Industry 4.0 Technology Implementation in the New Zealand Manufacturing Sector: An Empirical Study of Influencing Factors and Sustainability Perspectives

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Abstract

Industrialisation not only enables firms to develop and prosper but also causes social and environmental harms. Integrating Industry 4.0 technologies (I4Ts) into manufacturing processes is promoted as a way to increase the sector's sustainability. The prevailing narrative of extant literature is that I4T implementation results in positive sustainability outcomes, with little mention of negative outcomes. I4T implementation is considered essential to increase the global competitiveness and sustainability of New Zealand's manufacturing sector. However, little is known about the factors influencing I4T implementation in NZ manufacturing, or the contribution I4Ts make to sustainability. Consequently, this study has two objectives. One is to explore the factors influencing I4T implementation by examining its drivers, enablers, and inhibitors. The other is to explore managerial perspectives of the positive and negative contributions I4Ts make to sustainability.

A qualitative research methodology was adopted, and template thematic analysis was used to analyse data gathered from fifteen semi-structured interviews with senior executives employed within and connected to the NZ manufacturing sector. Institutional theory (INT) and dynamic capabilities theory (DCT) were used to interpret the findings.

The study found that NZ manufacturers employ dynamic capabilities to implement I4Ts as a strategic response to coercive and mimetic institutional forces. Key identified drivers were competitive and stakeholder pressures, data capture and analysis, I4T awareness, and labour shortages. Financial resources, skilled personnel, ERP systems, and change management were key enablers of I4T implementation. Conversely, high financial cost, lack of skilled personnel, resistance to change, and low production volumes were key inhibiting factors.

This study makes several contributions. The study contributes to theory by applying INT and DCT in an integrative framework that conceptualises I4T implementation from a fresh perspective. A number of novel findings were identified that could serve as a foundation for future research. Manufacturers can use the insights gained from this study to make informed decisions about I4T implementation, including how to maximise positive and minimise negative sustainability outcomes. For policymakers, the study identified various bases for developing policies and initiatives supporting I4T implementation and sustainable manufacturing.

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Related Publications

Conference Presentations and Proceedings

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List of Abbreviations

Abbreviation	Full form
3D printing	Three-dimensional printing
AI	Artificial intelligence
AM	Additive manufacturing
AR	Augmented reality
ARA	Advanced robotics and automation
BDA	Big data and analytics
Callaghan	Callaghan Innovation
CC	Cloud computing
CO_2	Carbon dioxide
DC	Dynamic capability
DCT	Dynamic capabilities theory
DT	Digital twin
EMA	Employers and Manufacturers Association
ERP	Enterprise resource planning
FTE	Full-time equivalent
GHG	Greenhouse gas
HOT	Human-Organisation-Technology model
I4.0	Industry 4.0
I4T	Industry 4.0 technology
IMF	International Monetary Fund
INT	Institutional theory
IoT	Internet of Things
ISO	International Organisation for Standardisation
M&E	Machinery and equipment
MBIE	Ministry of Business, Innovation & Employment
n/a	Not applicable
NZ	New Zealand
OECD	Organisation for Economic Co-operation and Development
RFID	Radio frequency identification
ROI	Return on investment
SDG	Sustainable Development Goal
SIRI	Smart Industry Readiness Index
SLR	Systematic literature review
SME	Small & medium-sized enterprise
SSI	Semi-structured interview

Abbreviation	**Full form**
TOE	Technology-Organisation-Environment framework
UK	United Kingdom
UN	United Nations
UNIDO	United Nations Industrial Development Organisation
US	United States
UTAUT	Unified Theory of Acceptance and Use of Technology

Chapter 1 Introduction

Climate change, pollution, and the depletion of Earth's finite natural resources are exacerbated by the demand for consumer goods that comes with population growth (United Nations, 2021). Producing goods in a sustainable manner is therefore of paramount importance. This is recognised in two of the Sustainable Development Goals (SDGs) (United Nations, 2015b): Goal 9, which calls for inclusive and sustainable industrialisation, and Goal 12, which specifically addresses the need to establish sustainable patterns of consumption and production. Integrating digital technologies into manufacturing is typically promoted as a way to achieve sustainable production by boosting economic performance and reducing the deleterious impacts on social and environmental well-being associated with traditional manufacturing processes (Kamble et al., 2018). A less prevalent view is that digital technologies lead to negative sustainability outcomes (Bohnsack et al., 2022). Consequently, if manufacturing is to achieve higher levels of sustainability, it is important to understand not only what influences manufacturers' use of digital technologies, but also how the technologies contribute to sustainability.

This study adopts an institutional and strategic management perspective, drawing on data from interviews with senior managers of New Zealand (NZ)-based organisations, to explore the factors that influence Industry 4.0 technology (I4T) implementation in manufacturing production operations and the ways I4Ts contribute to sustainability. In this study, the term 'implementation' covers adoption (decision to introduce), physical deployment and utilisation of I4Ts (Ghobakhloo & Ching, 2019; Zhou & Zheng, 2023).

This chapter provides an overview of the study and is structured as follows. First, the background of the study is presented, followed by an overview of NZ's manufacturing sector. Next, the justification for the study is provided along with the research gaps identified in the literature. The research objectives and questions are given in the fourth section, followed by a summary of the methodological approach taken to address the research objectives and questions. The significance of the study is set out in the sixth section, and the thesis structure is outlined in the final section.

1.1 Background of the study

1.1.1 Manufacturing and industrialisation

Manufacturing is the process of converting raw materials, such as crops, animals, fibres, metal ores and oils, or components into finished products (Ministry of Business, Innovation & Employment [MBIE], 2018). Manufacturing is recognised as "an engine of growth" (Haraguchi et al., 2017, p. 293) because it drives economic development in developing countries, and supports the continued economic prosperity of developed countries (Haraguchi et al., 2017).

However, manufacturing is also recognised for its contribution to environmental and social harms. Industrial activity has led to such significant changes in global environmental conditions that Earth is now considered to be "well outside of the safe operating space for humanity" (Richardson et al., 2023, p. 1). Procuring the raw, often finite, materials used by the manufacturing industry to produce goods, contributes to the destruction of natural habitats and biodiversity loss (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). And by burning fossil fuels to support its activities, industrialisation increased greenhouse gas (GHG) emissions, which have unequivocally caused global warming (Intergovernmental Panel on Climate Change, 2023). Further, manufacturing is recognised as a hazardous sector whose employees experience high levels of work-related accidents (International Labour Organization, 2023; UN Global Compact, n.d.-a). Consequently, government, business, and academia have turned their attention to identifying how the manufacturing industry might achieve a state of sustainability whereby it maintains its role as a driver of economic development, while simultaneously minimising its negative impact and maximising its positive impact on the environment and people (Ghobakhloo, 2020).

1.1.2 Sustainability, manufacturing, and digital technologies

The terms 'sustainability' and 'sustainable development' are often used interchangeably but represent different concepts. The concept of sustainable development is described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 8), emphasising the significance of economic development that is simultaneously "socially and environmentally sustainable" (p. xii). Conversely, the term sustainability is frequently used in the business context, which is typically conceived as incorporating the three core dimensions of sustainable development: economic, environmental and social sustainability, into business operations and decision making (Dyllick & Hockerts, 2002). Environmental sustainability is concerned with maintaining Earth's natural resources and eliminating environmental degradation (United Nations, 2015a). Social sustainability focuses on people's well-being. From an organisational perspective, social sustainability "…is about identifying and managing business impacts, both positive and negative, on people" (UN Global Compact, n.d.-b, para. 1). Economic sustainability can be described as the ability to generate long-term economic growth without depleting environmental and social resources (Cricelli & Strazzullo, 2021), meaning that the pursuit of economic growth should not come at the expense of people or planet.

Integrating digital technologies across all sectors of the global economy has been promoted as one of six transformations needed to achieve sustainability at a global level (Sachs et al., 2019). In turn, integrating digital technologies into manufacturing processes, or digitalising manufacturing, has been suggested as a way for the sector to achieve higher levels of sustainability by boosting economic productivity while simultaneously reducing harmful social and environmental impacts (de Sousa Jabbour et al., 2018; Sachs et al., 2019; Stock et al., 2018). The digitalisation of manufacturing is commonly referred to as Industry 4.0 or I4.0 (Culot et al., 2020; Tortorella et al., 2023).

1.1.3 Industry 4.0: the digitalisation of manufacturing

Industrialisation describes the process by which a country's economy transitions from a focus on agriculture towards a dependence on large-scale manufacturing (Szirmai, 2012), and is typically viewed as having gone through four revolutions, each driven by different technologies (Choi et al., 2022). The First Industrial Revolution was fuelled by steam engines which enabled manufacturing to be mechanised. Assembly lines and mass production were the hallmark of the second revolution, powered by electricity. The third revolution saw the introduction of computing and programmable devices, leading to automation. Finally, digitalisation led to a new era in manufacturing described as the Fourth Industrial Revolution or I4.0 (Kagermann et al., 2013).

I4.0 rose to prominence with the publication of the report *Recommendations for implementing the strategic initiative INDUSTRIE 4.0* (Kagermann et al., 2013). This report was the culmination of an initiative launched in 2011 by the German government to establish how to protect its domestic manufacturing industry from competition while simultaneously building upon and cementing the country's position as a global manufacturing leader.

As envisaged by the report's authors, the Internet of Things and cyber-physical systems formed the foundation of the I4.0 production environment, within which smart production processes, consisting of autonomous machines and systems, would create smart products in smart factories (Kagermann et al., 2013). The development of smart factories was expected to lead to more efficient, flexible, agile, and customer-centric production processes in which even single items could be manufactured to individual customer requirements at a profit (Kagermann et al., 2013). More efficient processes were expected to lead to a reduction in raw material and energy consumption and emissions. Further, routine tasks would be transferred to collaborative robots, leaving the human workforce free to take on more interesting and fulfilling roles. Digitalisation would also enable vertical integration of information technology and operational technology systems from the factory floor to all levels of the organisation, horizontal integration of value chains and lead to the creation of new business models (Kagermann et al., 2013).

1.1.4 Key Industry 4.0 technologies

When applied in a manufacturing context, digital technologies are often referred to as Industry 4.0 technologies (Bai et al., 2020; Dalenogare et al., 2018). Since it was first introduced, the number of technologies underpinning the I4.0 concept has increased as new technologies have been developed and integrated into manufacturing processes (Culot et al., 2020). As there is no definitive list of the digital technologies that enable I4.0 (Choi et al., 2022; Zheng et al., 2021), this section describes technologies identified from the literature that are considered most relevant for use in the production and operations areas which form the scope of the present study.

1.1.4.1 Internet of Things

The Internet of Things (IoT) is typically one of the first I4Ts implemented by manufacturers (Frank et al., 2019). In an IoT, physical devices such as sensors and radio-frequency identifiers (RFIDs) are digitally connected via a wireless network. This enables data to be collected and exchanged in real time between the devices, which facilitates process monitoring, energy consumption monitoring, and asset tracking in a manufacturing context (Zheng et al., 2021).

1.1.4.2 Big data and analytics

Big data refers to the vast amount of data generated by devices in an IoT. Data analytics is employed to convert data into information that can be used to monitor processes and inform decision-making (Zheng et al., 2021). In a business setting, data analytics is typically descriptive, predictive or prescriptive (Vahn, 2014). Descriptive analytics uses data to describe what has happened "from a second ago to decades ago" (van Rijmenam et al., 2019, p. 4), and can be used to analyse a firm's internal and external environment. In a manufacturing operations context, descriptive analytics could be used to track components or to monitor emissions (van Rijmenam et al., 2019). Predictive analytics uses past data to predict what will happen in the future (Dubey et al., 2019), and in a manufacturing environment, is used in the predictive maintenance of machinery (Zheng et al., 2021). Prescriptive analytics uses data, algorithms, and modelling to suggest actions to achieve a desired outcome (van Rijmenam et al., 2019). In manufacturing, prescriptive analytics can be used to optimise production schedules (Zheng et al., 2021).

1.1.4.3 Cloud computing

Most manufacturers will not be able to store and process the volumes of data produced by an IoT. Cloud computing offers an outsourced service that enables users to store and manage data on remote servers accessed via the internet (Alcácer & Cruz-Machado, 2019). This allows manufacturers to access powerful data processing capabilities that further support and enable their use of other I4Ts. Integrating cloud computing with IoT and big data analytics (BDA) supports a range of manufacturing activities and real-time decision making (Zheng et al., 2021).

