of technology however, changes could see technology such as 3D printing/AM change to suit larger scale-production, just as the use of computers have changed. Computers, which was the term previously used to describe humans who could work out complex problems/equations (Bromley, 1998) rather than machines, have transformed and evolved into machines that now fit into consumers' pockets instead of filling an entire room. Technology and its applications are constantly evolving, with the accessibility and widespread use of technology impacting on many industries and the everyday lives of people.

Technology in the manufacturing industry has seen the widespread digitisation and automation of business, which businesses need to be able to keep up with in order to compete today. With such changes occurring, there is concern that the state of manufacturing in Australia could decline further. There is cause for concern due to the immature practices and presence of high systems uncertainty, impacting on innovative capability, that highlight local industry readiness for predicted change is low. Australian manufacturing, which accounted for almost 30% GDP in the late 1950s/1960s, dropped to less than 10% only 40 years later (Milne, 2010). Employment decreased by over 100,000 people nationwide in the period 2008 to 2012 (Commonwealth of Australia, 2012), with other industries such as services increasing. Manufacturing has been established as being important to the nation, from productivity and economic benefit, strategic value, to being the foundation for innovation and innovative capability (Milne, 2010). More recent Government initiatives and research efforts (NSW Government-Department of Industry, 2018; Australian Government, 2016) to improve the state of manufacturing in Australia further highlight the significance of this area. There is hope however, for the changes currently occurring in Australian manufacturing, particularly for established manufacturers, as shown in the cases of best practice from the UK. These cases demonstrated that the shift towards advanced manufacturing does not mean that traditional manufacturing must disappear. Both methods can co-exist and complement each other, strengthening the organisation, community and potentially the manufacturing industry. For those organisations who are less established and in the start-up space, there is much opportunity due to a multi-disciplinary approach to product, process, supply chain design and a strong emphasis on service models in conjunction with the product. There is a great opportunity also for established SMEs to learn from agile, innovative start-ups, especially regarding product/service design. They can gain insight into innovative approaches to growing their business and value-offerings for customers, especially with the introduction of services to accompany

products, as well as common barriers to avoid. Overall, there is much opportunity to improve, and with the rate of technological change that is occurring, there are interesting times ahead for manufacturing in Australia.

7.6 Limitations

Importantly, this research did not aim to investigate all SCs in Australia, nor claim to generalise how mature every SC or VS is. It aimed to provide early insight into the state of SC maturity in Australia, the barriers to this and the link to innovation through conducting an exploratory investigation. Limitations of this research include the number of case studies selected, the type of case studies chosen, and the time taken to perform the research. The number of case studies selected was not large, and so a limitation could be generalisability. The research was limited to SMEs within manufacturing, and the time taken to perform the research was limited following the QSAM protocol for some cases, as compared to the single longitudinal study. Due to general limitations of research, such as time and financial resources (Remenyi et al., 1998), as well as the number of case studies chosen, this research was focused on case studies that were purposively selected to explore the current state of SC maturity in Australia, examples of best practice from the UK of innovative technology adoption and business impact, and a final case study to explore the rate of change and innovation within the SC of a start-up, as they progress towards becoming a more mature SME.

By providing insight into the state of SC maturity in Australia and innovation capability, this research invites and encourages further interest and future research into the exploration of additional SCs using QSAM, from different sized organisations and other industries, to be able to draw comparison between them and possibly discover exemplar SCs in Australia. Overall, this research offers multiple areas for possible future research, from methodology expansion, to the testing of models and including more Australian case studies in which to draw comparison from. There is much opportunity in this field, especially with the growing adoption of innovative technology and the need to increase innovative capability. Research of future 3D printing SCs may require further investigation into the printer cartridges, instead of powder, other raw materials or parts. The focus may be more towards materials engineering and printer operations systems. Technology could change how products are produced and sold on a larger scale than present (further influencing the paradigms of economies of scale versus economies of scope), introducing community centres or larger networks of local printers, and further shift jobs towards skills that may not exist yet. Future research opportunities are discussed further in Section 8.4.

Next, the conclusion is presented, including the contributions of this research to practice and academia, and areas for future research.

8. Conclusion

8.1 Introduction

Supply chains in the real world can be disorderly and chaotic. They may face an array of environmental impacts, from the larger more extreme effects of natural disasters and economic decline, through to impacts from the introduction of technology, to production bottlenecks, the bullwhip effect (Towill et al., 2007), and other daily issues that can require countless hours of firefighting. With each of these adding to increased levels of uncertainty, there is a need for improved SCM capability, especially within Australian manufacturing. SCM has become even more important in business today, as it is through SCs that businesses compete (Christopher, 2011). As Stevens (1989) and other researchers have identified, a starting point in which to assess and improve SC performance (Netland and Alfnes, 2011) can be via the determination of the level of integration or maturity of a SC. There are multiple commercial and academic tools/methodologies available to managers today for analysing the SC to determine this, as explored in Chapter 2, that can allow for the identification of the root causes of SC issues, and possible pathways to improvement and systems uncertainty reduction. With the many different methods available, each suiting different SCs and conditions, a consensus has not been reached on the best or most preferred method to diagnose or assess the state of SCs. What became clear from reviewing the literature however, is that whilst there is not a 'one size fits all approach' to SCM (Shewcuck, 1998, Christopher et al., 2006; Beck, Hofmann and Stölzle, 2012), choosing a tool or method and performing a SC assessment is advantageous (Böhme et al., 2014b; Pettit, Croxton and Fiksel, 2013; Netland and Alfnes, 2011; Ganasekaran, Patel and Tirtiroglu, 2001; Banomyong and Supatn, 2011), which occurred in this research, through the use of QSAM.

This research recognised the importance of SCs and SCM, and sought to gain further insight into the current state of SCs, barriers to this and the link to innovation and innovative capability enhancement within Australian manufacturing. An overarching research question was utilised to guide this research, thus being;

- ❖ What is the current status of SC maturity and innovation within Australian manufacturing SMEs and how can this be enhanced through the adoption of innovative technology and/or processes?

Literature revealed that SC maturity and integration had been established in international studies, however there was a gap in regards to Australian SCs. The focus of this research was narrowed further to include the SCs of SMEs within manufacturing, due to the significant number of SMEs in Australia, which account for over 95% of businesses (Ai Group, 2017; Gilfillan, 2015), and the strategic, economic

and overall importance of manufacturing to the nation. Both SMEs, including the less mature in their early growth or start-up phases, and the manufacturing industry have been linked to increased innovation and competitive ability (Milne, 2010) for the nation in which they are situated. Through the utilisation of the diagnostic tool QSAM in Chapter 4, this research was able to provide early insight into the state of SC maturity and innovation in Australia, by exploring VSs and SCs of two manufacturing SMEs. Importantly this research did not generalise the findings, however provided early insight only. Findings were consistent with international QSAMs, that revealed relatively low maturity levels and high levels of systems uncertainty overall. This resulted in lower levels of innovation and innovative capability, which is concerning due to the state of the current manufacturing landscape in Australia, which has become more competitive and is shifting towards more advanced manufacturing methods/technologies. This is an area of opportunity for Australian manufacturers to improve upon, with the possibility of the achievement of exemplar SCs in future viewed as being feasible if action is taken. The application of QSAM was extended in this research to allow for this link to innovation to occur, with lower levels of maturity being linked to higher levels of uncertainty and in turn, lower levels of innovation. This research revealed that the higher uncertainty levels translated to sub-optimal SC conditions, with more time needed to fix issues or 'fight fires', as summarised in Figure 4.9.

In Chapter 5, examples of best practice of case studies where innovative technology was adopted by SMEs to enhance their manufacturing and competitive capability were investigated. By exploring these cases, insight was gained into pathways of innovative technology adoption and the impact of this on VSs and manufacturing systems, as summarised in Figure 5.9, that could cautiously be generalised in similar contexts.

In Chapter 6, the researcher was able to continue the investigation into innovation enhancements through exploring the growth and evolution of an Australian start-up. This research provided insight into the different phases of growth and the applicability of CE, 3D-CE and the PDP model (Böhme et al., 2014a) in investigating the different phases of the journey. The rate of change and innovation faced by the fast-paced agile case study, produced significant results that could be used to assist other organisations in early stages of their journey, through to more mature organisations wanting to improve their performance, as summarised in Figure 6.8.

In summary, this research was able to address the overarching research question and establish early insight into SC maturity in Australia, as well as how innovative capability can be enhanced through the adoption of innovative technology (3D printing/AM), as well as innovative processes, products, SC design (3D-CE) and service, contributing to practice and academia, as will be discussed next.

8.2 Contributions

This research resulted in important contributions applicable to practice, academia, and even policy makers. Contributions from throughout the research have been summarised in Table 8.1, by research question. Next, the contributions will be discussed by findings area (from Chapter 4, 5 and 6).

8.2.1 The current state of supply chain maturity and innovation in Australia

This research began by contributing to the further generalisability of QSAM, through applying it to a new context (manufacturing SMEs in Australia). By utilising QSAM, this research provided insight into the lower SC maturity levels in Australian SMEs and systems uncertainty profiles, to allow for the benchmarking of performance as compared to other organisations internationally. Common barriers to SC maturity were identified and the relationship between them was established, providing further insight into the root causes for lower SC maturity and high levels of uncertainty. QSAM was further extended during this research to investigate the link to innovative capability, with lower levels of maturity and high systems uncertainty impacting on an organisation's innovative capability and sub-optimal SCM. Cross-case comparison between the two cases was performed, assisting in the development a conceptual model linking systems uncertainty to innovative capability (as shown in Figure 4.9). Inefficiencies, missed opportunities and 'firefighting' were found to be barriers to innovation, due to valuable time spent rectifying these issues instead of being used in value-adding activities.