1.1.4.4 Artificial intelligence

Artificial intelligence (AI) can be defined as "the mimicking of human intelligence using computers" (Olsen & Tomlin, 2020, p. 119). AI has enabled the creation of computers capable of learning, which consequently facilitates computers' ability to reason and solve problems, make predictions and take decisions, and understand and respond to language (International Organisation for Standardisation, 2023, para. 2). In manufacturing, AI can be used to conduct data analytics as described above and enables automation of production processes (Olsen & Tomlin, 2020).

1.1.4.5 Advanced robotics and automation

Manufacturing's use of robotics is well established (Olsen & Tomlin, 2020). However, the combination of IoT, cloud computing, and AI has enabled the development of more powerful robots, able to perform complex or mundane tasks in rapidly changing environments that may, at times, be challenging or even unsafe for humans (Choi et al., 2022; Zheng et al., 2021). Advanced robotics can operate autonomously or work collaboratively with humans in a shared working environment and are synonymous with automated assembly lines (Olsen & Tomlin, 2020).

1.1.4.6 Digital twins

A digital twin is a digital representation of a physical asset, process, or system (Choi et al., 2022). Real-time data is collected from IoT devices in the physical environment, which is used to run simulations in the digital twin environment. In this way, a manufacturer can, for example, test a process before committing it to production, or use simulations to identify problems such as component malfunctions and machine breakdowns pre-emptively.

1.1.4.7 Additive manufacturing

Additive manufacturing, also known as 3D printing, is the process of building up very thin, consecutive layers of raw material to create objects from a digital 3D model (Zheng et al., 2021). Additive manufacturing enables single parts and products to be produced on demand, which removes the need to hold inventory and facilitates tooling and prototyping (Choi et al., 2022). Compared to some traditional manufacturing techniques during which material is subtracted from a whole to produce an object and associated waste material, additive manufacturing produces little waste, as the process only uses the material needed to produce the object (Olsen & Tomlin, 2020).

1.1.4.8 Augmented reality

In augmented reality (AR), computer-generated images are overlaid onto physical objects and observed using AR-enabled devices such as smart phones and AR glasses (Choi et al., 2022). Within production operations, AR can be used to facilitate activities such as product assembly and machine maintenance.

From the above summary of technologies, it can be seen why IoT, big data analytics, and cloud computing have been described as ‘base technologies’ as they create a foundation which other I4Ts are built upon (Frank et al., 2019).

1.2 New Zealand’s manufacturing sector

NZ is a small advanced economy (Skilling, 2020), with a population of just over five million and a small domestic market. The manufacturing sector is an essential part of NZ’s economy and has been described by its government as having “the potential to supercharge [NZ’s] economic growth” (New Zealand Government, 2024, para. 2). According to the MBIE (2025a), “the sector employs 10 percent of the workforce, accounts for 8.4 per cent of gross domestic product ($21.6 billion), 82.2 per cent of goods exports ($54.2 billion) and 26.6 per cent of business expenditure on Research and Development ($976 million)” (p. 5). As such, manufacturing is a major employer and exporter, a key driver of innovation and, significantly, it is NZ’s second largest employer of Māori and Pacific peoples (MBIE, 2023).

While it makes significant and positive contributions to gross domestic product and employment, the sector also has substantial negative environmental and social impacts. In the year ending 2023, manufacturing was responsible for 11.5% of total NZ production-based GHG emissions, putting it second only to the agriculture sector (Stats NZ, 2025a). If NZ is to achieve its goal of net-zero emissions by 2050, manufacturing, in common with other sectors, needs to make substantial emission reductions (MBIE, 2023). The sector also produces large volumes of waste, 92% of which goes to landfill (Aurecon et al., 2024). Finally, the sector had the country’s highest work-related injury claim rate in 2023 at 151 claims per 1,000 full-time equivalent (FTE) employees (Stats NZ, 2024a). Latest figures show a fall to 123 claims per 1,000 FTEs in 2024, putting the sector in third place (Stats NZ, 2025b). The economic cost of these work-related injuries has been estimated at $1.23 billion (Employers and Manufacturers Association [EMA], 2024).

NZ’s manufacturing sector is dominated by small firms. As at February 2025, 22,680 manufacturing businesses employed 244,100 FTEs (Stats NZ, 2025c). 91% of manufacturing businesses were small firms employing fewer than 20 FTEs and 57% of small manufacturers had zero employees (Stats NZ, 2025c). Almost 75% of small manufacturers have annual sales of less than $1 million and only 5.4% generated more than $10 million in annual revenue (MBIE, 2025a). Large firms employing 100 or more people accounted for only 1% of all manufacturers but employed 53% of all manufacturing employees (Stats NZ, 2025c). Approximately 80% of NZ manufacturers serve the domestic market only (Ministry of Foreign Affairs and Trade, 2022).

Due to NZ's geographical isolation and distance from international markets, transportation costs for exporters are high, making it difficult for them to compete on price in overseas markets (MBIE, 2018). This has led manufacturers to specialise in low-volume, bespoke manufacturing with a focus on high value products and niche markets, rather than mass production (MBIE, 2018). It has been suggested that NZ manufacturers might compensate for the impact of high transportation costs by being more productive and efficient to reduce costs in other areas (Business NZ, 2022b). However, compared to other small advanced economies, NZ persistently demonstrates poor productivity performance which is attributed to a number of factors including its geographic isolation, a small domestic market lacking competition, and a high cost of capital which limits investment in new, productive technologies (International Monetary Fund [IMF], 2025).

Reflecting the view that digital technology use can enhance economic, environmental, and social sustainability (Sachs et al., 2019), NZ's government opined that applying digital technologies in manufacturing was essential to increasing the sector's productivity, global competitiveness, and sustainability (MBIE, 2023). However, NZ manufacturers currently lag behind their international counterparts with regard to digital technology implementation and have been described as "reluctant adopters of digital technology" (Clark, 2024, p. 7).

1.2.1 Manufacturing digitalisation policy

A Crown entity, Callaghan Innovation (Callaghan), led NZ's I4.0 initiatives until recently. Callaghan was established in 2013 to support innovation in the manufacturing and services sectors, which later included the remit to promote I4.0 (Callaghan Innovation, 2024b). Through Callaghan, manufacturers were able to connect with providers and users of I4Ts and access funding to undertake Smart Industry Readiness Index (SIRI) assessments to assess their readiness for I4T implementation (Callaghan Innovation, 2024a). However, the NZ government announced Callaghan's disestablishment in February 2025 (Callaghan Innovation, 2025b). To date, no announcements have been made regarding how I4.0 initiatives will be supported in the future.

At the time of writing, NZ does not have a government policy promoting digital technology use in manufacturing. Its previous government launched an Advanced Manufacturing Industry Transformation Plan in March 2023, which aimed to enhance the global competitiveness of the country's manufacturing sector and included a priority of increasing investment in I4Ts to increase productivity (MBIE, 2023). However, the plan was abolished following the election of the current government in October 2023.

1.3 Justification for the study

As noted above, despite its potential to enhance the sector's competitiveness, productivity, and sustainability, I4T implementation by NZ manufacturers is low, which suggests the need for empirical research to understand why this is the case. The present literature review highlighted three key research gaps. First, the literature review identified two previous studies that looked at drivers and inhibitors of I4T implementation in the NZ context (Hamzeh et al., 2018; Müller et al., 2024). However, Hamzeh et al. (2018) was a quantitative study that did not identify factors specific to the NZ context, while Müller et al. (2024) was a multi-country, multiple case study that included only one NZ manufacturer. Neither study explored enabling factors, which constitutes a significant gap, as identifying what practitioners believe would help increase I4T implementation should be central in devising supportive policies and initiatives. Therefore, this study addresses a research gap by adopting a qualitative approach to explore drivers, inhibitors, and enablers in a single study involving multiple NZ-based participants.

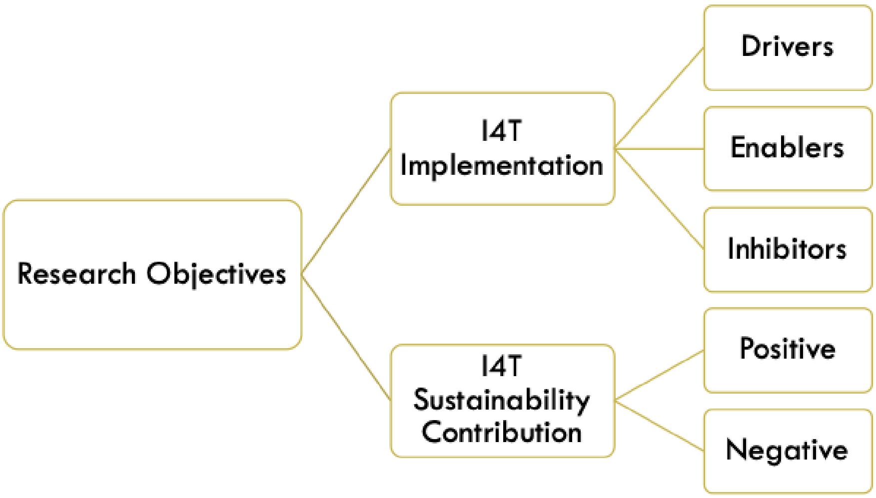
Second, previous studies have tended to focus on how I4Ts make positive contributions to sustainability and downplay the negatives (Ghobakhloo et al., 2021; Piccarozzi et al., 2022). By exploring both positive and negative outcomes, this study provides a balanced perspective on I4Ts' contribution to sustainability. Further, it answers calls for future research to consider the negative consequences of digital technologies on sustainability (Bohnsack et al., 2022; Liu et al., 2020).

Finally, the literature review revealed that studies exploring factors influencing I4T implementation, either lack a theoretical foundation or use theories other than institutional theory (INT) or dynamic capabilities theory (DCT). No study was identified that used both INT and DCT; therefore, this study bridges a theoretical gap by adopting both theories in an exploration of I4T implementation. Further, it answers a call for future research to use existing theories in novel ways when exploring the implications of technology on sustainability in manufacturing operations (Liu et al., 2020).

1.4 Research objectives and questions

The study has two research objectives (Figure 1.1). First, to identify factors influencing I4T implementation in New Zealand-based manufacturing production operations, by exploring drivers, enablers and inhibitors. Second, to explore managerial perspectives of the positive and negative ways I4Ts contribute to sustainability dimensions.

Figure 1.1: Research objectives



Based on the research gaps highlighted in the previous section and the objectives outlined above, this study addresses the following research questions:

RQ1: What factors drive Industry 4.0 technology implementation?

RQ2: What factors enable Industry 4.0 technology implementation?

RQ3: What factors inhibit Industry 4.0 technology implementation?

RQ4: How do Industry 4.0 technologies contribute to sustainability?

1.5 Research methodology

This study was positioned within an interpretivist research paradigm in which a qualitative, exploratory research design and abductive reasoning were used to address the research questions (M. Saunders et al., 2016). Ethics approval was gained before approaching prospective participants, and the study was deemed low risk. Participants were selected purposively using the criterion sampling technique (Nyimbili & Nyimbili, 2024). Primary data were collected via fifteen semi-structured interviews: thirteen with senior managers employed by manufacturing companies, one with a consultant to manufacturers wanting to implement I4Ts, and one with a government employee tasked with promoting I4.0. Secondary firm-related data, such as websites and I4.0 case studies, were also reviewed. All interviews were recorded and transcribed verbatim using automated transcription software. A template thematic analysis approach was taken to analyse and identify themes within the data (King & Brooks, 2017a), which was supported by NVivo data analysis software (Lumivero, 2025). INT and DCT were applied as theoretical lenses to interpret the data. Throughout this study, research quality and rigour were maintained with reference to the criteria proposed by Guba (1981) to assess the trustworthiness of qualitative research.

1.6 Significance of the study

This study makes several theoretical and practical contributions. As noted in section 1.3, this study bridges research gaps and addresses calls for future research. The study contributes empirical data in the NZ context, enriching the knowledge on I4T implementation in manufacturing entities. Significantly, and to the best of the researcher's knowledge, this study is the first to adopt INT and DCT to explore the factors influencing I4T implementation. An integrative framework is presented which lays the foundation for a new approach to conceptualising I4T implementation.

Manufacturers can use the findings from this study to inform their own I4T implementation initiatives by developing an improved understanding of the factors that helped and hindered their peers. And by raising awareness of both positive and negative sustainability outcomes, the study will help firms make more informed decisions about I4T use, enabling them to proactively plan for and mitigate potential negative consequences. Additionally, although high costs inhibit I4T implementation, the study identified relatively low-cost tools, such as AI and augmented reality, that manufacturers can use to enhance inclusivity and safety in the workplace.

Policymakers and industry bodies can use the findings from this study to develop policies and initiatives that support manufacturing's future productivity and sustainability through I4T implementation. Further, the study revealed an opportunity for policymakers to pursue a triple transition agenda (OECD, 2023) that simultaneously addresses green, social, and digital transitions for manufacturing sustainability.

Finally, the study identified an opportunity for academia to collaborate with industry to ensure that courses prepare students with the skills required by a future, digital manufacturing sector.

1.7 Thesis structure

This thesis comprises six chapters. Chapter 1 presents the background, justification and significance of the study, along with the research objectives, questions, and overview of the methodology.

Chapter 2 provides a review of extant literature related to the factors that drive, enable and inhibit I4T implementation in manufacturers, and the contributions I4Ts make to sustainability. INT and DCT are introduced, and the chapter concludes with a conceptual framework that depicts the synthesis of the theories with the research objectives/questions. Research gaps and relevant calls for future research are presented throughout.

Chapter 3 discusses the research methodology including the research philosophy, methodological choice and research design. Criteria and strategies used to select participants are provided, followed by a discussion of data collection methods and materials. The study's use of template thematic analysis is discussed in detail, and the chapter concludes with the approach taken to address ethical considerations and research quality.

Chapter 4 presents the findings in relation to the research questions, following the analysis of data gathered from fifteen semi-structured interviews. Key themes and sub-themes are presented along with descriptive information regarding the participants' use of I4Ts.

Chapter 5 discusses the research findings. Drawing on INT and DCT, the key themes and sub-themes derived from the thematic data analysis are discussed and compared with the literature. Finally, the key themes are synthesised with INT and DCT into an integrative framework for I4T implementation leading to sustainability outcomes.

Chapter 6 concludes the study. First, the key findings are briefly revisited. Then the theoretical, managerial, and policy implications of the study are highlighted. Limitations of the study are outlined, and the chapter concludes with suggestions for future research.

Chapter 2 Literature review and theoretical lenses

2.1 Introduction

This chapter presents a review of literature that considers factors influencing I4T implementation and I4T contributions to sustainability within the context of manufacturing production operations. It also introduces two theories used to interpret the research findings. The chapter is structured as follows.

Following this introduction, the chapter continues with an outline of the procedures taken to identify relevant literature. The influencing factors referred to in this study are defined in section 2.3. The literature review runs through sections 2.4 to 2.7. Research gaps identified from the literature review, and the research questions resulting from these gaps, are presented in the relevant section. Section 2.8 provides an overview of INT and DCT, which are synthesised into a conceptual framework presented in section 2.9. Concluding comments are made in section 2.10.

2.2 Literature search procedures

Peer-reviewed academic literature was reviewed to inform the research and identify research gaps. Scholarly literature was sourced from two electronic databases: Massey University's Discover database and Google Scholar. The Discover database enables searches of the University's library of publications and a range of third-party academic databases including Scopus. The following phrases, keywords and derivatives were used in the literature search: New Zealand, Industry 4.0, institutional theory, dynamic capabilities, technology, manufacturing, smart manufacturing, production, sustainable, driver, motivator, barrier, challenge, enabler, inhibitor, implement, adopt, impact, qualitative. The search items were applied in various combinations in electronic database searches to find relevant literature. To be considered relevant for this study, an article had to be available in English and relate to manufacturing production and operations. The literature search mainly focused on articles covering I4T implementation in general rather than the implementation of specific I4Ts, and included primary research and systematic literature reviews (SLRs). No date restriction was applied. Descriptive properties of the literature reviewed can be found in Table 2.1.

Table 2.1: Literature reviewed for influencing factors

Author	Method	Data collection	Theory used	Unit of analysis	Industry	Context	Article scope		
							Drivers	Enablers	Inhibitors
Ghobakhloo et al. (2021)	Qualitative	SLR	No	Journal articles	n/a	n/a		•	•
Ghobakhloo et al. (2022)	Qualitative	SLR	TOE	Journal articles	n/a	n/a	•	•	
Graham (2024)	Qualitative	SSIs	TOE	Manufacturers	Generic pharmaceutical	Canada	•	•	•
Hamzeh et al. (2018)	Quantitative	Survey	No	Manufacturers	Multiple	New Zealand	•		•
Horváth & Szabó (2019)	Qualitative	SSIs	No	Manufacturers and suppliers	Multiple	Hungary	•		•
Intalar et al. (2024)	Qualitative	SSIs	No	Manufacturers	Multiple	Thailand	•	•	•
Kagermann et al (2013)	Report	n/a	No	Manufacturers	Multiple	Germany	•		
Khai-Leang Yeap et al. (2024)	Quantitative	Survey	No	Manufacturers	Electrical and electronics	Malaysia	•		•
Khin and Kee (2022)	Qualitative	SSIs	UTAUT	Manufacturers	Multiple	Malaysia	•	•	•
Kiel et al. (2017)	Qualitative	SSIs	No	Manufacturers	Multiple	Germany	•		•
Leesakul et al. (2022)	Mixed	SSIs & Survey	No	Manufacturers, legal experts, consultants, ethicists	Multiple	UK	•	•	•
Müller et al. (2018)	Quantitative	Survey	No	Manufacturers and suppliers	Multiple	Germany	•		•
Müller et al. (2024)	Qualitative	Multiple case study	TOE	Manufacturers	Multiple	Multiple inc. New Zealand			•
Rojas-Berrio et al. (2022)	Qualitative	SSIs	No	Manufacturers and suppliers	Multiple	Colombia	•	•	•
Skalli et al. (2024)	Qualitative	SSIs	No	Manufacturers	Multiple	Morocco	•	•	•

Author	Method	Data collection	Theory used	Unit of analysis	Industry	Context	Article scope		
							Drivers	Enablers	Inhibitors
Sony (2020)	Qualitative	SLR	No	Journal articles	n/a	n/a	•		•
Sony et al. (2021)	Mixed	Survey	No	Manufacturers and service providers	Multiple	Asia, Europe, North America	•		•
Sureeyatanapas et al. (2023)	Quantitative	Survey	No	Manufacturers	Sugar	Thailand	•		•
Tay et al. (2021)	Qualitative	SSIs	No	Manufacturers	Multiple	Malaysia			•
Veile et al. (2020)	Qualitative	SSIs	HOT	Manufacturers	Multiple	Germany		•	

Note. HOT = Human-Organisation-Technology model; SLR = Systematic Literature Review; SSI = Semi-Structured Interview; TOE = Technology-Organisation-Environment framework; UTAUT = Unified Theory of Acceptance and Use of Technology

2.3 Definition of influencing factors

This study describes the factors that influence I4T implementation as drivers, enablers and inhibitors. When conducting the review, it was noted that drivers and enablers are often conflated in studies exploring I4T implementation (e.g., El Baz et al., 2022; Ghobakhloo et al., 2022; Kumar et al., 2022). However, the researcher felt that drivers and enablers do not represent the same concept. Therefore, the present study follows the approach taken by Lee and Klassen (2008) by differentiating between drivers and enablers, and adopts their definition that "a driver is a factor that initiates and motivates firms…whereas an enabler is a factor that assists firms" (p. 580).

The terms 'barrier' and 'challenge' were often used interchangeably in the literature to describe a factor that makes I4T implementation difficult. Da Silva et al. (2020) differentiated between barriers and challenges in their SLR, describing a barrier as something that can prevent successful implementation and a challenge as something that has a negative influence on implementation but which a firm can mitigate. In the present study, the term 'inhibitor' is used to encompass both barriers and challenges as defined by Da Silva et al. (2020) and represents any factor that makes I4T implementation difficult. All three terms are used interchangeably in the literature review.

2.4 Drivers of I4T implementation

This section highlights driving factors that initiate and motivate firms to implement I4Ts.

2.4.1 Production efficiency and productivity

Within manufacturing, production efficiency is concerned with making the optimal use of resources and minimising waste without compromising product quality (Horváth & Szabó, 2019). According to Jenkins (2024), production efficiency is "the key to reducing costs, staying competitive, minimizing waste and keeping up with customer demand" (para. 1). Productivity is a measure of the amount of goods produced from a given level of resources. For a firm to improve productivity, it must either be able to produce more while using the same level of resources or be able to produce the same amount using less resource (Clegg et al., 2025).

All of the articles reviewed for driving factors cited issues related to efficiency and productivity as key drivers of I4T implementation. Studies found that manufacturers were motivated to implement I4Ts to reduce costs and optimise resources by, for example, minimising production errors, reducing machinery downtime and reducing waste (Horváth & Szabó, 2019; Khai-Leang Yeap et al., 2024; Khin & Kee, 2022). Müller et al. (2018) and Skalli et al. (2024) found that opportunities to reduce the use of resources such as raw materials, water, and energy were key drivers of I4T implementation among German and Moroccan manufacturers respectively.

2.4.2 Stakeholder requirements

The literature suggests that responding to stakeholder demands and needs drives I4T implementation. Implementing I4Ts to reduce errors and defects enables firms to satisfy customer and regulatory demands for consistently high quality products (J. Graham, 2024; Intalar et al., 2024; Khin & Kee, 2022; Sony et al., 2021). Developing agile production capabilities, which enable firms to respond rapidly to changing customer requirements, was identified as a key driving factor in a number of studies (Intalar et al., 2024; Kiel et al., 2017; Müller et al., 2018; Sony et al., 2021). Müller et al. (2018) found that operational agility was a stronger driving factor for SMEs than MNEs, which the authors attributed to SMEs generally focusing more on operational than strategic issues.

2.4.3 Competition

Gaining and maintaining a competitive advantage was the impetus for the development of I4.0 (Kagermann et al., 2013) and continues to be a driver today. Sony et al. (2021) found that Asian, European and North American manufacturers expected I4.0 implementation to lead to a competitive advantage, by reducing costs and enabling changing customer needs to be met. Kiel et al. (2017), and Müller et al. (2018), both found that capitalising on strategic opportunities related to long-term viability and competitive advantage was the main driver of I4T implementation among German manufacturers. Increasing their capability to respond to competitive pressures, and creating new business opportunities were found to be key drivers of I4T implementation among Hungarian manufacturers (Horváth & Szabó, 2019).

2.4.4 Human resources

The literature indicated that resolving HR-related issues drives firms to implement I4Ts. Leesakul et al. (2022) interviewed industry experts in their study exploring the challenges and concerns that arise when I4Ts, such as collaborative robots, are implemented in the workplace. The authors concluded that labour shortages were a key driver of robotics implementation in the UK manufacturing sector because manufacturers struggled to fill roles considered dull, repetitive or physically demanding, so adopted automation to fulfil tasks that humans did not want to do. Difficulty accessing labour was similarly identified as a key driver of I4T implementation in Hungarian, Malaysian and Thai labour markets (Horváth & Szabó, 2019; Khin & Kee, 2022; Sureeyatanapas et al., 2023). In addition to filling resource gaps, Graham (2024) found that some manufacturers were driven to implement I4Ts to increase their attractiveness as an employer in order to retain existing staff and attract new employees. Other studies found that the potential to improve working conditions was a driver (Horváth & Szabó, 2019; Müller et al., 2018).

2.4.5 Operational control and decision making

The literature revealed that senior management is motivated to implement I4Ts to enable real-time assessment of operational performance, and swift corrective action to be taken before processes fail (Horváth & Szabó, 2019; Sureeyatanapas et al., 2023). Sony et al. (2021), and Skalli et al. (2024), identified that the potential to make decisions informed by operational data was a key driver of I4T implementation.

2.4.6 I4T awareness

The literature identified that developing an awareness of I4Ts is an experience that motivates senior management to begin implementation initiatives. Ghobakhloo et al. (2022) suggested that senior management awareness is the driving force behind I4T implementation, attesting that "top management's strategic awareness of Industry 4.0 is the stepping stone for SMEs' movement toward Industry 4.0 digital transformation" (p. 1051). Khin and Kee (2022) concluded that it is not only a general awareness of I4Ts that drives implementation but also senior managers' knowledge of the potential benefits of using them. Graham (2024) similarly identified knowledge of the advantages of I4Ts as a "foundational driver" (p. 35) that motivated manufacturers to develop implementation strategies.

2.4.7 Research gap and research question one

Table 2.1 shows that one study considered drivers of I4T implementation in the NZ context. In the survey conducted by Hamzeh et al. (2018), respondents were given six options of potential benefits/drivers of I4T implementation and instructed to select one option. While this approach aids statistical analysis, it leaves no scope to identify drivers specific to the NZ context. Consequently, the present study closes a methodological gap by adopting a qualitative approach to explore the factors that drive I4T implementation in NZ-based manufacturers, and asks the following research question:

RQ1: What factors drive Industry 4.0 technology implementation?