8.2.2 The impact of the adoption of innovative technology on manufacturing systems/value streams

Aspects to consider before the adoption of innovative technology were identified (Rylands et al., 2015), and pathways for implementation were captured in two cases of best practice from the UK. Using SC mapping and the business model canvas (Osterwalder and Pigneur, 2010) as a lens, the business impact to VSs/manufacturing systems pre and post the adoption of 3D printing/AM was explored for two manufacturing SMEs. By doing so, this allowing for both the important factors for consideration (via the business model canvas) and flow (via VS mapping) of the changes to be captured. This research was one of the early studies focused on business/SC impacts as compared to other studies, that were focused more so on engineering and technical aspects of 3D printing/AM (Rylands et al., 2015). A model to capture the adoption and business impacts of 3D printing in the manufacturing process (Rylands et al., 2016) have been summarised in Figure 5.9, which could be used as a guide to practitioners and academics in guiding future 3D printing/AM adoption journeys.

8.2.3 Product, manufacturing and supply chain design innovation

A longitudinal case study was carried out in a start-up in order to investigate the growth of an agile, young organisation in its early stages, and the impacts of fast-paced change and innovation. Utilising a longitudinal case study added to empirical knowledge that had been identified as lacking in the literature in regards to understanding start-ups and their growth and survival (Scaringella, 2017). By exploring a start-up before it matured, it allowed for the identification of barriers or issues faced during growth that could be used by other practitioners on their journey of business growth or improvement. An existing model, the PDP model (Böhme et al., 2014a) was applied, tested and extended during this research, in conjunction with the manufacturing paradigm, CE/3D-CE (Fine, 1998), which was also extended during this research. From this, a model was formed, as per Figure 6.8, that could be used as a framework for other start-ups. The case organisation was undergoing constant evolution and this research provided insight into innovation that occurred through product, process, supply chain design and services.

Table 8.1: Research contribution by research question

| Theory | Research Question | Methodology | Contribution | Chapter |
|---|---|------------------------------|--|----------|
| <p>Supply chain integration: Stevens (1989); Stevens (2016);</p> <p>Uncertainty circle model: Mason-Jones & Towill (1998) Parnaby & Towill (2009)</p> <p>Systems thinking: Maani and Cavana, 2007; Kefalas, 2011</p> <p>Manufacturing systems: Parnaby, (1979); Parnaby and Towill (2009)</p> | <p>1. How mature are Australian supply chains in practice?</p> | <p>QSAMs</p> | <p>1.1 The further generalisability of QSAM in the Australian context. 1.2 Addition to the international QSAM database of knowledge. 1.3 Identification of systems uncertainty and SC maturity in practice in Australia. 1.3 Early insights into the benchmarking of SC maturity in Australia compared to International data/studies. <i>Early insight suggests that that Australian supply chains are not as mature as most international SCs that they were compared to. This suggests that there is an opportunity for stronger supply chain management to take place.</i> 1.4 Established uncertainty profiles for two Australian SCs. <i>High uncertainty was evident across all four aspects of the uncertainty circle model (process, control, supply, and demand).</i></p> | <p>4</p> |
| <p>Business model canvas: Osterwalder and Pigneur (2010)</p> | <p>2. How do barriers to supply chain maturity impact on business innovation?</p> | <p>QSAMs</p> | <p>2.1 Identification of common barriers to innovative opportunities in Australian manufacturers/ organisations through the use of root cause/cause and effect analysis. 2.2 Early insight into the relationship between the barriers in Australian organisations through the use of cause and effect diagrams and root cause analysis. 2.3 Extension of QSAM to investigate the link between barriers, low SC maturity and uncertainty to innovative capability, as summarised in Figure 4.9.</p> | <p>4</p> |
| <p>Business model canvas: Osterwalder and Pigneur (2010)</p> | <p>3. How do organisations adopt innovative technology into their existing supply chain? - <i>Focusing on 3D printing/AM</i></p> | <p>Multiple case studies</p> | <p>3.1 Identification of adoption aspects and pathways for businesses considering the implementation of innovative technology (3D Printing/AM). 3.2 Providing insight into an innovative technology (3D printing/AM) from a business/SC perspective. <i>Other earlier research on 3D printing/AM focused more on the engineering or technical aspects of the technology.</i></p> | <p>5</p> |

| | | | | |
|---|---|---------------------------------------|--|-----------------|
| <p>Value streams: Womack and Jones (1996)</p> | | | <p>3.3 Testing of AM adoption aspects and the impact on VSs/the manufacturing system. 3.4 Identification of knowledge centres during the adoption of innovative technology 3.5 Establishment of and the link between/role of knowledge centres and SMEs/organisations during innovative technology adoption.</p> | |
| | <p>4 What is the business impact of innovative technology adoption on the existing VSs/business manufacturing system?</p> | <p>Multiple case studies</p> | <p>4.1 Identification and mapping of additional/new VSs introduced through the implementation of innovative technology (3D Printing/AM) in conjunction with traditional manufacturing. 4.2 Combination of VSM and business model canvas as a lens for impact analysis (factors and flow), pre and post innovative technology adoption. 4.3 Development of a model to summarise 3D printing adoption and business impact (Figure 5.9), which could be used as a guide in future cases.</p> | <p>5</p> |
| <p>Manufacturing Systems: Parnaby, (1979); Parnaby and Towill (2009) PDP Model: Böhme et al. (2014a) CE and 3-DCE: Fine (1998; 2000)</p> | <p>5 How do manufacturing start-up SMEs upscale the production of innovative products overtime?</p> | <p>Single longitudinal case study</p> | <p>5.1 Application/testing, verification and extension of the PDP model (theory). 5.2 Development of a model of operationalisation/framework to complement other models (the Business model canvas for example) to assist organisations (start-up companies through to established organisations) with product, process, SC design and service (see Figure 6.8). 5.3 Added to knowledge on the growth/journey of start-ups in the Australian context through a single longitudinal case study. 5.4 Extension of theory (CE/3D-CE), with a fourth dimension suggested for future testing as part of Figure 6.8.</p> | <p>6</p> |

Source: Author

8.3 Relevance of research to practitioners and industry

This applied exploratory research is relevant to practitioners and industry as it provides insight into the current state of SC maturity in Australia and innovative capability enhancements through multiple means, including innovative technology adoption, product, process, service and supply chain design, that could be applicable and beneficial with regards to the changing Australian manufacturing landscape. Firstly, by utilising QSAM, it brings practitioners and academics together with benefits for both. The academic benefits through gaining access to assess real-world supply chains, and for the practitioner, importantly it provides an unbiased snap-shot or health check of the SC at that point in time that can be benchmarked. The practitioner gains insight into their SC through the data collected by the QSAM team, including the collection and analysis of mixed methods data. This includes but is not limited to SC, process and VS mapping, cause and effect analysis, the identification of root causes, major pains and areas where improvements or 'quick hits' can be made. This data is presented to the organisation, gaining validation, and presented to the practitioners in a final report that can be used by the practitioners to improve their SC maturity and systems uncertainty profiles. By collaborating with the QSAM team, the practitioners gain insight into their SCs with minimum impact to the organisation. The practitioners are able to continue with daily operations, whilst getting insight into their SC which is linked to theory.

This research provides benchmarking results for Australian and international SCs, that practitioners can use to see where their organisation is positioned in regards to other SCs from multiple industries, including exemplar SCs from the automotive industry. With many SCs displaying low integration and maturity levels, it shows practitioners that there are multiple SCs that need attention and gives the practitioner a starting point from which to improve.

Multiple conceptual models are also presented in this thesis that could be used to assist practitioners in improving their journey towards improved innovation capability (Figure 4.9), insight into adoption aspects and business impacts of 3D printing in manufacturing (Figure 5.9), and innovation through product, process, service and supply chain design through exploring the journey of a start-up (Figure 6.8).

Industry is competitive and practitioners are often looking for alternate modes to compete or ways to improve their business. Whilst there was evidence during this research of good practice and improvements initiatives in industry, such as through the use of manufacturing philosophies including lean, practitioners are often 'sold products' or theories that don't fit their business needs. This research provided relevant data and feedback for organisations that suited their business needs and could be

used to improve their performance, as well as provide important data for academia to learn from and further bridge the academic/practitioner gap.

8.4 Further research opportunities

This thesis presented contributions for academia and practice, as summarised in this chapter, and offered areas for future research opportunities throughout.

8.4.1 The current state of supply chain maturity and innovation in Australia

Due to the current state of SC maturity and innovative capability of SMEs within manufacturing in Australia, there is great opportunity for further research and improvement. Future research including a larger sample of additional SCs to add to the benchmarking of Australian organisations would be valuable, as well as follow up QSAMs with these organisations to see how they have changed. The inclusion of larger organisations would also be beneficial to be able to compare results to those seen within SMEs, as well as including industries other than manufacturing to gain insight into the performance of other industries. This would also allow the researcher to build up knowledge on root causes leading to lower SC maturity and increased systems uncertainty, that could be further generalisable to other organisations or settings. Future QSAMs could include other SC members, such as suppliers and customers, to gain a more holistic view of the state of the SC. There is also an opportunity for the researcher to review QSAM and possibly extend or improve upon the diagnostic tool in future research, and further test the extended PDP model in other settings (Figure 4.9).

8.4.2 The impact of the adoption of innovative technology on manufacturing systems/VSS

There is further opportunity to investigate the adoption process and business impact of 3D printing in a larger sample size of organisations, including in Australia. This research focused on two case studies from the UK, due to them being cases of best practice from which findings could possibly be generalisable to other contexts, which Australian organisations can learn from. As innovative technology becomes more widespread in Australia, it would be advantageous to investigate the impact that it has on a larger sample of organisations, including SMEs to larger organisations. The model in Figure 5.9 could be helpful to industry in guiding their journey of innovative technology adoption. Future research may also branch out to include other forms of innovative technology, such as robotics, artificial intelligence, simulations, and so on, as Industry 4.0 becomes more widespread.

8.4.3 Product, manufacturing and supply chain design innovation

This research included a single longitudinal case study that occurred over the period of approximately 16 months. It allowed the researcher to gain further insight into their journey and SC evolution as compared to other forms of case studies that are more limited by time. Due to sample size limitations

in this research, there is an opportunity to conduct additional longitudinal case studies and further add to knowledge in the field. This would allow researchers/practitioners the ability to draw comparisons between results and build up a more robust understanding of the impacts of product, process, supply chain design and service, or CE/3D-CE in manufacturing start up SMEs. There is an opportunity to test Figure 6.8 in future research to see if further extensions to the model are possible, and also to include organisations of different sizes and industries to gain further validation of results and understanding of opportunities available.