2.5 Enablers of I4T implementation

This section considers factors that help firms implement I4Ts. It appears that less research has been conducted to identify enablers of I4T implementation compared to drivers and inhibitors with fewer relevant articles retrieved. This observation was also made by Khin and Kee (2022).

2.5.1 Financial resources

Ghobakhloo et al. (2021) reviewed 745 articles in an SLR and found that financial resources was the most often cited enabler of I4T implementation. Intalar et al. (2024) found that financial resources were a crucial enabler of I4T implementation for firms of all sizes. However, large firms were more able to self-fund their I4T initiatives compared to SMEs, which were typically reliant on government funding due to a lack of internal financial resources. In common with Intalar et al. (2024), Khin and Kee (2022) found that SMEs typically relied on government support but found that some SMEs self-funded I4T initiatives because the wait for government funding put them at a competitive disadvantage. Veile et al. (2020) also noted the importance of financial resources and observed that return on investment was the most common measure used to evaluate the success of I4T implementation initiatives.

2.5.2 Knowledge and skills

In order to operate and support I4Ts, a manufacturer's employees need to have a different skillset from the one needed to operate and support traditional manufacturing equipment (MBIE, 2023). Under I4.0, employees on the shopfloor conduct less manual labour, and instead need to develop and utilise analytical, problem-solving, and decision-making abilities in addition to being conversant with data-driven systems (Grybauskas et al., 2022). Having appropriately skilled employees therefore eases the transition from traditional to digital manufacturing and was recognised as an enabler in the literature. The literature suggested that firms need to assess and build internal skills capabilities through digital skills training programs, and supplement these with skilled new hires and consultants where necessary (Ghobakhloo et al., 2022; Intalar et al., 2024; Leesakul et al., 2022). Studies indicated that

I4T implementation is enabled by having appropriate skills at all levels of the organisation, from employees on the shop floor with the skills necessary to interact with new machinery through to employees with specific digital IT and engineering skills (Khin & Kee, 2022). Participants in the study conducted by Graham (2024), specifically noted that staff are needed with the skills required to transform data into meaningful information.

2.5.3 External support

The literature highlighted the important role external bodies play in enabling I4T implementation. Graham (2024) suggested that support from external entities such as consultants and industry bodies helps firms develop the initial I4T awareness needed to consider their implementation. Once awareness had been raised, governments play a crucial role in supporting other enabling factors by providing funding, enacting supportive policies and supporting training initiatives to build a skilled workforce (Ghobakhloo et al., 2021, 2022; Khin & Kee, 2022). Some studies highlighted that collaborating with suppliers and academia can help manufacturers access I4T-specific knowledge and training at reduced cost (Khin & Kee, 2022; Rojas-Berrio et al., 2022), while participants in the study conducted by Veile et al. (2020), felt that industry collaboration with academia would help firms develop a pipeline of skilled individuals necessary to support I4T implementation.

2.5.4 Senior management support

The literature suggests that senior management support is an essential part of I4T implementation, necessary to develop I4T implementation strategies, drive and monitor the implementation process, and ensure that other enabling factors are identified and secured (Ghobakhloo et al., 2022; J. Graham, 2024; Skalli et al., 2024). Intalar et al. (2024) found that senior management support and involvement, in the form of setting a clear digitalisation plan, monitoring progress and performance, and encouraging employee collaboration in the implementation process, was key to enabling successful I4T implementation.

2.5.5 Culture and change management

Implementing I4Ts into an existing organisational environment represents a "radical change initiative" (Sony et al., 2021, p. 5), that involves changes to established work procedures, skills requirements and organisational structures, all of which impact employees (de Sousa Jabbour et al., 2018). Consequently, effective change management strategies that capture and address employee concerns before they develop into operational barriers were identified in the literature as enablers of I4T implementation (Intalar et al., 2024; Leesakul et al., 2022). Skalli et al. (2024) suggested that technology implementation is enabled by a supportive corporate culture, a view echoed by Veile et al. (2020), who suggested that senior management should develop a corporate culture open to change by exhibiting and promoting behaviours that demonstrate support for the transition to new technologies.

2.5.6 Research gap and research question two

As noted earlier, it appears that fewer studies consider the factors that help firms implement I4Ts compared to the factors that drive or inhibit implementation. This represents a significant oversight as identifying what practitioners believe would help increase I4T implementation should be central in devising supportive policies and initiatives. Additionally, Table 2.1 shows that enablers of I4T implementation in the NZ context are absent from the literature. However, NZ's geographical isolation, unique culture, and small advanced economy characteristics may lead to novel I4T implementation challenges requiring novel enablers. Consequently, this study adds to the relatively limited body of knowledge regarding enabling factors and helps fill a contextual gap by asking the following research question:

RQ2: What factors enable Industry 4.0 technology implementation?

2.6 Inhibitors of I4T implementation

This section considers factors that make I4T implementation difficult.

2.6.1 Costs and lack of financial resources

The costs associated with I4T implementation, such as technology acquisition and integration costs, employee training and development costs and ongoing maintenance costs, were identified in the literature as inhibiting factors (Kiel et al., 2017; Müller et al., 2024; Sony et al., 2021). Further, studies found that external consultants are sometimes needed to supplement firms' internal skills capabilities which represents an addition implementation cost (J. Graham, 2024; Skalli et al., 2024).

Firms need financial resources to cover I4T implementation costs. Consequently, the literature highlighted that insufficient financial resources inhibit I4T implementation (Ghobakhloo et al., 2021; J. Graham, 2024; Hamzeh et al., 2018). While the high cost of implementation applies to manufacturers of all sizes, the literature suggested that it poses a particular challenge for SMEs, who typically have lower levels of financial resources compared to larger manufacturers (Horváth & Szabó, 2019; Müller et al., 2024; Sony, 2020). Short-term financial performance measures may also hamper I4T investment. As a result of the level of financial commitment required, firms may not be able to present a compelling business case for I4T investment, particularly where funding providers focus on profitability in the short term (Horváth & Szabó, 2019; Kiel et al., 2017; Müller et al., 2024).

2.6.2 Lack of knowledge, skills and competencies

The literature identified a lack of appropriately skilled employees as a barrier to I4T implementation. Manufacturers from a variety of nations agreed that a lack of employees with the digital skills needed to assess, implement, use, and maintain I4Ts is a critical barrier inhibiting their implementation (Müller et al., 2024). Leesakul et al. (2022) suggested that the low availability of digitally skilled individuals is due to manufacturing's poor image, which makes it less attractive to prospective employees compared to other industries. Other studies highlighted a view that universities do not equip graduates with the skills and competencies firms need to support I4T implementation (Rojas-Berrio et al., 2022; Skalli et al., 2024; Tay et al., 2021). Although most studies mentioned skills gaps in relation to operational staff, Horváth & Szabó (2019) noted that firms lacking managers with the competencies to lead I4T implementation are likely to struggle, and suggested this is more of a challenge for smaller firms. In addition, the literature identified that a general lack of knowledge about I4Ts inhibits their implementation because, as Rojas-Berrio et al. (2022) concluded, firms cannot implement I4Ts without first being aware that they exist.

2.6.3 Lack of senior management support

The literature identified that a lack of senior management support can negatively impact I4T implementation in a number of ways. In the first instance, I4T implementation is unlikely to occur if senior managers fail to recognise the potential benefits of their use (Intalar et al., 2024). When benefits are recognised, implementation efforts are unlikely to succeed if senior management fails to develop a strategic implementation plan and allocate sufficient resources to the project (Horváth & Szabó, 2019; Müller et al., 2024; Sureeyatanapas et al., 2023). Some studies noted that senior managers feel they cannot spare the time to plan and support a strategic initiative such as I4T implementation, due to the pressures of dealing with day-to-day, operational issues (J. Graham, 2024; Hamzeh et al., 2018).

2.6.4 Organisational culture and resistance to change

As previously noted, I4T implementation involves organisational change. The literature identified that I4T implementation is inhibited by organisational cultures that do not embrace and effectively manage change (Müller et al., 2024). Horváth and Szabó (2019) noted that resistance to change and poor change management are significant barriers to I4T implementation. The authors found that both operational and strategic employees may fear how their roles might change due to I4T implementation, which was a sentiment echoed in other studies (Khin & Kee, 2022; Kiel et al., 2017; Sony et al., 2021). Skalli et al. (2024) further noted that a corporate culture that breeds a fear of failure is likely to inhibit successful I4T implementation.

2.6.5 Technology integration

The complexity of integrating I4Ts into existing organisational infrastructure was recognised as a challenge to I4T implementation (J. Graham, 2024; Skalli et al., 2024), compounded by a lack of technological standardisation (Müller et al., 2024; Skalli et al., 2024). Technical integration, both vertically within the firm, and horizontally between the firm and its supply chain, was the most frequently mentioned challenge from the interviews conducted by Kiel et al. (2017), in Germany, and was also identified as an inhibiting factor in Hungary and Malaysia (Horváth & Szabó, 2019; Tay et al., 2021). Müller et al. (2018) suggested that the complexity of technology integration has a greater inhibiting influence on large firms compared to small firms, which they attributed to large firms being less operationally flexible. Some studies also noted that data security risk is a factor that can cause firms to defer I4T implementation (Kiel et al., 2017; Müller et al., 2024; Skalli et al., 2024).

2.6.6 Research gap and research question three

Table 2.1shows that two studies (Hamzeh et al., 2018; Müller et al., 2024) considered barriers in the NZ context. For reasons previously stated, the survey conducted by Hamzeh et al. (2018), was not able to derive inhibitors specific to the NZ context by virtue of its quantitative methodology. In contrast, the study conducted by Müller et al. (2024), adopted a qualitative, multiple-case study approach to investigate barriers and enablers to I4T implementation among 15 manufacturing SMEs, one of which was NZ-based. However, inhibitors specific to the NZ context cannot be fully discerned because the findings from the individual case studies are amalgamated. Further, the study includes the experiences of only one NZ-based manufacturer, which is a significant limitation if a researcher is looking to explore inhibitors from a NZ context. Consequently, the present study adopts a qualitative methodology to collect data from multiple NZ-based manufacturers to address the following research question:

RQ3: What factors inhibit Industry 4.0 technology implementation?

2.7 I4T contribution to sustainability dimensions

This section of the literature review presents an overview of studies that consider how I4T use contributes to sustainability dimensions. Articles that focus on the positives are reviewed first, followed by articles that highlight the negatives. A further research gap and the fourth research question are given in section 2.7.5.

2.7.1 Contribution to the Triple Bottom Line

In business practice, the 'three dimensions' perspective of sustainability is often referred to as the 'triple bottom line' or TBL (Elkington, 1999). The TBL concept was proposed to help organisations develop and assess sustainable business operations. It requires a firm to identify and simultaneously manage the impact it has, both positive and negative, on each of the three sustainability dimensions, rather than just focusing on the traditional bottom line of profit (Elkington, 1999). Giving due regard to each dimension reinforces that maximising profit for shareholders at the expense of the needs of other stakeholders is no longer considered an acceptable business practice, and that achieving economic prosperity must be balanced with the need for environmental sustainability and social equity (Busch et al., 2023).

From the literature, there appears to be general agreement that I4T use will make a positive contribution to the TBL of sustainability. In their seminal report, Kagermann et al. (2013) opined that I4.0 will increase competitiveness, improve production and resource efficiency, create better work environments and facilitate more flexible roles that people can enjoy for longer. Stock and Seliger (2016) expected I4.0 to positively contribute to all three dimensions, environmental sustainability in particular, through the more efficient use of resources such as raw materials, water and energy. In their SLR, Kamble et al. (2018) argued that I4Ts have the potential to reduce waste, overproduction and energy consumption, improve workplace safety and working conditions, and reduce manufacturing costs.

Some researchers have attempted to assess the impact individual I4Ts have on TBL. By conducting an SLR, Machado et al. (2020) concluded that each of the nine I4.0 technological pillars identified in the report by Rüßmann et al. (2015) can positively contribute to each sustainability dimension. Consequently, the authors concluded that firms should aim to implement a combination of technologies that make the most positive contribution across all three sustainability dimensions. Bai et al. (2020) adopted a quantitative approach to evaluate the sustainability contribution made by seventeen I4Ts deployed in four different manufacturing sectors. The authors found that wireless communication technology had the most significant impact on sustainability in general, but that different technologies had the most significant impact in individual sectors. Consequently, the authors concluded that implementing I4Ts for sustainability should be considered in context as the impact of each technology differs by dimension and industry sector. The study only considered the benefits of I4Ts which led the authors to recommend "a more complete consideration of the potential negative sustainability impacts of each technology" (Bai et al., 2020, p. 11).

The multiple case-study conducted by Felsberger et al. (2022) identified many positive contributions to TBL. For example, automated process monitoring led to reduced errors and costs, AI was used to optimise production processes leading to reduced energy consumption and costs, and general I4T use led to an increase in employee knowledge and skills. Margherita and Braccini (2020) conducted a multiple case study of four Italian manufacturers that had implemented I4Ts. The authors reported positive contributions to all three sustainability dimensions with firms benefiting from more efficient production processes, fewer defects, less waste and resource use, and cleaner and safer work environments.

2.7.2 Contribution to economic and environmental sustainability

The literature revealed that the primary use of I4Ts is to generate economic benefits, typically by increasing production efficiency and productivity (Calabrese et al., 2023; Ghobakhloo et al., 2021). I4Ts are expected to make a positive contribution to environmental sustainability by reducing energy usage, enabling more efficient use of natural resources and materials, facilitating the reuse of materials, and by reducing the level of greenhouse gases and other harmful emissions into the environment (Javaid et al., 2022). The reduction in energy and resource use has a positive impact on productivity and efficiency, which results in reduced costs and can lead to increased business competitiveness and profitability (Cricelli & Strazzullo, 2021).

The survey conducted by Nara et al. (2021) in the Brazilian plastics industry found that the use of IoT, sensors and robotics was expected to reduce costs, waste, and resource use leading to increased profitability. Chiarini (2021) found that Italian production managers perceived I4Ts to have different impacts on environmental sustainability. For example, whilst sensors and radio frequency identification (RFID) tags were expected to reduce energy consumption and waste, robots were perceived to increase energy usage.

The economic and environmental benefits received from the implementation of I4Ts may not remain constant over time. Bonilla et al. (2018) considered the impact of I4Ts over different timelines of operation, and concluded that the technologies are likely to make a negative contribution to environmental sustainability when they are first deployed because fabricating new devices and equipment leads to increased resource use, and waste increases when obsolete machinery is disposed of. However, positive contributions were expected to prevail once the initial implementation phase had passed.

It is notable that two surveys of Italian manufacturers found little support for I4T implementation to achieve environmental sustainability. Following a survey of 200 manufacturing operations managers familiar with I4Ts, Chiarini et al. (2020) concluded that respondents did not use I4Ts to achieve environmental sustainability, even though they thought it was a relevant and important strategic pursuit. In a similar vein, implementing I4Ts to capitalise on environmental opportunities was not a driver for the majority of manufacturers surveyed by Brozzi et al. (2020). The authors expressed disappointment at this finding, and concluded that more needed to be done to raise awareness of real-world examples where I4Ts have improved firms' sustainability and overall business performance.

Case studies conducted by Jena et al. (2020), Jagtap et al. (2022), and Ranade et al. (2024), each demonstrate how IoT can be used to reduce a firm's impact on the environment and concurrently benefit economic performance. Following the implementation of an IoT-based system, a cement manufacturer was able to reduce its energy consumption, waste generation, carbon footprint, and water consumption while experiencing a concurrent increase in productivity (Jena et al., 2020). Jagtap et al. (2022) found that sensors and smart meters installed at various points in the production process allowed a beverage manufacturer to conduct real-time monitoring of its energy usage, enabling it to reduce energy consumption and realise annual cost savings. This outcome was replicated in the case of a medical device manufacturer who introduced IoT with the specific intention of improving energy efficiency and reducing costs (Ranade et al., 2024).

Two Italian case studies highlight the contribution of robotics and automation to economic and environmental sustainability. The use of autonomous machines in a ceramics manufacturer reduced wastage, and increased productivity and product quality, leading to an increase in sales and net profit (Braccini & Margherita, 2019). Through the use of life cycle costing, Stefanini and Vignali (2022) were able to demonstrate that replacing manned forklifts with automated guided vehicles in the internal logistics operations of a food manufacturer was more cost-effective due to reduced operating costs, and simultaneously resulted in less environmental impact under most life cycle assessment measures.

2.7.3 Contribution to social sustainability

The literature revealed that I4Ts' contribution to social sustainability has not been as widely researched compared to the other two dimensions (Felsberger & Reiner, 2020; Grybauskas et al., 2022; Pech-Rodríguez et al., 2022).

Piccarozzi et al. (2022) conducted an SLR on the relationship between I4.0 and sustainability and noted that, while research including the social dimension has increased since 2014, it was under-researched compared to economic and environmental dimensions. Where social sustainability was considered, the authors concluded that studies focused on how changes to the work environment affected employees after I4T implementation. For example, factories are projected to become safer as robots and automation take on hazardous and monotonous tasks, enabling employees to assume more fulfilling roles (Grybauskas et al., 2022). From a wider perspective, Stock et al. (2018), and Cosma et al (2025), both concluded that I4T use would result in a reduction in harmful emissions and noise, which would have a positive social impact on communities near to factories by increasing quality of life. Studies also identified the potential for more highly skilled roles as a result of I4T implementation (Felsberger & Reiner, 2020; Grybauskas et al., 2022).

Practical examples in the literature appeared to focus on environmental and economic sustainability. However, a few examples relating to social sustainability were identified. For example, Papetti et al. (2018) designed and implemented an IoT infrastructure that monitored employees as they worked in the packing area of an Italian sole manufacturer. Sensors fitted in wearable devices and at a testing site collected data on employees' physical movements and psychological comfort. By analysing the data collected, the authors were able to make suggestions to improve the ergonomics of the working environment. The authors concluded that a more ergonomically fit workplace would have a beneficial impact on employee health, which in turn would increase productivity. Similarly, an Italian ceramics manufacturer improved employees' working conditions by transferring physically strenuous tasks to autonomous machines, and by replacing employees with robotics in some of the more hazardous areas of production (Braccini & Margherita, 2019). The study also found that employees benefited from competencies and skills development as a result of being trained to use I4Ts.

2.7.4 Consideration of negative contributions

It has been argued that digital technology use will lead to unintended negative consequences for sustainability. In proposing a governance framework to aid its successful implementation, Kovács (2018) noted, "it is rather strange that available studies are merely focusing on the positive effects of Industry 4.0 while not mapping the interactions that may warn of unintended negative consequences" (p. 3). Similarly, Bohnsack et al. (2022) stated that "new technologies have always led to unintended consequences" (p. 600), and developed a framework that illustrates how the intended outcome of using a technology may not be realised in practice, but may instead result in unintended negative or unintended positive consequences for sustainability. Despite this, the prevailing narrative of extant literature is that I4Ts will make a positive contribution to sustainable manufacturing, with little mention of negative contributions (Dieste et al., 2023).

Some SLRs have recognised this imbalance in studies. For example, Ghobakhloo et al. (2021) conducted an SLR of 745 journal articles related to I4.0 and "did not find a single article dedicated to the possible disadvantages of Industry 4.0" (p. 13), and argued that potential negative impacts on social and environmental sustainability had been understudied. Piccarozzi et al. (2022) conducted an SLR of 192 articles to analyse the relationship between I4.0 and sustainability, and found that only six articles mentioned any type of negative relationship, while 125 articles reported only positive relationships between I4.0 and sustainability. Consequently, the authors stated "while there are numerous studies on the positive aspects of the introduction of Industry 4.0 in firms, potential risks are not so investigated" (Piccarozzi et al., 2022, p. 11).

A few studies have focused on the negative aspects of I4T implementation (Piccarozzi et al., 2022). Birkel et al. (2019) developed a comprehensive suite of risks related to I4T implementation covering economic, ecological, social, technical, IT and legal/political risk dimensions. The primary sub-risk under each respective dimension were financial (uncertainty regarding ROI and high investment costs), increased consumption, job losses, technical integration, cyber-attacks, and inadequate digital infrastructure. The authors concluded that risk identification and mitigation is essential for successful I4T implementation. Dieste et al. (2023) conducted a Delphi study with 43 experts to assess the probability of occurrence and expected severity of 12 negative impacts on environmental and social sustainability resulting from I4T use. The experts considered an increase in e-waste to be the problem most likely to occur and with the highest environmental impact, followed by a rise in natural resource consumption, particularly of rare earth metals. The top negative impact with respect to social sustainability, was loss of privacy and autonomy due to sensors monitoring and tracking employees' actions and locations. The expert panel could not agree whether jobs would be lost or created on balance (Dieste et al., 2023). The authors concluded that firms should be aware of the potential for unintended negative impacts to occur when implementing I4Ts.

The potential for job losses is a theme often raised in relation to social sustainability. The perception among employees surveyed in NZ was that repetitive jobs with low complexity are at risk of being replaced by digital technologies (Brougham & Haar, 2017). A survey among UK manufacturing employees similarly found that a large majority of respondents thought that unskilled workers would be replaced by robots (Leesakul et al., 2022). These survey findings contrast with case studies, which found that I4T implementation does not necessarily lead to job losses (Braccini & Margherita, 2019; Jena et al., 2020; Margherita & Braccini, 2020; Stefanini & Vignali, 2022). This is due to the fact that management can choose to retain staff by providing opportunities for retraining and skills development to use the new technologies, as well as by redeploying displaced employees to other areas of the organisation (Margherita & Braccini, 2020).

The high financial costs associated with I4T implementation represents the predominant negative contribution to economic sustainability (Ghobakhloo et al., 2022; Kamble et al., 2018).

2.7.5 Research gap and research question four

As outlined above, only a few studies consider the negative contributions that I4Ts can make to sustainability dimensions, which represents an imbalance in the literature. Bohnsack et al. (2022) urge researchers to "develop critical thinking and not only consider the opportunities but also the drawbacks of digitalization" (p. 601). Likewise, Liu et al. (2020) call for more attention on negative aspects of I4T implementation stating, "regarding research findings, it seems that we have mainly focused on the pros of new technologies on sustainability in operations and supply chain but so far rarely addressed the cons" (p. 4). Given the financial cost of implementing I4Ts, it is imperative that firms are aware of the potential drawbacks of their implementation in addition to the potential benefits. Consequently, the present study addresses the lack of a balanced view in the literature and answers calls for future research, by exploring the positive and negative contributions I4Ts make to sustainability through the following research question:

RQ4: How do Industry 4.0 technologies contribute to sustainability?

2.8 Theoretical lenses

This section discusses two theories employed in this study to guide the research and help understand how drivers, enablers and inhibitors influence I4T implementation: INT and DCT. Following the approach known as theoretical triangulation, two theories are used to gain more in-depth insights into I4T implementation than would be possible with a single theory alone, and to compensate for deficiencies in either theory (Cornelissen, 2025; Thurmond, 2001).

2.8.1 Institutional theory

INT provides a perspective on the influence an organisation's operating environment has on its behaviour (Meyer & Rowan, 1977). INT positions the organisation as operating within the context of an organisational field. An organisational field is a "cultural construct" (Powell & DiMaggio, 2023, p. 5), inhabited by "those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products" (DiMaggio & Powell, 1983, p. 148). Firms within an organisational field operate according to "social expectations and prescriptions about what constitutes appropriate ('legitimate') behavior" (Hinings et al., 2018, p. 53). By conforming to the norms and expectations of their organisational field, organisations maintain a social licence to operate, thereby increasing their probability of survival (Meyer & Rowan, 1977).

Within INT, the concept of institutional isomorphism explains the observation that organisations operating in the same organisational field gravitate towards homogeneity by adopting similar or the same practices, structures and strategies (DiMaggio & Powell, 1983). DiMaggio and Powell (1983) posit that three types of external pressure contribute to institutional isomorphism: coercive, mimetic and normative pressures. These pressures are summarised in Table 2.2.

Table 2.2: Summary of external institutional pressures

Institutional pressure	Description
Coercive	"Formal and informal pressures exerted on organizations by other organizations upon which they are dependent and by cultural expectations in the society within which organizations function" (DiMaggio & Powell, 1983, p. 150).
Mimetic	Pressures that encourage one organisation to copy the behaviour of another (DiMaggio & Powell, 1983).
Normative	Pressures emanating from membership of formal and informal professional networks (DiMaggio & Powell, 1983).

Coercive pressures to conform are placed upon an organisation by external actors such as customers, suppliers, shareholders, and government bodies, and also derive from socio-cultural expectations of appropriate corporate behaviour (DiMaggio & Powell, 1983; Hinings et al., 2018).

Mimetic pressures encourage firms to copy others. This might happen by the diffusion of 'best practice' by a consultant working with various organisations, by the movement of employees from one organisation to another, or by one firm intentionally copying the practices of a market leader (DiMaggio & Powell, 1983). DiMaggio and Powell (1983) state that uncertainty about how to proceed in a given situation drives firms to copy other organisations whose practices appear to be successful. Therefore, mimetic pressures tend to be greater in organisational fields experiencing high levels of uncertainty (Ukobitz & Faullant, 2022), such as fields in which "organizational technologies are poorly understood" (DiMaggio & Powell, 1983, p. 151).