In summary, future research opportunities could include a larger sample size of different sized organisations from multiple industries within Australia to build up the database of knowledge. An exploratory investigation into innovation from a SC network perspective and how Industry 4.0 could be diffused into supply networks could be an area of future research, as well as understanding the role of Universities as knowledge centres and their responsibility, investigating what the right or optimum level of maturity is, and what other industries are adopting the technology of Industry 4.0 and how it is impacting on them.

8.5 Concluding remarks

Adaptation means not clinging to fixed methods, but changing appropriately according to events, acting as is suitable (Yu, as cited by Cleary, 1988, p. 125)

Supply chains are undergoing constant change. This is particularly evident in SMEs within manufacturing in Australia. Being able to identify improvement areas and areas of opportunity, as well as adapt to constant changes in the environment is necessary. This becomes even more imperative with the introduction of innovative technology as part of Industry 4.0 and the changes that this brings, highlighting the need for strong SCM understanding and capability.

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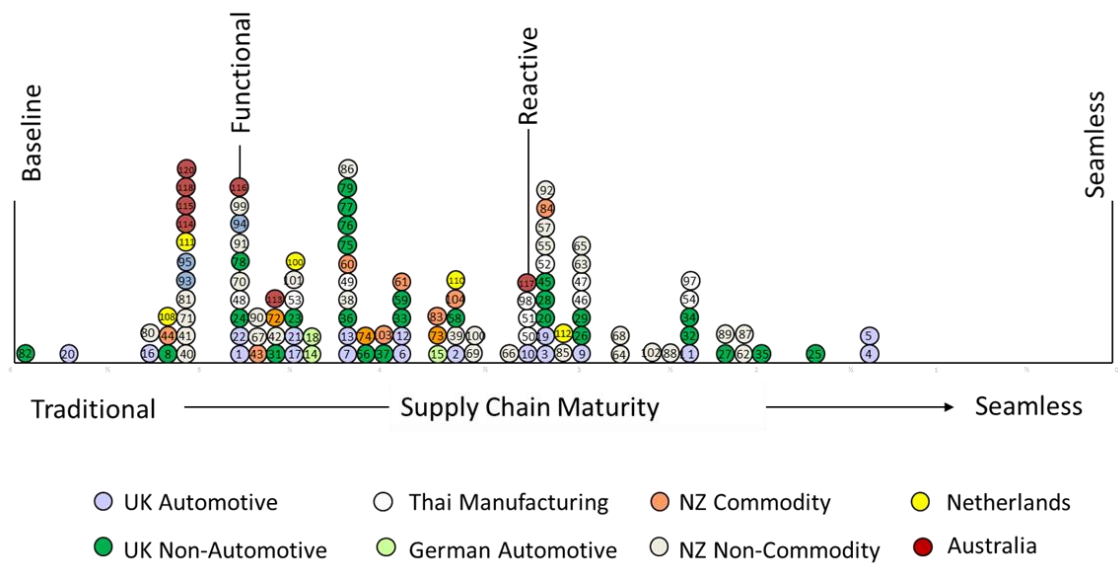
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10. Appendices

Appendix A: Quick Scan Audit Methodology (QSAM) maturity in practice

Supply chain maturity in practice



Source: Adapted from Childerhouse et al., 2011d, p. 544

Appendix B: Quick Scan Audit Methodology (QSAM) protocol documents

B.1. Supply chain integration maturity questionnaire

Supply Chain Integration Maturity Questionnaire

Select a single value stream to analysis. The value stream should be a major product family that is reasonably representative of the supply chain operations. If necessary repeat the questionnaire for other value streams if major differences are present.

| | |
|--|--|
| Organisation Name | |
| Interviewee Name | |
| Product Name | |
| Brief description of the product and its associated value stream | |
| Major value adding processes (e.g. assembly or machining) | |
| Location of Plant/ organisation | |

| Outbound Logistics | Definition | Response | Units |
|-----------------------------|---|----------|-------|
| Customer Delivery Lead Time | Please state the time between when a firm order is placed and when the product is delivered. (Call-off) | | |
| Customer Delivery Frequency | State the frequency of deliveries to your customers for the specified product. | | |
| Number of Customers | Please state the number of alternative customer companies. | | |
| Customer Locations | State the number of customer locations the specified product is deliver to. | | |
| Customer Delivery Distance | State the average customer delivery distance. | | |

| Internal Logistics | Definition | Response | Units |
|-------------------------------|---|----------|---|
| B.O.M. Levels | Please state the number of levels in the Bill of Materials for the specified product. | | |
| Manufacturing Lead Time | State the average time between when the raw materials are taken out of stock to when the final product is completed ready for delivery. | | |
| Position of De-Coupling Point | Products are manufactured and distributed to stocking points close to the customer. End products are held in stock at the end of the production then sent to customers on demand. Sub-assemblies held in stock, no FG stock, final assembly triggered by specific customer order. Only raw materials are kept in stock; each order for a customer is a specific project. No stocks are kept at all; purchasing takes place on the basis of the specific customer order. | | Make and ship to stock Make to stock Assemble to order Make to order Purchase and make to order |

| Product Characteristics | Definition | Response | Units |
|------------------------------|--|----------|---------------------|
| Product Variety | State the number of variants of finished goods for the specified product. (i.e. FG live part numbers) | | |
| Product Margins | What is the products profit margin? | | |
| Annual Volume | What was last years total sales volume? Please also specify the units (e.g. tones, pallets). | | |
| Echelons from end consumer | Number of organisations carrying out activities on the product before end consumption, excluding transport. | | |
| Length of product life-cycle | Please state your best estimate of the products total life-cycle length. | | |
| Customer Schedule Stability | Please give your best estimate of the percentage variation between what was scheduled one month ahead and what was actually required on the day. | | |
| Stage of product life-cycle | Which of the three alternatives best describes the current stage of the products life-cycle? | Infancy | Maturity Decline |

| Inbound Logistics | Definition | Response | Units |
|------------------------------|---|--------------------|--------------------|
| Number of Suppliers | How many different suppliers do you require for the specified product? | | |
| Customer Specified Suppliers | How many suppliers are specified by the customer? | | |
| Suppliers Delivery Lead Time | Please state the average time between when you place a firm order with your suppliers and when they deliver the product (Call-off). | | |
| Suppliers Delivery Frequency | How frequently do your suppliers deliver components for the two specified products? | | |
| Suppliers Delivery Distance | State the average delivery distance for the suppliers of the specified product. | | |
| Bought Out Components | How many different bought out components are required to produce one product? | | |
| Supplier relationships | On the whole how close a relationship do you have with your suppliers? | Partnership 1 2 | Adversarial 3 4 |

Source: Childerhouse, 2002

B.2. Complex material flow

Complex Material Flow

| Class of symptoms | Symptoms of complex material flow | Observed Symptom 1= present, 2= not present or ?= not looked for or investigated |
|--------------------------------|--|---|
| Dynamic behaviour | Systems-induced behaviour observed in demand patterns. | |
| | System behaviour often unexpected and counter-intuitive. | |
| | Causal relationships often geographically separated. | |
| | Excessive demand amplification as orders are passed upstream. | |
| | Rogue orders induced by system "Players". | |
| | Poor and variable customer service levels. | |
| Physical situation | Large and increasing number of products per pound of turnover. | |
| | High labour content. | |
| | Multiple production and distribution points. | |
| | Large pools of inventory throughout the system. | |
| | Complicated material flow patterns. | |
| | Poor stores control. | |
| Operational characteristics | Shop floor decisions based on batch-and-queue. | |
| | "Interference" between competing value streams. | |
| | Causal relationships often well separated in time. | |
| | Failure to synchronise all orders and acquisitions. | |
| | Failure to compress lead times. | |
| | Variable performance in response to similar order patterns. | |
| Organisational characteristics | Decision-making by functional groups. | |
| | Excessive quality inspection. | |
| | Multiple independent information systems. | |
| | Overheads and indirect costs allocated across product groups, and not by activity. | |
| | Excessive layers of management between CEO and shop floor. | |
| | Bureaucratic and lengthy decision-making process. | |

Source: Childerhouse and Towill, 2003

B.3. Simplified material flow questionnaire

Simplified Material Flow Questionnaire

For each of the following 12 simplicity rules rank how closely they are adhered to.

| Rule | Description and definition | Adherence (1=never, 2=sometimes, 3=most of the time or 4=always) |
|------|--|---|
| 1 | Only make products which can be quickly despatched and invoiced to customers | |
| 2 | In any one 'time bucket' only make components needed for assembly in the next period | |
| 3 | Streamline material flow and minimise throughput time, i.e. compress all lead times. | |
| 4 | Use the shortest planning period, i.e. the smallest run quantity that can be managed efficiently | |
| 5 | Only take deliveries from suppliers in small batches as and when needed for processing or assembly | |
| 6 | Synchronise 'time buckets' throughout the supply chain | |
| 7 | Form natural clusters of products and design processes appropriate to each value stream | |
| 8 | Eliminate all uncertainties from all processes | |
| 9 | Understand, document, simplify and only then optimise (UDSO) the supply chain | |
| 10 | Streamline and make highly visible all information flows throughout the chain | |
| 11 | Use only proven, simple yet but robust Decision Support Systems | |
| 12 | The operational target is to facilitate a Seamless supply chain i.e. all players to "think and act as one" | |

Source: Childerhouse and Towill, 2003

B.4. Uncertainty questionnaire

Uncertainty Questionnaire

| Questions asked of each value stream | Rating by QS Team | | | |
|--|-------------------|--------------|-----------------|-------------------|
| | Strongly agree | Weakly agree | Weakly disagree | Strongly disagree |
| The value added process(es) generates low system uncertainty | 1 | 2 | 3 | 4 |
| The supplier side generates low system uncertainty | 1 | 2 | 3 | 4 |
| The demand side generates low system uncertainty | 1 | 2 | 3 | 4 |
| The system controls do not generate uncertainty | 1 | 2 | 3 | 4 |

Source: Towill et al., 2002

B.5. Semi structured interviews overview

| <i>Who to interview</i> | <i>Example areas to cover</i> |
|--|---|
| Factory manager | Strategy, future factory focus (internal and the market), systems, initiatives, motivation, market. |
| Logistics manager | Overview of the total logistics system, systems, performance measures. Material delivery systems. |
| Customer interface | Customer base, measures of performance, customer satisfaction levels, communication channels, schedules visibility, demand patterns, changes, volumes, mix, future customer requirements. |
| Production scheduling | Systems architecture, schedule stability, perceived customer demands, production problems, information flow map. |
| Raw material scheduling | Systems used, amount of expediting, typical lead-times, profile of goods-in, information flow map. |
| Production manager | Scheduling, machines, material flows, change programmes, shop floor structure, team structure, shift patterns, equipment down-times, union issues, changeovers, scrap rates. |
| Shop-floor team (including team leader and operator) | Roles and responsibilities, communication channels, working conditions, team meetings, continuous improvement programmes, shop-floor changes, shift patterns. |
| Goods-in | Procedures, document control, transport issues. |
| Goods-out | Procedures, document control, transport issues. |
| Quality manager | Procedures, change programmes, process capabilities, customer requirements, scrap rates. |
| Human resources | Resource issues regarding the workforce, local labour pool problems, union issues, training budgets and programmes. |
| Equipment engineers | Organisation of team, reactive/proactive management, budget, machine capability, operator performance. |

B.6. Semi-structured interviews – example of additional questions

Finance:

1. What is the view and strategy towards obsolete stock?
2. What kind of organisational investments are being planned in the next 5 years?
3. Is there an acquisition strategy?
4. What is the inventory strategy for the future?
5. What is your opinion of getting a new warehouse from a finance point of view?
6. Are there bonus strategies/incentives companywide?
7. Are there risk management strategies in place? (e.g. hedging?)
8. What are the payment conditions and discounts (e.g. for customers, suppliers)?
9. What problems /major pains/ improvement opportunities do you see in the organisation? (e.g. projects)
10. What is being done well? (good practice)
11. Structure of the business – what needs to happen in order for the business to grow?
12. What are the core competencies of the business?

Source: Author

Organisational culture:

1. What cultural barriers exist? Why?
2. What is the level of trust like? Win-lose negotiations/feeling?
3. What is the level of co-operation like? Is there information sharing? Are win – win situations created?

Technology:

1. What are the costs like for feasibility studies?
2. What are your hardware and software costs?
3. What are your management costs?

4. Source of funding versus price of failure to adapt – describe this for your organisation.

Organisation:

1. What is your supply chain structure/ organisational structure?
2. Can you describe your organisation's transactions? Are they often/periodic? Span of contracts?
3. Governance – how is your supply chain directed and controlled?
4. Describe the member interactions/relationships within the supply chain/organisation
5. Is there volatility in or in-between departments or is there stability?
6. Describe how information is shared (e.g. emails, meetings, phone calls, etc)
7. Describe the technical skills in the organisation
8. Are there product champions?

Source: Based on Mason-Jones et al., 2001; Towill, 1991

B.7. Semi-structured interview questions – example of additional questions specific to 3D printing

Technical:

| | | |
|---|---|---|
| 1 | Printing capability | Are multi-materials/colours required? Are the printers capable of this? (material type and/or production of unique structures). |
| 2 | Quality outcome (ISO) | Is quality assurance such as ISO required? What is the quality of the 3DP / AM items? Are there controls or processes in place to monitor or rectify any issues? |
| 3 | Technology (machine types /technology suits available) | What industry are you in? What products do you want to 3D print? What type of machine(s)/printer(s) will you need? (E.g. metal, polymer, bio or other?) Is the chamber volume / number of chambers sufficient? Is this the best or most suitable production tool? |
| 4 | Product and process complexity (support structures, geometric complexity, moulds) | Are supports required in producing specific items? Does the complexity of the item warrant the use of 3D printing over traditional production methods? |
| 5 | Raw materials (chemical composition, particle size, new/recycled) | What type of raw materials will be required? (e.g. powder, filament) Are the raw materials reliant? (Both source and chemical composition). Will they be purchased from suppliers or produced in-house? |
| 6 | CAD/design | Can design be done in-house or will it be outsourced? |

| | | |
|---|----------|---|
| | | Is the required technology available to the business? (E.g. CAD). |
| 7 | Function | What will the function of the finished part/product be? Is 3DP/AM capable of producing this? |

Managerial/business:

| | | |
|---|---|--|
| 1 | Supply chain capability | Is the supply chain capable of adapting to the changes brought about by 3D printing? What changes have to be made? Timeframe? |
| 2 | Product/product lifecycle | What product / part is to be produced? What is the lifecycle of it? Are you producing a part to fit a product or vice versa? |
| 3 | Raw material (e.g. type, availability, weight) | What raw materials will be required? (E.g. powder, filament). Is the material recycled or new? What is the mass of the raw material? Is it readily available? Common? |
| 4 | Inventory cost | Is inventory space an issue with current / traditional manufacturing? Are there systems in place to manage it? |
| 5 | Operational strategy (design to order/make to order process simplification) | Will 3DP be used for short-run production or specialized/customized items? What type of manufacturing will be taking place? Will 3DP/AM be used to produce prototypes or in the manufacturing process? Will it be labour intensive? High-volume products? |

| | | |
|----|---|---|
| | | What is the build-rate for your product? |
| 6 | Marketing strategy (customer wants/needs) | Describe your marketing strategy |
| 7 | Production location/hubs/infrastructure | Where will the production location be? Will it be part of a hub? |
| 8 | Logistics/transport cost | What type of transport will be used? Is the mass of the raw materials / finished product lightweight/small/heavy/large? Are there more specific routes that can be chosen to maximise logistics time/cost? Custom checks/ taxes, etc? (time and costs to consider) |
| 9 | Lead time compression | Will there be bottlenecks in getting raw materials, 3Dprinting/production, and logistics in getting the item to the customer? Is the lead time competitive? |
| 10 | Patents/Intellectual property/copyright | Have relevant patents expired or due to expire soon? Have there been any IP/ copyright issues in your area that should be considered before progressing? |
| 11 | Supply chain flexibility and design | Are there plans in place for the evolution of your supply chain? Are there emerging networks that could help your organisation? |
| 12 | Suppliers | Are suppliers reliable? Are you using local or international suppliers? Can the task be done in-house? |
| 13 | Scalability | Can the business model be scaled up if necessary? |

Social:

| | | |
|---|---|--|
| 1 | Sustainability/reduced environmental impact | How energy intensive is the material being used? Emissions? Recyclable content of material? Are there better materials that can be used? Can your environmental impact be improved by the used of 3D printing/Additive manufacturing? |
| 2 | Consumer/ community concerns/ acceptance/ethics | What ethical concerns surround your product? Are there ways that this could be improved? Are there concerns regarding traditional methods vs. new methods of producing products? (craftsmanship) |
| 3 | Community/Government/University involvement | Is the area in which you are based an entrepreneurial area? Are there other groups or organisations that could assist you? Or that you could work with/network with? Is there Government funding or a budget for your area? |
| 4 | Education (transforming society) | Are the community aware of or educated in 3DP/AM? Is there anything that your company could do to improve this? (e.g. marketing/promotions, education programs, working with local educational institutions, etc) to create awareness. |

Environmental:

| | | |
|---|---|--|
| 1 | Changing technology | Do you have multi-material, multi-colour, batch production capability? Is your organisation ready for 3D printing? |
| 2 | Changing consumer demand and abilities | Do you have an idea of what demand will be like in the future? Is your organisation ready for this? |
| 3 | Simulation models and development times | Is your organisation using simulation to assist in shortening development times? |

Source: Based on Rylands et al., 2015

Appendix C: Impact statement examples

C.1. Company 1– impact statement

“SUPPLY CHAIN TESTIMONY

From day one starting with the Supply Chain innovation introduction document I knew this program was going to yield results. I found the team to be much more than Academics with many years of practical experience in various industries that we could relate to.

Each member of the audit team delivered not only on how to conduct an effective audit from the extensive audits already carried out but were able to relate to all positions within our company ranging from warehousing, production assembly, financial, administration, sales, etc.

It was also of great interest to see where we bench marked in supply chain performance across many industries and different countries.

In closing I thoroughly recommend the audit process to any company as long as you're prepared to open your business and listen to brutally honest, unbiased views.

Look forward to your report

Cheers”

- Company 1 - Customer Service and Logistics Manager

C.2. Company A – impact statement

“Basically, whilst the information is gathered by yourself on a visit plus talking with us it gives third parties a possible different perspective when the information is presented by third party and has been published as a peer reviewed item.

I have used it for company advantage whilst having a review done by the company bankers also the factoring company we use.

I use the item when going abroad and especially in Finland whilst engaging with VTT (the government research organisation for Finland)

I've used for consultant who was gathering information on the company

Academically we have been included in a supply chain research project done by the University of Liverpool and I referred your paper to them.

When I am interviewed by different organisations, I would normally use your paper as part of the introduction prior to interview.

When students interview me, I normally refer them to your paper after the interview.

Especially when student's questionnaire is quite often not appropriate to how we perform as a business”.

- Company A - Director

Appendix D: Quick Scan Final Reports

D.1. Company 1 – Quick Scan Audit report

Executive Summary

Company 1's supply chain integration level is judged in the lower percentile for both investigated value streams namely Boxes and Techno. Especially, the high amount of external (supply and demand uncertainty) as well as the value stream control elements for both value streams are judged high uncertainty. Root causes for low levels of supply chain maturity have been identified using systems thinking via cause and effect analysis: Limited supplier relationship management, a poorly integrated information system, large amount of tacit knowledge and quality management treated as a necessity is holding back the organisation in driving efficiency across the operational and managerial level. Also, the unclear company strategy and therefore the lack of strategic alignment raises questions/ concerns of the future direction/ state of Company 1.