Finally, DiMaggio and Powell (1983) used the term 'professionalisation' to theorise that formal and informal professional networks, such as universities, professional membership associations and industry bodies, exert normative pressures on employees to approach their work in a particular way, which leads to the diffusion and adoption of the same or similar set of ideas, policies and procedures across different organisations. Consequently, normative pressures tend to be greater in organisational fields subject to professional standards, such as accounting and medicine (Abane & Cobbina, 2024).

2.8.1.1 Prior research

INT has been used in previous studies to examine technology implementation by manufacturers. Some studies concluded that coercive, mimetic and normative pressures all have a role to play in technology implementation and adoption. These include Dubey et al. (2019), who employed INT with the resource-based view to develop a model examining the role of institutional pressures in building the resources necessary for big data capabilities in Indian manufacturers; Correia Simões et al. (2020), who used INT along with the diffusion of innovations theory and the TOE framework to examine factors influencing intentions to implement cobots in Portuguese and French manufacturers; Zhou and Zheng (2023), who combined INT with the TOE framework in a quantitative study investigating the relationship between drivers of I4T adoption in Chinese manufacturers; and Sony and Aithal (2020), who used INT with the resource-based view to develop a model to explain the digital transformation of the Indian engineering industry. In contrast, Ukobitz and Faullant (2022), who conducted a quantitative analysis of isomorphic pressures within the Mexican footwear manufacturing sector, concluded that coercive pressures had no significant influence on 3D printing technology adoption, but that mimetic and normative pressures both had a direct and indirect influence by increasing the perceived benefits of the technology.

2.8.1.2 Rationale for using INT

INT is commonly used to analyse influences on the technology implementation process within organisations (Molinillo & Japutra, 2017), and the articles outlined above support its use in this study. Further, given its basic premise that external pressures direct organisations to act in a certain way, the use of INT is relevant to this study's exploration of factors that drive I4T implementation.

2.8.2 Dynamic capabilities theory

In an exploration of factors influencing I4T implementation, DCT can be used to provide a complementary but contrasting view to INT. While INT posits that external forces drive firms to become more homogeneous, DCT holds that firms become more heterogeneous when they exploit their unique set of internal and external resources in the pursuit of long term competitive advantage (Teece et al., 1997). Although alternative approaches to the concept of dynamic capabilities (DCs) have been developed (Eisenhardt & Martin, 2000; Lin et al., 2016), the framework proposed and further developed by Teece et al. (1997) is used in this study as it is well established and widely used in the literature (Ellström et al., 2022).

DCT is a strategic management framework first described by Teece and Pisano (1994) and further developed by Teece et al. (1997) to explain how and why firms endure or fail during periods of rapid technological change in the business environment. Teece and colleagues posited that successful firms are the ones who develop DCs to respond to change. DCs are defined as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece et al., 1997, p. 516), and take three forms: sensing, seizing and reconfiguring capabilities (Teece, 2007). DCs are further underpinned by microfoundations which represent the skills, organisational structures and processes that enable a firm to develop sensing, seizing and reconfiguring capacities (Teece, 2007).

Sensing capabilities relate to the ability of a firm's management to identify and manifest opportunities and identify threats (Teece, 2007). Microfoundations for sensing opportunities and threats include formal assessments by, for example, conducting a macro-environmental analysis (Whittington et al., 2020), analysing the firm's competitive environment adopting Porter's five forces framework (Porter, 2008), or having internal resource dedicated to strategic scenario analysis (Warner & Wäger, 2019). On a more informal basis, firms might obtain information about opportunities and threats from suppliers, customers, networking and the media (Ellström et al., 2022; Teece, 2007). According to Teece (2007), the key to dynamic sensing is having the capability to "constantly scan, search, and explore across technologies and markets, both 'local' and 'distant'" (p. 1322).

Once opportunities and threats have been identified, seizing capabilities enable the firm to mitigate threats and exploit opportunities. This might be achieved by changing the make-up of existing resources and/or acquiring new resources such as technology or personnel (Vu et al., 2023), by providing new products and services to meet changing customer needs or by introducing new business processes (Teece, 2007). Because this stage typically requires a financial investment in resources and a commitment to organisational change, it is not unusual for firms to fail to seize upon identified opportunities or adequately mitigate threats (Teece, 2007).

Finally, Teece (2014) posits that strategic managers maintain their firm's competitiveness by utilising reconfiguring capabilities to reorganise the organisation where appropriate. This is achieved by "enhancing, combining, protecting, and reconfiguring the business enterprise's intangible and tangible assets" (Lin et al., 2016, p. 865) to remain congruent with the changing business environment. Reconfiguring microfoundations include developing new business models, hiring individuals with the skills needed to effectively respond to identified opportunities and threats (Warner & Wäger, 2019), and training and upskilling employees (Vu et al., 2023).

Although typically depicted in a linear fashion, Leemann and Kanbach (2022) noted that firms are unlikely to develop DCs in a set order and may, for example, reconfigure resources before seizing opportunities.

2.8.2.1 Prior research

Previous studies have used DCT to examine technology implementation in organisations. Some of the following articles refer to digital transformation, which can be defined as "the use of digital technologies…to enable major business improvements" (Warner and Wäger, 2019, p.1).

Vu et al. (2023) used DCT to examine how managers in Bolivia and Vietnam identify and respond to opportunities and challenges associated with I4T implementation. From their analysis of interview data, the authors concluded that managing resistance to change and investing in human and technological resources were key DCs firms need to develop when conducting I4T implementation.

Demeter et al. (2020) used a DC framework proposed by Lin et al. (2016), to examine how and why a Hungary-based automotive supplies manufacturer adapted its resources and competences during a four-stage digital transformation process. The study found that each stage of the firm's transformation began with sensing capabilities, followed by seizing and reconfiguring capabilities in varying combinations.

The study conducted by Warner and Wäger (2019) explored the experiences of senior executives to investigate how traditional firms build DCs for digital transformation. The authors developed a process model that disaggregates the DCs proposed by Teece (2007) into nine sub-capabilities of digital transformation, and concluded that I4T implementation leads to varying degrees of change to firms' business models, collaborative approach, and culture.

Taking a similar approach to Warner and Wäger (2019), by examining a firm undergoing digital transformation and from interviews with consultants who provide advice on digital transformation, Ellström et al. (2022) identified six routines, developed from sensing, seizing and reconfiguring DCs, that facilitate successful digital transformation. The authors suggested that firms need to be able to identify opportunities and threats through broad scans of the external environment, assess internal digital infrastructure capabilities, and develop a coherent digital strategy that identifies activities that can be conducted in-house and those which need to be outsourced.

Finally, Graham and Moore (2021) considered the role of knowledge-based DCs, such as a firm's absorptive capacity, in technology adoption. From semi-structured interviews, this US-based study found that technology adoption is influenced by a firm's sensing, seizing, and knowledge-based DCs, which inform its perception of the benefits and risks of adoption.

2.8.2.2 Rationale for using DCT

The basic premise of DCT is that successful organisations are the ones able to gain or maintain a competitive advantage by adapting internal and external resources to remain congruent with their changing business environment (Teece et al., 1997). The literature review indicated that factors that enable and inhibit I4T implementation often reflect the resources available to an organisation, and how the organisation manipulates those resources. Therefore, DCT provides an appropriate framework to consider factors that enable and inhibit I4T implementation.

2.8.3 Combining INT and DCT

As the literature review shows, the present study adopts a novel approach by combining INT with DCT to examine the factors that influence I4T implementation in manufacturers. Using the two theories together addresses the limitations identified in each.

INT provides a theory for how static organisational fields breed conforming, homogeneous organisations but it has been criticised for not being able to explain why and how organisational fields and organisations change (Nedzhvetskaya & Fligstein, 2020). DCT compensates for this perceived weakness, as it provides a framework which posits that organisational change occurs when firms' management develop and reconfigure internal and external resources to gain or maintain competitive advantage.

Conversely, DCT has been criticised for ignoring the contexts within which firms operate, and the impact environmental conditions might have on senior managements' ability to develop or use DCs (Barreto, 2010). INT compensates for this perceived weakness by providing a framework that shows how environmental factors influence organisational decision-making.

2.8.3.1 Research gap

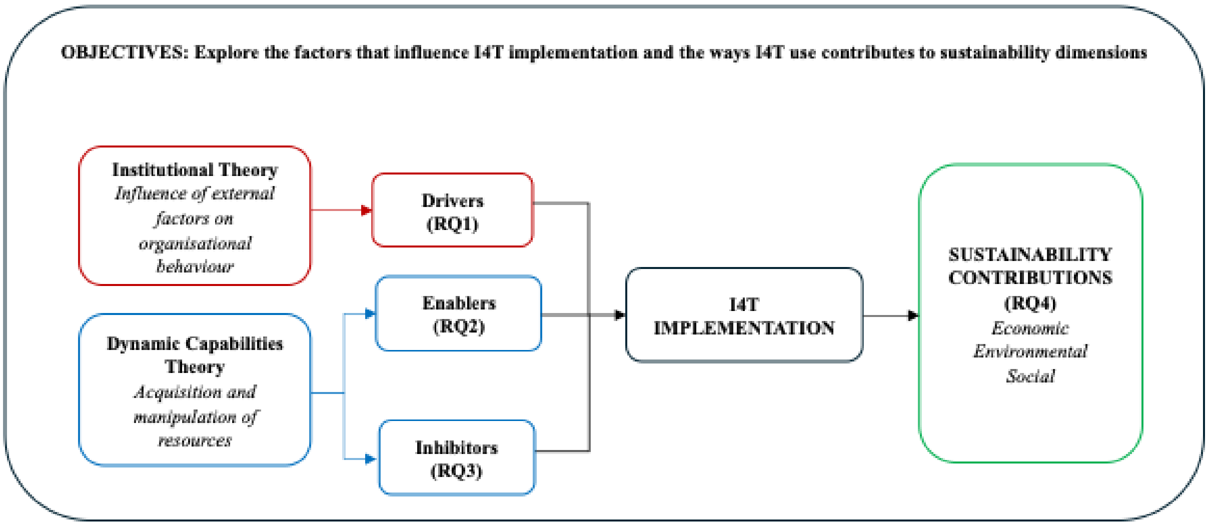
The literature review revealed that the majority of studies exploring factors influencing I4T implementation lack a theoretical foundation, and that INT and DCT have not been used together in an exploration of the drivers, enablers or inhibitors of I4T implementation. Consequently, the study bridges a theoretical research gap.

Employing INT in the present study answers a call for future research from Fogaça et al. (2022) who called for more studies looking at I4.0 from an institutional perspective. Gölgeci et al. (2017) contended that synthesising "both [INT] and [DCT] in a single framework can reveal unique and rich insights" (p. 250), and called for future research adopting this approach. Commenting on the use of information processing theory, RBV, TOE and stakeholder theory in papers focused on new technologies in operations and supply chains, Liu et al. (2020) encouraged researchers "to adopt more useful and relevant theories in their research, either applying old theories in the new contexts or in an attempt to extend the existing ones" (p. 4). Therefore, the synthesis of INT and DCT in the present study also addresses the latter two calls for future research.

2.9 Conceptual framework

When more than one theory is used to understand a research problem, their synthesis may be referred to as a conceptual framework which "represents an 'integrated' way of looking at the [research] problem" (Imenda, 2014, p. 189). Informed by the literature review, research questions and theories, and following the rationale given in 2.8.1.2 and 2.8.2.2, INT and DCT were synthesised into a single conceptual framework for I4T implementation. This conceptual framework is used in the present study to help guide the study and interpret the research findings (Imenda, 2014), and is depicted in Figure 2.1.

Figure 2.1: Conceptual framework for I4T implementation linking INT and DCT



2.10 Conclusion

This chapter presented a review of literature related to the drivers, enablers and inhibitors of I4T implementation within manufacturing production operations, and the positive and negative contributions I4Ts make to sustainability. INT and DCT were introduced as two theories used to guide the study and a conceptual framework was presented. Research gaps and relevant calls for future research were highlighted, which this study aims to address by adopting a combined exploratory/explanatory, qualitative research approach to address the stated research questions. This approach is discussed in detail in the next chapter.

Chapter 3 Research Methodology

3.1 Introduction

The aim of this study is to explore the factors that drive, enable and inhibit the implementation of I4Ts in NZ-based manufacturers and to explore managerial perspectives of the ways I4T use contributes to sustainability dimensions. This chapter outlines the methodological approach taken to fulfil the research aim.