A multitude of improvement opportunities were identified. However, Company 1 is currently operating with an ambiguous strategy that is poorly communicated within the organisation. The ambiguous target of 100million revenue is not well translated into business objectives, which results in an unclear growth strategy, unclear core competence, unclear marketing strategy and ultimately averaging of customer service. Prior to engaging in major improvement efforts, it is recommended to clearly identify Company 1's future direction. Further, strategically aligned value streams need to be identified, which are tailored to customer expectations.

Quick Scan Audit Methodology

The Quick Scan is a tried and tested method for auditing the health of supply chains. Five researchers from the University of Wollongong conducted the audit in October/ November 2013. In total, some 40 person days were invested in evaluating the status of supply chain operations at Company 1 (NSW). The Quick Scan team examined the integration of the internal supply chain and its fit with the wider supply chain setting.

Findings

The overall level of supply chain integration was judged in the lower percentile for both products namely Boxes and Techno. Techno scored slightly better due to the smaller amount of demand uncertainty. Both products face high supply and control uncertainty. Table 1 provides the benchmark scores for Boxes and Techno on n=120.

| | Techno | Boxes |
|---------------------------------|---------------|--------------|
| Complexity Symptoms | 91st | 94th |
| Simplified Material Flow | 89th | 96th |
| Supply Chain Uncertainty | 84th | 101st |

Table 1: Benchmarking performance of Company 1

Although the Quick Scan was primarily focused on identifying weaknesses and improvement opportunities for advancement at Company 1, four important positive aspects were noted during the investigation:

1. A strong willingness to drive efficiency into the organisation
2. Commitment to solving problems – responsiveness to the customer
3. Strong market position and the initiative to implement e-business solutions
4. Identified growth potential in particular around value adding products.

Five major areas of shortcoming were observed namely unclear business strategy, limited supplier relationship management; poor IS integration, large amount of tacit knowledge, and quality management treated as a necessity.

Unclear Business Strategy

Company 1 is currently operating with an ambiguous strategy that is poorly communicated within the organisation. The ambiguous target of 100million revenue is not well translated into business objectives, which results in an unclear growth strategy, unclear core competence, unclear marketing strategy and ultimately averaging of customer service. Prior

to engaging in improvement efforts, it is recommended to clearly identify Company 1's future direction.

Company 1 has entered a so-called grey zone where additional growth will most likely result in high amounts of rework and firefighting due to a lack of structure, policies and procedures. In order to grow; a more structured and procedural organisation is required. However, Company 1 will lose some of its flexibility; something highly desired by their current customer base. Hence, the key for long-term success is a clear and meaningful company strategy including a clear vision of the future state of the organisation. This vision and strategic development process will allow for strategic alignment to take place on the investment strategy site, marketing site and ultimately on the logistics and supply chain management site. Meaningful, cross-functional KPI's will finally reinforce these objectives on a human resources level. The following question for the QSAM team remains: *"Are you better off being a dwarf challenging the giants?"*

Limited Supplier Relationship Management

Company 1 is experiencing variation in service lead time from their suppliers. Especially the performance of Supplier A supplying out of India (Goa) and Sri Lanka results in large amounts of buffer inventory due to poor supplier performance. Despite many socialisation tactics to improve the responsiveness and performance of Supplier A; Company 1 is frequently let down by their supplier. An experienced procurement professional would help Company 1 to improve and potentially restructure its supplier base. This role further requires a strong contract management focus to obtain better equality in buyer – supplier relationships.

Poor IS integration

The business strategy, once well translated into business objectives, will also guide the critical review of existing practices and procedures as well as existing tools and IT systems resulting in the identification of further potential improvements/investments. The Quick Scan team suggests investing resources in data cleansing (stock keeping units, remove ZSCRAP, actual inventory on stock, location of stock in warehouse, adjustment of

warehouse location and picking slip order, record stock availability dates in the system and not arrival dates) and the development of clear and unambiguous rules for:

- forecasting (frequency of adjustment, clear responsibility),
- replenishment (reorder of stock to reach minimum or maximum stock levels? to secure delivery for a specific time period – e.g. 3 months, six months? critical review of defined stock levels)
- ordering (fixed dates per month to combine orders from different product managers from one supplier into one shipment)
- and the processing of customer orders (clear prioritization rules of orders for internal and external customers).

Large Amount of Tacit Knowledge

Company 1 has a strong tacit knowledge base, which leaves the organisation vulnerable to individual decision makers. Decision Making can be classified as an art rather than a science.

A random stock take conducted by the QSAM team revealed the following:

- more items on stock than listed
- more items on the pallet sheet than on stock or
- less stock in warehouse than recorded on system.

The outcome of this practice is high picking inefficiency. Further, location knowledge is required (expertise) in order to improve picking lead time. Additionally, the picking lists are not structured sequentially. This means that the pickers decide the sequence of picking based on their insider knowledge. These two examples of “firefighting” are judged time-consuming and hence can be classified as non-value-adding activities.

Firefighting is also present on the managerial level. Within the sales department for example, customer orders are confirmed and products are sold although the availability of stock is not guaranteed. This leads to a change of customer orders or rework (e.g. door painting). Recording the availability of and making this information transparent will improve sales team decision making.

Additionally, the QSAM team suggests to use the valuable knowledge of each employee to learn from mistakes and to learn by experience. It is essential to make this knowledge of each individual transparent (explicit) and available (e.g. supported by an IT-system). Explicit knowledge will allow Company 1 to improve processes efficiency and to strengthen the company sustainably. Using IT-systems to its full extend (e.g. Pronto) may generate more visibility and make required data and information available for every employee; therefore, converting decision making as a tacit knowledge art form into a scientific fact-base procedure.

Quality Management Treated as a Necessity

Whilst Company 1 has ISO 9001 accreditation, the QSAM team identified improvement opportunities within the area of quality management. Quality Management should be the engine that drives continuous improvement across the organisation and be embraced throughout Company 1. Developing measurements in each department and getting complete and accurate data will allow Company 1 to better assess current performance, identify cause and effect, and set benchmarks for future improvement.

Partial information on picking errors/accuracy for example was previously recorded in the warehouse system and if continued, this could help improve visibility and understanding of cause and effect for the errors. During a random stock take for three items, a 72% accuracy level was recorded. One area of failure was due to more stock being on the pallet sheet than on the actual pallet, which could be highlighted in a toolbox meeting, updated and used for future learning's. Data for quality management could also be collected and recorded by Customer Service during their daily interaction with customers and shared with other departments. DIFOT could be extended to DIFOTTS to include not just delivery in full on time, but also to specification. Identifying clear measures/KPI's and aligning them with business strategy will assist strengthening Company 1's position.

Quick Hit solutions:

Despite the efforts of developing a well-informed strategy and align the business to pull into one direction the QSAM team also identified a few Quick Hits. Quick Hits are short term solution that will have a small but immediate impact on Company 1's operation.

- Prioritizing of picking slips according to importance of customer.
- Measure picking accuracy and improve using DB as an internal customer and/ or the packers to record and provide feedback.
- Record and make transparent the availability of stock; not arrival date of shipment. This is especially important for the sales and marketing team.
- Record all quality incidents for accurate and complete data; so better-informed decisions can be made on operations integrity.
- Roll out toolbox at management level for more effective communication.
- Sensor check all orders from your top priority customers to avoid service let down.
- Implement R&D and future outlook meetings amongst Product Managers.

D.2. Company 2 – Quick Scan Audit report

Executive Summary

Company 2's supply chain integration level is judged in the lower percentile for the entire company as well as for the sites in NSW '1', NSW '2', and NSW '3'. The supply chain integration level for the site in the ACT is judged reactive. Especially, the high amount of external (particularly demand uncertainty) as well as the internal process and supply chain control elements are judged high uncertainty.

Root causes for low levels of supply chain maturity have been identified using systems analysis via cause and effect analysis. Changing strategies and a contradicting manufacturing philosophy, infrastructure in NSW '3' and skill basis are holding back the organisation in driving efficiency/ effectiveness across the operational and managerial level. These root causes result in declining profitability despite growing revenue as well as a threat of knowledge drainage. A multitude of improvement opportunities were identified. However, Company 2 requires to clearly identify their manufacturing philosophy around operational excellence and obtain buy-in throughout the organisation. The growth target and the acquisition strategy (e.g. ACT) are poorly communicated within Company 2 and the lack of management focus results in poor strategy implementation (e.g. lean journey). Therefore, it is recommended to work out a clear strategy and manufacturing philosophy and effectively communicate the overarching direction. Additionally, understand and document your material and information flows first before simplifying and optimising them.

Quick Scan Audit Methodology

The Quick Scan is a tried and tested method for auditing the health of supply chains. Five researchers from the University of Wollongong conducted the audit in November 2013. In total, some 40 person days were invested in evaluating the status of supply chain operations at Company 2 (including NSW '1', NSW '2', NSW '3' and ACT). The Quick Scan team examined the integration of the internal supply chain and its fit with the wider supply chain.

Findings

Taking a look at the cross-company comparison of Company 2 related to the simplicity of the material flow the QSAM (Quick Scan Audit Methodology) Team obtained a heterogeneous result. ACT is positioned best at place 25 out of 107 within the Company 2 group. NSW '2' is at the 82 percentile out of 107 and hence in the lower quartile of the ranking. By getting four very different ranks according to the simplicity of the material flow, Company 2 as a group has the unique chance to identify good and bad practices on the four sites trying to consequently transferring good and eliminating bad practices company wide.

| | ACT | NSW '1' | NSW '2' | NSW '3' |
|--------------------------|------------------|------------------|------------------|------------------|
| Simplified material flow | 25 th | 63 rd | 82 nd | 51 st |
| | | | | n=107 |

Table 1: Benchmarking performance Company 2

Although the Quick Scan was primarily focused on identifying weaknesses and improvement opportunities for advancement at Company 2, important positive aspects were noted during the investigation:

- Willingness to improve
- Aiming at simplicity and time compression
- Innovative thinking in a commodity market
- Loyalty of core individual staff
- Problem solvers/ fire fighters
- Good attitude to get things done on-time
- Senior-Management: Good overall SC-understanding
- Management: Weekly continuous improvement meetings (toolbox)
- Dashboard-IT Integration

Changing strategies and contradicting manufacturing philosophy

Company 2 is operating in a manufacturing to order environment where lean is decoupled from agile strategies at the inwards goods warehouse; meaning that the order penetrates far upstream with a high level of customization. Additionally, each paper can follow a multitude of different avenues until the finished product is ready for dispatch. Company 2 is currently rolling out lean manufacturing; however lean is not perceived as a manufacturing philosophy rather than a toolbox. Hence, the company has not progressed very far on their lean journey. Additionally, senior managers in the organization are not convinced that lean manufacturing is the right path to go. The manufacturing strategy needs to be closely looked at and a clearly aligned strategy defined so that all workers and manager pull the organization in the same direction.

Company 2 is operating in a highly uncertain environment and hence changed strategies frequently to adjust to the changing conditions. However, these changing strategies resulted in a lack of and/ or changing focus from senior management. These changes of focus made other sites (e.g. NSW '1', NSW '2') wonder about how serious senior management is about making these sites work properly. What is described is a lack of understanding how to operationalize the existing portfolio of sites which is partly also influenced by a contradicting manufacturing philosophy.

Infrastructure Strathfield

The site in Strathfield is currently running out of space, especially on Fridays around despatch and especially inwards goods. Store capacity is exhausted and pallets get piled up which creates a hazard under the Health and Operational Strategy. Additionally, piling of pallets is classified inefficient as it leads to double handling. One possible solution for these inefficiencies can be to build up a pallet shelf, where pallets can be stored efficiently and safely.

Skill basis

The skills at each site vary, with predominantly trainee staff at NSW '2' to over 10+ years' experience per employee (including both the shop floor and management) at other sites. The knowledge and skills at each site though tends to be tacit knowledge and not widely communicated and/ or documented. It would be of benefit to Company 2 if major processes were documented. Rather than just generic job descriptions, documenting the key 10 or so tasks into procedures for each role would assist people in knowing exactly what they are responsible for. These documents could also be used when people are on leave or even for training new employees. With the potential risk of knowledge drain in the organization, it is important to give employees both; empowerment and clearly communicated expectations and key tasks.

- With regards to potential knowledge drain, survey results show that more than half of those surveyed did not feel that breaks and variety of work or work/life balance was seen as being important to Company 2. Employees though do strive to be flexible and work overtime to ensure that the product gets to the customer.
- The potential knowledge drain will amplify the effect of increasing inefficiencies due to strong individual tacit knowledge.

Training for both management and the shop floor could also be of benefit, from ensuring that all have access to key systems (such as Da Vinci and the Dashboard) and are trained to use them by IT, to perhaps further executive training for Management in regards to strategic management, operations strategy, and change implementation.

Quick Hit solutions:

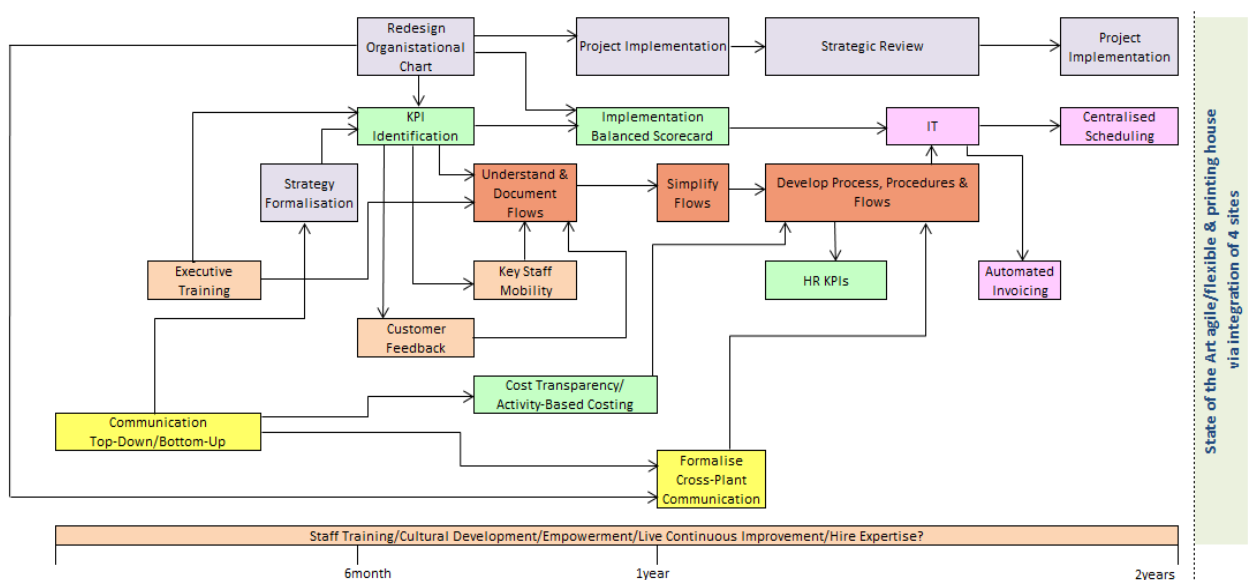
Despite the efforts of implementing continuous improvement and lean process flows the QSAM-team also identified a few Quick Hits. Quick Hits are short term solutions that will have a small but immediate impact on Company 2s' operation:

- KANBAN-system NSW '2'/NSW '3'
- Put break-up of the order on tickets (customer locations)

- VMI for suppliers at NSW '2'
- Sales reps/use job specification sheets
- Key tasks per role & an organizational chart
- Newsletter – Bottom up/top down (celebrate success)
- Acknowledge success
- DIFOTIS (internal customer)
- Letterbox & phone (NSW '2')
- Company Signage (be proud of Company 2)
- Develop overview of site capabilities and communicate throughout the organisation
- Share phone numbers

Improvement Opportunities:

Based on the suggested Quick Hints the QSAM team suggests medium to long term solutions which will have a valuable and sustainable impact on Company 2's operation:



In order to be able to effectively drive change in the organization; a more rigorous attempt by management should be considered. The classic Understand – Document – Simplify and then Optimise approach to business process re-engineering can form the basis for change. The

QSAM team judges the following KPI's as beneficial for Company 2 to start understanding their business processes better:

- Delivery in full on time to specification (DIFOTIS / Warrawong and customer/ supplier)
- Service Level Agreement supplier/maintenance
- Run Times/throughput machines
- Order lead time (production lead Time)
- Scrap rates & non conformance
- Work in Progress
- Rework
- Schedule stability

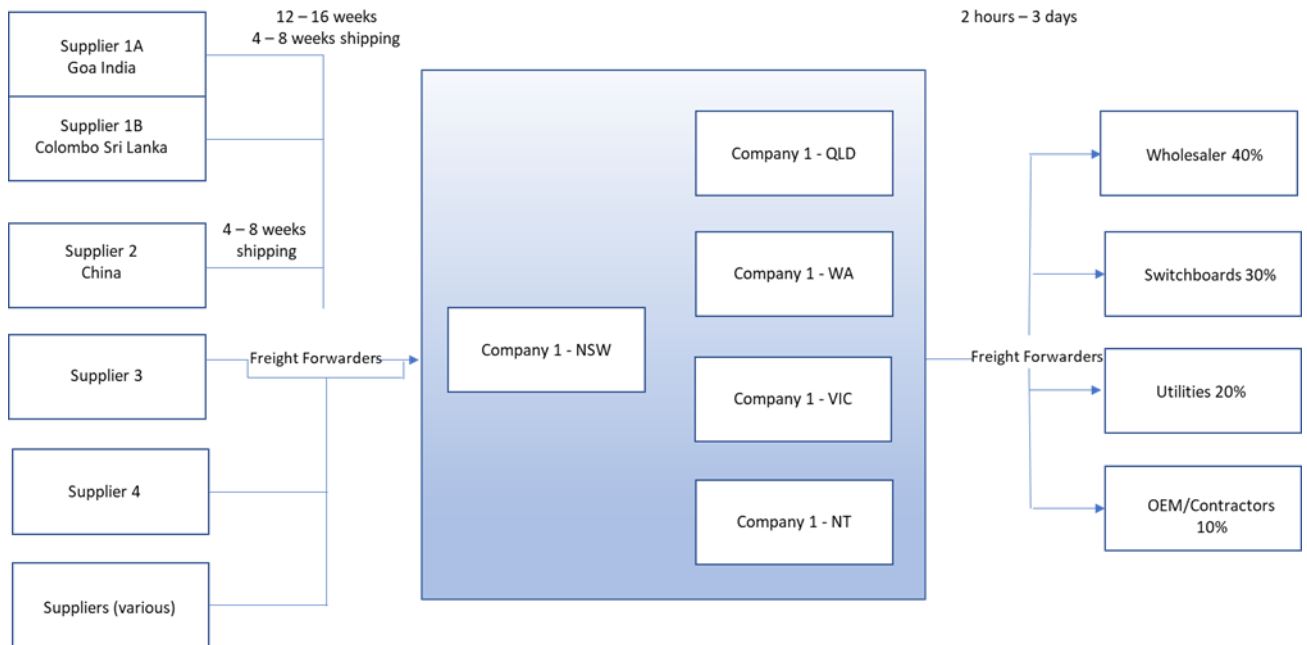
Appendix E: Quick Scan Audit Methodology (QSAM) – interview participants from Companies 1 and 2

| Company 1 interviewees: | | Company 2 interviewees: | |
|-------------------------|--|-------------------------|-------------------------------------|
| 1 | Managing Director and CEO | 1 | Managing Director and Owner |
| 2 | Customer Service and Logistics Manager | 2 | Managing Director |
| 3 | Supply Chain Manager | 3 | Manager – ACT site |
| 4 | Marketing & Quality Manager | 4 | Production Manager - ACT |
| 5 | Product Manager A | 5 | Sales Representative |
| 6 | Projects Manager | 6 | Sales Representative |
| 7 | Product Manager B | 7 | Production Manager – NSW 1 |
| 8 | National Warehouse Receiving Supervisor | 8 | Logistics Manager |
| 9 | Leading Hand | 9 | Customer Interface |
| 10 | Warehouse Manager | 10 | Quality Manager |
| 11 | Customer Interface /Marketing & Sales – National Sales Manager | 11 | Pre-press Manager |
| 12 | Customer Interface – Internal Sales Team Leader | 12 | Production Scheduling |
| 13 | Customer Interface – Sales: State Manager – NSW/ACT | 13 | Press room and bindery Manager A |
| 14 | Business Manager - Systems and Enclosures | 14 | Press room and bindery Manager B |
| 15 | Logistics Officer | 15 | Shop-floor team |
| 16 | IT Manager | 16 | Goods-in Manager |
| 17 | Accounts Manager | 17 | Equipment Engineer/IT |
| 18 | Finance Director | 18 | Accounts Manager |
| | | 19 | Factory Manager |
| | | 20 | Scheduler, Press room Supervisor |
| | | 21 | Bindery Manager |
| | | 22 | Designer, HR, Marketing |
| | | 23 | Goods-out Manager |
| | | 24 | Goods-In Manager |
| | | 25 | Customer Service |
| | | 26 | Production Manager – NSW 2 |
| | | 27 | Bindery Manager/ Operations Manager |
| | | 28 | Dispatch/Warehousing |