3.2 Research philosophy

According to M. Saunders et al. (2016), "The term **research philosophy** refers to a system of beliefs and assumptions about the development of knowledge" (p. 124) which encompasses assumptions about ontology and epistemology. Ontological assumptions relate to what a researcher considers to be real while epistemological assumptions refer to assumptions about knowledge, what it is and how it can be communicated (Scotland, 2012). It is important that a researcher has an awareness of their own research philosophy because it underpins the choices the researcher makes with regard to how their research is conceived, designed and conducted (M. Saunders et al., 2016).

This study was guided by an interpretivist research philosophy. Interpretivism consists of a range of different intellectual standpoints concerned with understanding human actions and the mechanisms that influence them (Bell et al., 2022). According to Putnam and Banghart (2017), interpretivism is "based on the belief that reality is socially constructed or made meaningful through actors' understandings and interpretations of events" (p. 2).

Within the interpretivist research philosophy, the present study took a constructionist ontological position in viewing an organisation as a social construct that exists due to the actions and interactions of individuals within the organisation and external observations of the organisation (Gioia et al., 2013; Putnam & Banghart, 2017), and adopted a subjectivist epistemology which is concerned with the subjective meaning individuals' derive from interactions with their environment (Scotland, 2012). An interpretivist research philosophy is suited to this study because its exploration of factors influencing I4T implementation and the use of I4Ts for sustainability is based upon senior managers' subjective perspectives and experiences (Scotland, 2012).

3.3 Approach to reasoning

Different approaches to reasoning can be used to synthesise data and generate new knowledge: deductive, inductive and abductive approaches. In deductive approaches, a study starts with a rule/theory and data analysis seeks to confirm or refute the rule/theory, while inductive approaches start with data which is analysed with the aim of developing a universal rule/theory (Timmermans & Tavory, 2012). In contrast to deductive and inductive approaches to qualitative data analysis, an abductive approach "is neither data-driven nor hypothesis-driven" (Thompson, 2022, p. 1411). Instead, a researcher moves iteratively between empirical data, extant literature and theory to explain the research findings and perhaps develop new theoretical ideas (Thompson, 2022; Timmermans & Tavory, 2012).

A predominantly abductive reasoning approach was taken in this study. An abductive approach fits with the study's aim and research methodology because it "does not aim to discover a singular objective truth… [but] to find the most logical solution and useful explanation for phenomena" (Thompson, 2022, p. 1411). Further, in an approach typical of abductive analysis, this study synthesises two theories into a conceptual framework (see 2.9) which was used to guide the study and develop plausible explanations for the patterns and unique features identified in the data (Thompson, 2022; Timmermans & Tavory, 2012).

Timmermans and Tavory (2012) state that abduction "depends on the researcher's cultivated position" (p. 173) and that the ability to perceive and interpret 'surprises' in the data comes, in part, from a researcher's background. As such, an abductive approach is congruent with the researcher's position as a mature student with a broad educational background and extensive professional, senior management experience gained in the financial services sector. Further, it is recognised as an acceptable approach to combine with thematic analysis (Khurshid et al., 2025; Thompson, 2022), which is discussed in section 3.9.

3.4 Methodological choice

A qualitative research strategy was employed as it aligns with the research philosophy guiding the study and with the study's aim of exploring I4T implementation and use in the NZ context through senior executives' subjective perceptions and opinions. Perceptions and opinions regarding such organisational phenomena might also be captured through the use of quantitative methods, such as in the studies conducted by El Baz et al. (2022), Harikannan et al. (2020), Khai-Leang Yeap et al. (2024), Müller et al. (2018), Sureeyatanapas et al. (2023), and Yu and Schweisfurth (2020). However, in each of the afore-mentioned studies the authors derived factors influencing I4T implementation from extant literature before evaluating those factors using statistical modelling techniques or multi-criteria decision-making analysis. This suggested that adopting a quantitative approach would not enable influencing factors specific to the NZ context to be identified because, under a quantitative research approach, these variables have to be known before data collection begins. To illustrate the point, by conducting semi-structured interviews within a qualitative methodology, Skalli et al. (2024) claimed to identify three drivers of I4T implementation specific to the Moroccan manufacturing context. Consequently, in order to gain a rich and in-depth account of senior executives' experiences and to facilitate the discovery of issues specific to the NZ context, a qualitative approach was deemed appropriate (M. Saunders et al., 2016).

3.5 Research design

M. Saunders et al. (2016) describe research studies as having either an exploratory, explanatory, descriptive or evaluative purpose, or a combination of purposes. This study had a combined exploratory/explanatory purpose. It was exploratory in seeking to identify what factors influence I4T implementation and how I4T use contributes to sustainability dimensions. Concurrently, the study had an explanatory element as it employed INT and DCT to consider why and how manufacturers implement I4Ts.

A cross-sectional time horizon was chosen as this enabled rich and in-depth data to be collected from a number of participants at a particular point in time while accounting for the time constraints of the study (M. Saunders et al., 2016).

3.6 Participants

This study focused on the factors influencing manufacturers to implement I4Ts and how the use of I4Ts by manufacturers contributes to sustainability dimensions. However, primary data was collected from senior individuals employed within or connected to the manufacturing sector in their role as representatives of their organisation. Consequently, the unit of analysis upon which research conclusions were based was a NZ-based manufacturer, and the unit of data collection was an individual employed in or connected to the manufacturing sector (Yin, 2018).

3.6.1 Sampling strategy

Sampling is a technique used to limit data collection to a sub-group of a population (M. Saunders et al., 2016). Interpretive research typically uses small sample sizes to collect in-depth information about individuals' experiences (Davies & Fisher, 2018). As they are not concerned with generalising findings to a broader population outside the study's boundaries (Prasad & Prasad, 2002), interpretive studies can adopt non-probability sampling strategies (Bell et al., 2022). This study adopted purposive sampling which is a non-probability sampling technique used to focus participant selection on "people with particular characteristics who will better be able to assist with the relevant research" (Etikan et al., 2018, p. 3). A number of purposive sampling techniques exist (Nyimbili & Nyimbili, 2024). Criterion sampling was used in this study, by which pre-determined selection criteria were used to select participants with knowledge and experience relevant to the research topic and who were considered likely to be able to answer the research questions (Etikan et al., 2018; Nyimbili & Nyimbili, 2024).

3.6.2 Selection criteria

To be included in the study, manufacturers needed to have implemented at least one of the I4Ts described in Chapter 1. Individuals were expected to hold a senior position within their organisation, have solid knowledge of the firm's I4.0 initiatives and have an awareness of sustainability issues. Two non-manufacturing organisations were included in the study for their experience of advising manufacturers on I4T implementation. Their inclusion provided a broad industry perspective of I4T implementation within the manufacturing sector which supplemented the perspectives gained from individual manufacturers (Ellström et al., 2022; Warner & Wäger, 2019).

3.6.3 Recruitment strategy

The websites of entities focused on manufacturing and those promoting I4.0 were reviewed to identify potential participants for this study. Table 3.1 lists the sources used to identify potential participants.

Table 3.1: Sources used to identify potential participants

Source	Description
Callaghan Innovation	A government-owned entity whose remit included promoting I4.0
AMA (Advancing Manufacturing Aotearoa)	An industry body representing manufacturing businesses
NZ Manufacturer	An online magazine serving the manufacturing sector
MAKE NZ	An industry body representing manufacturing businesses
EMA (Employers and Manufacturers Association)	An association providing outsourced services and training to industry, including the promotion of I4.0
LMAC	A consultant providing services to manufacturers
TIN (Technology Information Network)	An industry body focused on the technology industry and the use of technology in industry
LinkedIn	An online, professional network that enables contact between individuals and organisations

Manufacturers located in the Auckland, Canterbury and Waikato regions were targeted as these areas constitute the country's top three regions for manufacturing employment (Business NZ, 2022a). By reviewing each of the sources listed in Table 3.1, firms and individuals mentioned in connection with I4.0 were identified in each target region. As individual email addresses were not typically publicly available, LinkedIn was used to connect with and message potential participants with a broad outline of the research's aim. It was also used to send messages to organisations, asking to be connected to relevant individuals who might be interested in participating in the research.

Individuals interested in taking part in the study were invited to contact the researcher at their university email address for further information. Individuals who made contact were sent an Information Sheet (Appendix A) and a Consent Form (Appendix B) by email. The Information Sheet contained details of the study, informed participants of their rights and advised how confidentiality of data and personal anonymity was maintained and with whom they could raise questions. The Consent Form was used to evidence participants' autonomy and willingness to participate in the study and to evidence their consent for the interview to be recorded.

3.6.4 Sample size

Before data collection begins, there is no way to know how many interviews will be sufficient to collect the data necessary to address the research question(s) (Baker & Edwards, 2012). Once data collection begins, the concept of data saturation can be used as a guide. B. Saunders et al. (2018) state that data saturation "relates to the degree to which new data repeat what was expressed in previous data" (p. 1897) and indicates when data collection can stop and data analysis should begin. While acknowledging that data saturation is a helpful concept, Guest et al. (2006) opine that "the idea of saturation… provides little practical guidance for estimating sample sizes, prior to data collection" (p. 59) and suggest that data saturation can be reached from between six and twelve interviews. Advice received from the researcher's supervisors was to collect data from at least fifteen participants. Ultimately, this study collected data from fifteen individuals representing fifteen organisations which exceeded the number suggested by Guest et al. (2006), and met the number suggested by the researcher's supervisors.

3.6.5 Participant characteristics

Table 3.2 shows characteristics of the firms and individual participants at each firm. Thirteen manufacturers were included in the study, along with one consultant to manufacturers and a government agency responsible for promoting I4.0. Individual participants all held senior positions within their organisations. A code was assigned to each firm and participant to maintain anonymity. To further enhance anonymity, each firm's activity is only broadly outlined with a description derived from the ANZSIC codes used to compile and analyse industry statistics in Australia and NZ (Australian Bureau of Statistics, 2013).

As there is no official definition given in NZ for a small, medium or large firm, the definitions for firm size were derived by reference to two government sources. MBIE defines a small business as having less than 20 employees (MBIE, 2025b). Stats NZ, NZ's official data agency, defines a large business as one with 100 or more employees (Stats NZ, 2024b). Extrapolating from these two definitions, a medium-sized firm is defined in this study as one having 20 to 99 employees.

Table 3.2: Participant characteristics

No.	Firm code	Activity	Size	Location	Market scope	Participant code	Participant role	Interview duration (minutes)
1	M1	Machinery and Equipment Manufacturer	Medium	Auckland	International	P1	Managing Director	72
2	M2	Electrical Equipment Manufacturer	Large	Christchurch	International	P2	General Manager	72
3	M3	Window Frame Manufacturer	Medium	Christchurch	Domestic	P3	Production Engineer	51
4	M4	Textile Product Manufacturer	Large	Auckland	Regional	P4	Chief Technology Officer	51
5	M5	Fabricated Metal Product Manufacturer	Medium	Auckland	International	P5	Chief Executive Officer	56
6	M6	Pharmaceutical and Medicinal Product Manufacturer	Large	Auckland	International	P6	Operational Technology Manager	109
7	M7	Dairy Product Manufacturer	Large	Auckland	International	P7	Operational Technology Manager	43
8	M8	Paper Stationery Manufacturer	Medium	Hamilton	Regional	P8	Site Manager	84
9	M9	Fabricated Metal Product Manufacturer	Medium	Hamilton	International	P9	Finance Manager	57
10	M10	Ventilation Equipment Manufacturer	Large	Christchurch	International	P10	Group Financial Controller	69
11	M11	Professional and Scientific Equipment Manufacturer	Large	Auckland	International	P11	Chief People Officer	84
12	M12	Pharmaceutical and Medicinal Product Manufacturer	Medium	Auckland	International	P12	Chief Operating Officer	57
13	M13	Ventilation Equipment Manufacturer	Large	Auckland	International	P13	Chief Operating Officer	50
14	C1	Consultant	n/a	Nationwide	n/a	P14	Owner	71
15	GA1	Government Agency	n/a	Nationwide	n/a	P15	Manager	58

Note. Regional market covers NZ, Australia and Pacific Islands. International refers to markets other than Domestic and Regional.

3.7 Materials

A two-part interview guide was developed to facilitate data collection. In qualitative studies an interview guide serves as a prompt to remind the interviewer to explore the broad areas considered important and relevant to addressing the research questions (Kallio et al., 2016). As such, the interview guide is not a rigid document. Instead, it allows the interviewer the flexibility to adjust specific questions in response to participants' responses while simultaneously providing a structure to the interview (Kallio et al., 2016).