Source: Author

Appendix F: Company 1 – Quick Scan Audit findings

F.1. Company 1 – overall supply chain



Source: Adapted from QSAM feedback presentation

F.2. Company 1 – airfreight

| Customer | Supplier name | ETD | ETA | Goods Description | Pieces |
|-----------|---------------|------------|------------|--------------------|--------|
| Company 1 | Supplier A | 18.10.2013 | 22.10.2013 | Electrical | 1 |
| Company 1 | Supplier B | 20.10.2013 | 22.10.2013 | Metal cable cleats | 1 |
| Company 1 | Supplier B | 22.10.2013 | 24.10.2013 | Metal cable cleats | 5 |
| Company 1 | Supplier B | 23.10.2013 | 25.10.2013 | Metal cable cleats | 6 |
| Company 1 | Supplier A | 22.10.2013 | 27.10.2013 | Electrical | 5 |

Source: Adapted from QSAM feedback presentation

F.3. Company 1 – sea

| Customer | Shipment | Arrival date according to container schedule | | | |
|----------|---------------|--|-------------|-------------|-------------|
| | | @14.10.2013 | @21.10.2013 | @28.10.2013 | @31.10.2013 |
| A | SEA4004 | 13.11.2013 | 05.11.2013 | 05.11.2013 | 18.11.2013 |
| B | 768774-770526 | 18.11.2013 | 18.11.2013 | 18.11.2013 | 18.11.2013 |

Source: Adapted from QSAM feedback presentation

F.4. Company 1 – warehouse inefficiency

| Picking accuracy, stock location and integrity | |
|---|-------|
| Picking error according to the system: | <0.5% |
| Picking error according to the internal customer: | >15% |

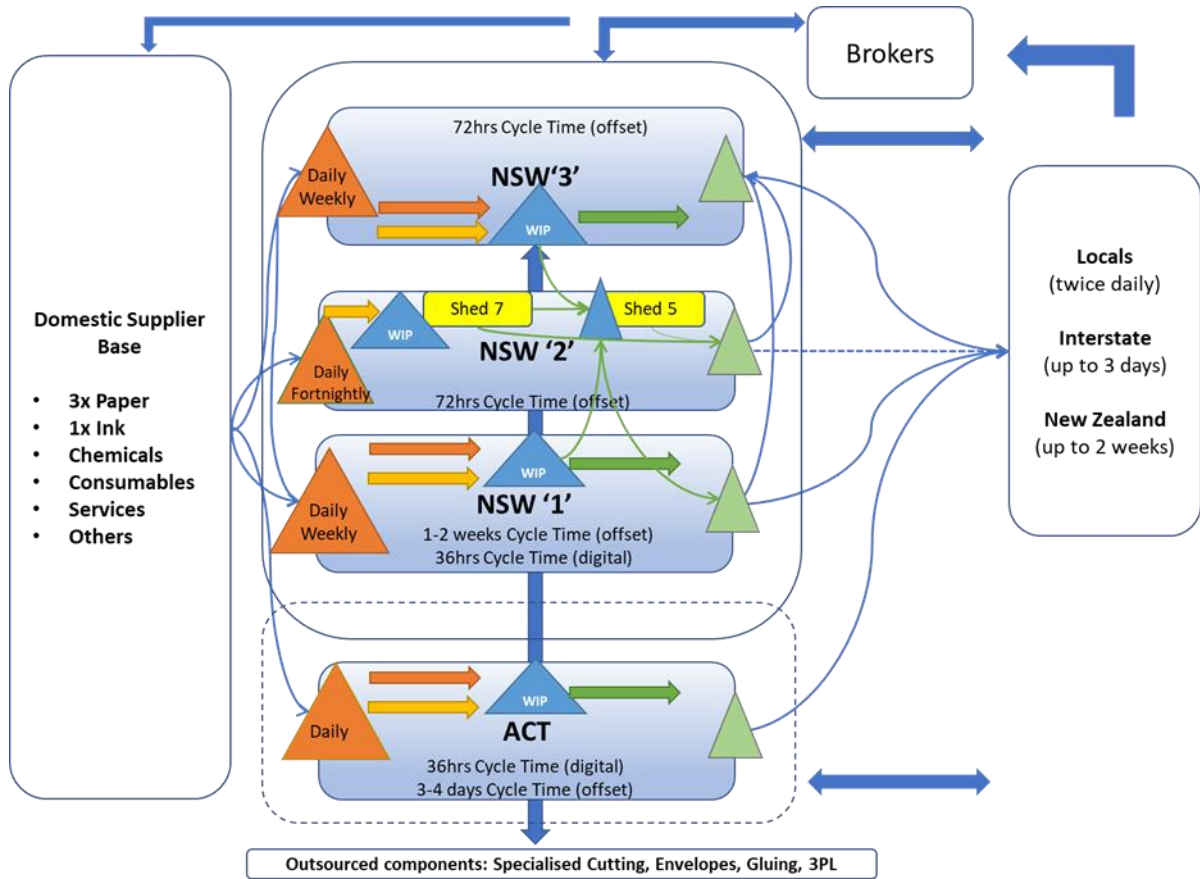
| Location and stock integrity: | |
|--------------------------------------|---|
| Company 1's impression: | 85% of the SKUs are at the right place in the right quantity |
| Pickers impression: | 30-40% of the SKUs are not at the right place in the right quantity |

Source: Adapted from QSAM feedback presentation

- A random stock take was conducted by the QSAM team during the site visit
- The result: 13 out of 18 items were in the correct place and in the correct quantity (72% correct).
- Reasons for failures: 1 x more items in stock than in the system, 1 x more items on the pallet sheet than in stock, and 3 x less stock in the warehouse than in the system.

Appendix G: Company 2 - QSAM Findings

G.1. Company 2 – overall supply chain



Source: Adapted from QSAM feedback presentation

G.2. Company 2 – Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis

| Strengths | Weaknesses |
|--|---|
| <p>Culture</p> <p>Employer of choice</p> <p>People</p> <p>Trust in management</p> <p>Continuous improvement procedures</p> <p>Continuous improvement information</p> <p>Competitive intelligence – structure, adaptability/agility</p> | <p>Integration</p> <p>Disengaged people</p> <p>Structure</p> <p>Transparency for staff</p> <p>Communication – at all levels</p> <p>Rapid growth</p> <p>Lean buy-in – from the bottom up, implementation</p> <p>Problem solving/ quick fixes</p> <p>Teamwork – silos</p> <p>Profitable</p> <p>Logistics</p> <p>Competitive intelligence – market scope (narrow/national)</p> |
| Opportunities | Threats |
| <p>Right people/right place</p> <p>Lean thinking</p> | <p>Skills - industry isolation</p> <p>Environmental considerations – e.g. competition, new technology, product life cycle, change in government, industry consolidation, falling Australian dollar, high market fluctuations, divide in industry players (very big or very small players), fight for survival</p> |

Source: Adapted from QSAM feedback presentation

G.3. Company 2 – machine downtime due to poor supplier performance (ACT)

| Month/period | Downtime in hours |
|---|--------------------------|
| 12 th September 2013 – 30 th September 2013 | 14.6 |
| 1 st October 2013 – 31 st October 2013 | 42 |
| 4 th November 2013 – 19 th November 2013 | 59.6 |

Source: Adapted from QSAM feedback presentation

G.4. Company 2 – Heidelberg offset printer performance

| Company 2's classification | Efficiency | Actual result (no. of jobs) |
|-----------------------------------|-------------------|------------------------------------|
| Poor | 20% or worse | 29 |
| Good | 21% to 50% | 14 |
| Great | 51% or better | 7 |

Source: Adapted from QSAM feedback presentation

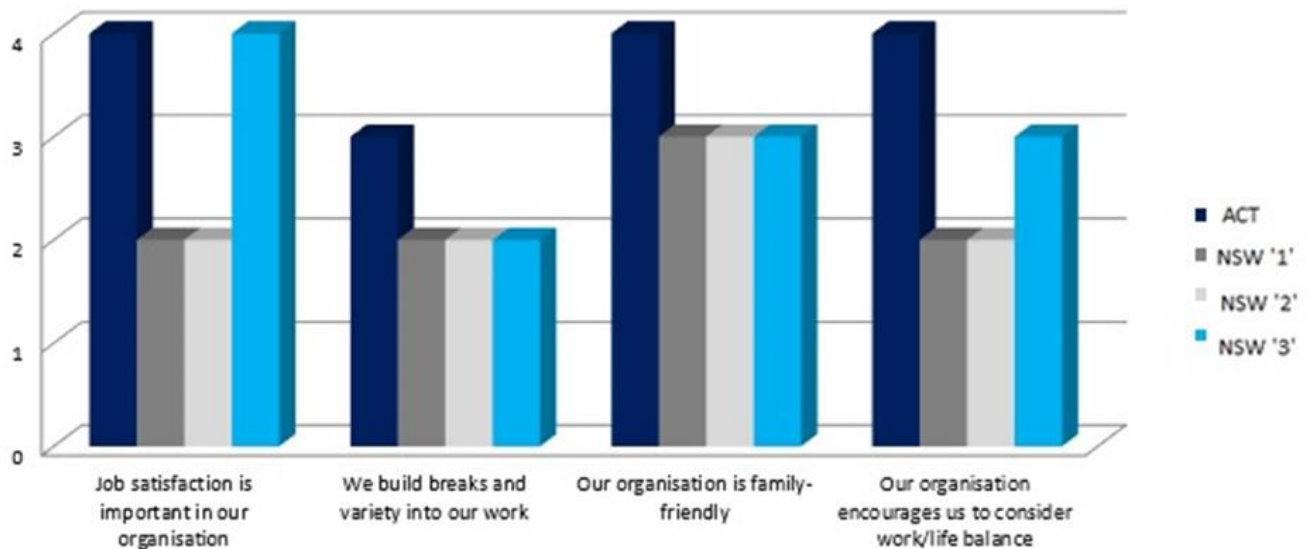
G.5. Company 2 – survey results for job satisfaction

- 59 surveys were completed in total across the four sites
- Random selection
- 15 categories were rated from 1 (weak) to 4 (strongly agree)

Survey categories

| Category | | | | | |
|----------|------------------|----|---------------|----|---------------|
| 1 | Learning | 8 | Creativity | 15 | Good practice |
| 2 | Customers | 9 | Planning | | |
| 3 | Job satisfaction | 10 | Values | | |
| 4 | Change | 11 | Fairness | | |
| 5 | Trust | 12 | Leadership | | |
| 6 | Management | 13 | Evaluation | | |
| 7 | Transparency | 14 | Communication | | |

Job Satisfaction



Source: Author

- Results varied by site
- 52% said that Company 2 views job satisfaction as being important
- More than 50% did not agree that breaks and variety of work was seen as important to Company 2, or that work/life balance was encouraged
- Most agreed that Company 2 is family friendly

G.6. Company 2 – sample of overtime data for full-time employees during 2013

| Month | Overtime in hours | Hours per employee | Overtime expenses in \$ |
|-----------|-------------------|--------------------|-------------------------|
| July | 4,294 | 37 | 168,000 |
| August | 4,129 | 36 | 161,000 |
| September | 4,564 | 39 | 178,000 |
| October | 3,729 | 32 | 145,000 |

Source: Adapted from QSAM feedback presentation

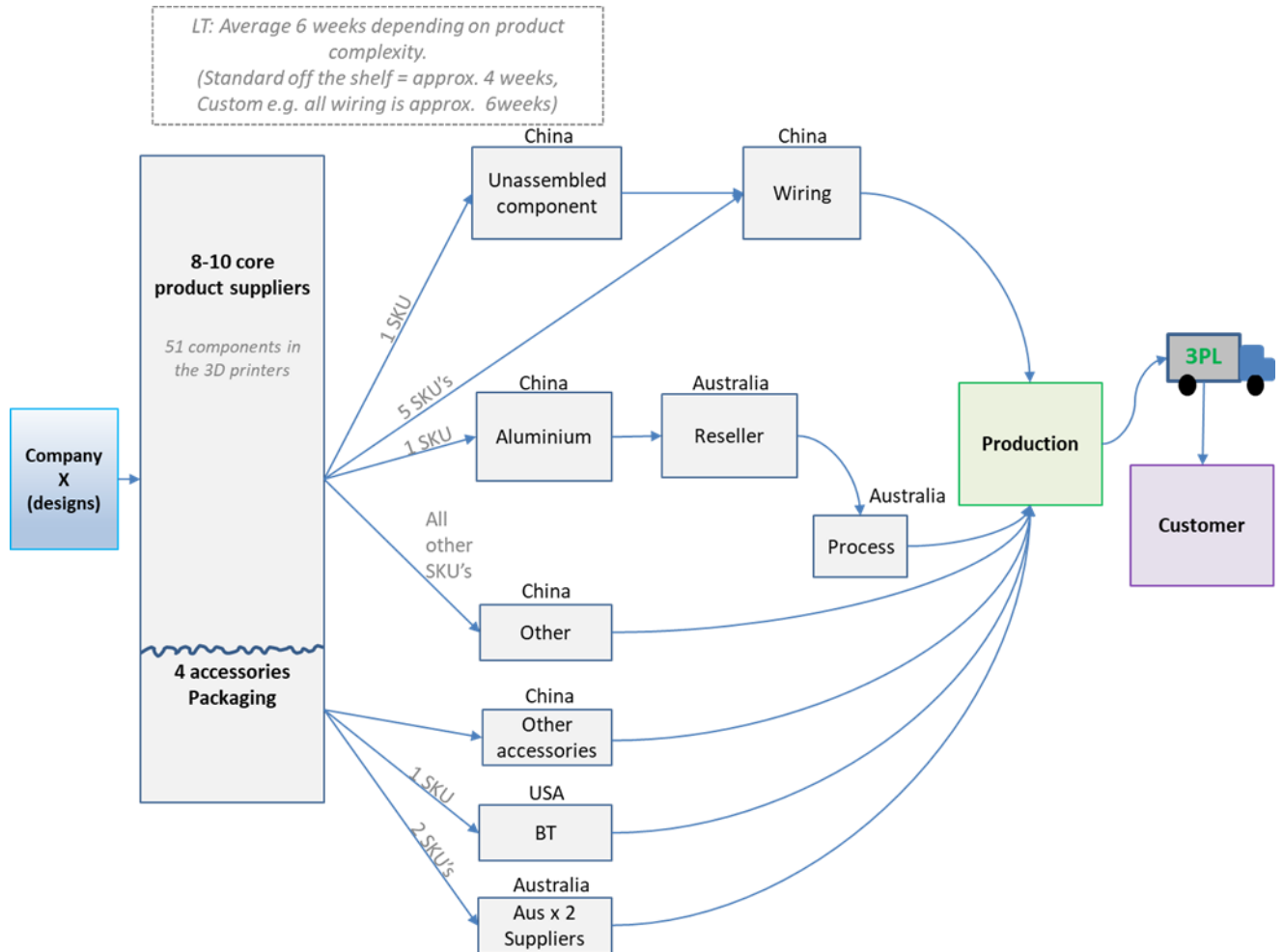
G.7. Company 2 – sample of overtime data for casual employees during 2013

| Month | Overtime in hours | Overtime expenses in \$ |
|-----------|-------------------|-------------------------|
| July | 4,183 | 125,500 |
| August | 4,547 | 136,000 |
| September | 5,758 | 173,000 |
| October | 4,465 | 134,000 |

Source: Adapted from QSAM feedback presentation

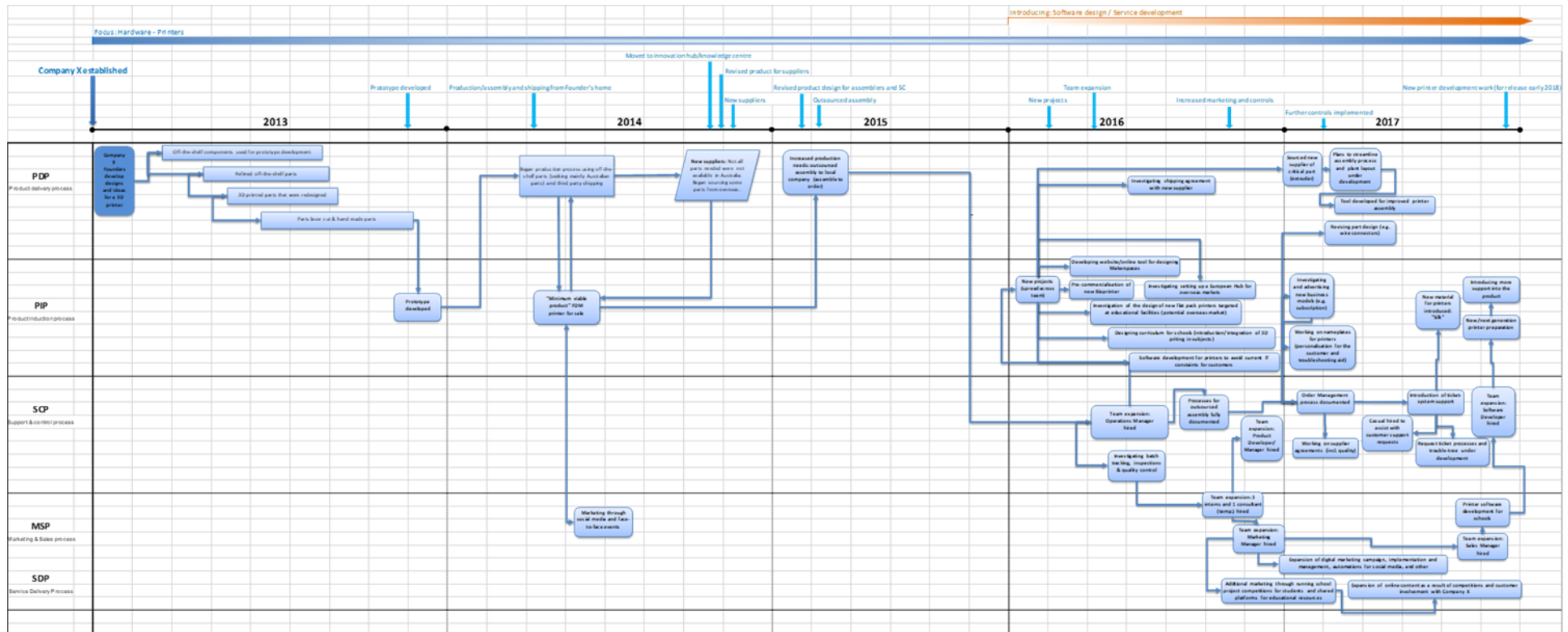
Appendix H: Company X

H.1. Company X - overall supply chain



Source: Author

H.2. Company X's journey (detailed version)



Source: Author