An example of an interview guide used in this study can be found in Appendix C. As the participants in this study included manufacturing and non-manufacturing entities, slightly different versions of the interview guide were used depending on which type of participant was being interviewed. Nonetheless, each interview guide has the same broad structure. Part A contained prompts to thank the interviewee for their participation, to remind them of the aim of the study and of their rights, and to obtain agreement to proceed with the interview (M. Saunders et al., 2016). Part B contained open-ended interview questions which were developed to address the research questions and designed to allow the interviewee to respond freely regarding their perceptions and experiences. A conscious effort was made to draft the questions in a way that would not lead the participant to respond in a particular manner (Gioia et al., 2013).

The questions in Part B were divided into three groups. The first group of questions was designed to gather descriptive information about the firm and the individual. They also helped ease the interviewee into the interview as the questions were non-contentious and easily answered (M. Saunders et al., 2016). The second group of questions was designed to address the first three research questions of this study. Therefore the interviewees were asked about their experience of I4T implementation within their organisation and associated drivers, enablers and inhibitors. In the final group of open-ended questions, designed to address RQ4, the interviewee was asked for their views/perceptions of how I4T use contributes to sustainability dimensions. In the very last question, the interviewee was given free rein to elaborate on any element pertinent to the discussion.

Because there is no definitive list of the technologies, participants may have different understandings regarding what constitutes an I4T. Therefore, and following the approach taken by Stentoft et al. (2021) and Graham and Moore (2021), participants were shown a list of the technologies described in section 1.1.4. Participants were advised that the list was not exhaustive and encouraged to highlight other pertinent technologies. The list proved to be a useful tool which helped interviewees recall the technologies used by their organisations.

All interviews were recorded using a hand-held, digital recorder. The MacWhisper transcription software was used to transcribe the interviews.

3.8 Data collection

Qualitative research typically relies on non-statistical methods to collect and analyse text-based, audio-based and visual forms of data (Prasad & Prasad, 2002). Further, as stated by Levitt et al. (2017), "constructivist-interpretive researchers seek to use dialogical exchanges with participants in order to uncover meanings that are held by sets of people or systems" (p. 7). Such exchanges can be achieved through semi-structured interviews (Busetto et al., 2020), which was the data collection method used in this study. Using semi-structured interviews with open-ended questions facilitates a degree of consistency in the questions asked whilst allowing the participant freedom to express their understanding and experience in their own words (Bell et al., 2022), which aligns with the research philosophy and methodological choice of the study. Semi-structured interviews also allow researchers flexibility to respond to each participants' individual experience by asking unscripted follow-up questions which may enable novel insights to be discovered (Busetto et al., 2020).

Interviews were conducted during the period from 30 January to 14 March 2025. Thirteen of the fifteen interviews were conducted in person, on a one-to-one basis, at the participant's workplace in Auckland, Christchurch or Hamilton. In addition to facilitating rapport-building with the interviewees (O'Leary, 2021), conducting in-person interviews provided the researcher with the opportunity to observe I4Ts in action during tours of manufacturing facilities after the interview concluded. Two interviews were conducted online using Microsoft Teams due to geographic distance from the interviewee. The interview guide was closely followed during each interview to ensure that each participant was asked about the main topics of interest. Additionally, the semi-structured nature of the interviews allowed the researcher freedom to pursue relevant lines of enquiry that emerged from participants' responses.

In total, almost 16½ hours of interview data were collected which amounted to 294 A4 pages when transcribed. Interviews ranged in length from approximately 43 minutes to 109 minutes, resulting in an average interview length of 66 minutes. The duration of each interview is shown in Table 3.2.

Secondary firm-related data, such as information held on the firm's own website and I4.0 case-studies about the firms held on third-party websites, was reviewed and the factory tours mentioned above provided an opportunity to corroborate what was said during some of the interviews. By triangulating different methods of data collection, a greater understanding of I4T implementation within the firms participating in this study was gained which added to the study's robustness (Denzin, 2012).

3.9 Data analysis choice

This section provides an overview of the chosen data analysis method.

3.9.1 Thematic analysis

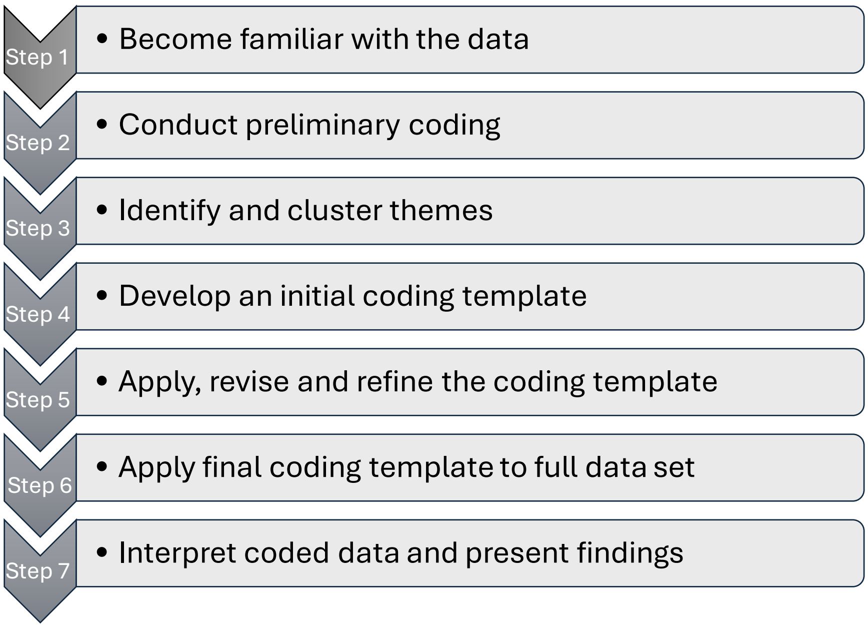
Data were analysed using thematic analysis which is a technique widely used to analyse qualitative data (Bell et al., 2022). Thematic analysis is a method encompassing a group of approaches (Braun & Clarke, 2021b) that share a common aim of "…identifying, organising and interpreting themes in textual data" (King & Brooks, 2018, p. 220) leading to "rich descriptions, explanations and theorising" (M. Saunders et al., 2016, p. 579). Thematic analysis is not bound to any underlying ontological or epistemological position, making it a flexible data analysis method (King & Brooks, 2017b). A key benefit of thematic analysis is that it enables the large amount of data typically produced in qualitative research to be distilled into key themes that are more digestible and more easily conveyed to the study's target audience (King & Brooks, 2018).

As previously stated, thematic analysis is not one approach but a group of approaches (Braun & Clarke, 2021b). Braun and Clarke (2021a) describe three approaches to thematic analysis which they define as coding reliability approaches, reflexive approaches, and codebook approaches. This study adopts template thematic analysis, commonly referred to as template analysis, which Braun and Clarke (2021a) describe as a codebook approach to thematic analysis. According to Braun and Clarke (2021a), codebook approaches "combine the qualitative research values" (p. 39) of their own, well-documented, reflexive approach with a structured framework that facilitates "efficient delivery of analysis to a fixed deadline and meeting predetermined information needs" (p. 39).

3.9.2 Template analysis

This study uses the template analysis approach recommended by King and Brooks (2017a), which typically follows the seven steps shown in Figure 3.1. The method is initially similar to Braun and Clarke's reflexive approach in that familiarisation with the data, coding, and theme generation are common to both. The two approaches diverge at the point where template analysis introduces the development of a coding template which is used to systematically analyse the data (King & Brooks, 2017a). Although the process is depicted as linear in Figure 3.1, in practice the approach is highly iterative with many of the steps revisited as data analysis progresses.

Figure 3.1: Typical steps taken during template analysis



Note. Adapted from "Doing template analysis: A guide to the main components and procedures" by King, N and Brooks, J.M. In *Template Analysis for Business and Management Students.* SAGE Publications Ltd. (https://doi.org/10.4135/9781473983304)

In common with other approaches to thematic analysis, template analysis involves the clustering of codes to develop sub-themes and themes. However, template analysis is characterised by "its emphasis on hierarchical coding… [which] allows for analysis of the textual data at varying levels of specificity" (King & Brooks, 2017a, p. 34). Consequently, there is no set limit to the number of levels of coding within a template analysis approach which supports a granular analysis that enables researchers to "capture the richest and most detailed aspects of their data" (King & Brooks, 2018, p. 225).

3.9.3 Rationale for using template analysis

Given that thematic analysis is not a single approach, the researcher made what Braun and Clarke (2022), describe as a "deliberative decision" (p.4) to use template analysis in this study. When researching the use of thematic analysis as an approach to analyse interview data, the researcher read a number of articles by Braun and Clarke including *Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches* (Braun & Clarke, 2021a). The paper describes and compares three approaches to thematic analysis: coding reliability approaches, reflexive approaches and codebook approaches.

Reading Braun and Clarke (2021a) was the first time that the researcher had encountered approaches to thematic analysis other than the reflexive approach. It was immediately apparent from the paper that so-called coding reliability approaches were not aligned with the constructionist ontological/ subjectivist epistemological approach underpinning this study because of their leaning towards objectivity and reliability, therefore the use of this approach was discounted. The choice between using a reflexive or codebook approach was not as simple to make, however Braun and Clarke's (2021a) assertion that "codebook approaches… [are used] often for pragmatic reasons such as…efficient delivery of analysis to a fixed deadline" (p. 39), led to a deeper review of template analysis. Following further investigation, the researcher decided that template analysis would be an appropriate method to use in this study because it aligned with the research philosophy and enabled the flexibility to use abductive and inductive approaches to data analysis (Khurshid et al., 2025; King & Brooks, 2017b). The researcher also felt that the structure provided by the use of a coding template would be helpful to a first time user of thematic analysis.

Further, the researcher noted that template analysis supports the use of *a priori* themes, which are "themes identified in advance of coding" (King & Brooks, 2017a, p. 29). In contrast, reflexive thematic analysis does not support the use of *a priori* themes. In summarising ten core assumptions of reflexive thematic analysis, Braun and Clarke (2022) state, "Themes are analytic outputs, not inputs, and are developed after coding and from codes" (p. 9) which clearly rules out the use of *a priori* codes within a reflexive thematic analysis approach. Given that this study identifies drivers, enablers and inhibitors as specific areas of interest, the intention to use them as *a priori* codes was identified early on (King & Brooks, 2017a).

Consequently, this was another reason why template analysis was considered the most appropriate thematic analysis approach to use in this study.

Template analysis has been widely used in business, management and social science research (King & Brooks, 2017b). Template analysis has been used in articles recently published in top quartile publications, covering a range of research areas (Ashraf & Lindebaum, 2025; Bastl et al., 2012; Homann et al., 2021; Oukes et al., 2024), including technology use (Behnke & Janssen, 2020; Madan & Ashok, 2025). Therefore, this study's use of template analysis is supported by extant literature.

3.10 Data analysis approach

Together with gaining familiarity with the data, coding is the foundation of thematic analysis. Coding involves labelling a segment of data with a code that represents its meaning within the study's context (M. Saunders et al., 2016). In this study, a coded segment of data is referred to as a reference. This section provides a detailed account of the steps taken to code and analyse the interview data following the process summarised in Figure 3.1.

3.10.1 Preparation for coding

Interviews were transcribed verbatim on the same day they took place using the MacWhisper transcription software. Interviews were transcribed verbatim and the narratives kept in their authentic form to preserve interviewees' voices and stay true to the data (Thompson, 2022). At the time of conducting the interviews, the MacWhisper software was not able to automatically assign speaker identifiers to the text. Therefore, after the automatic transcription was produced, speaker identifiers were assigned manually whilst simultaneously listening to the interview to ensure correct placement of the identifiers. This provided an initial opportunity to revisit the interview and gain familiarity with the data. At the same time, any misspellings in the transcript were corrected and it was amended for missing or incorrect text to ensure that the transcript accurately reflected what was said during the interview. Next, the proof-read transcript was converted to a Microsoft Word document and, following the procedure recommended by King and Brooks (2017a), assigned line numbers, page numbers, wide margins and double-line spacing to facilitate coding. Finally, each transcript was printed in preparation for coding which was initially conducted manually.

3.10.2 Manual coding process

Before coding began, each interview was listened to and the transcript read again to ensure understanding of and familiarity with the data. Five transcripts were then selected from which to develop an initial coding template. The five transcripts chosen represented a mix of medium- and large-sized manufacturers and also included the participant from the government agency who provided a broad industry view which complemented the more firm-specific data provided by the manufacturers. This subset was chosen to encompass views across a broad range and help to produce a comprehensive initial template (King & Brooks, 2017a).

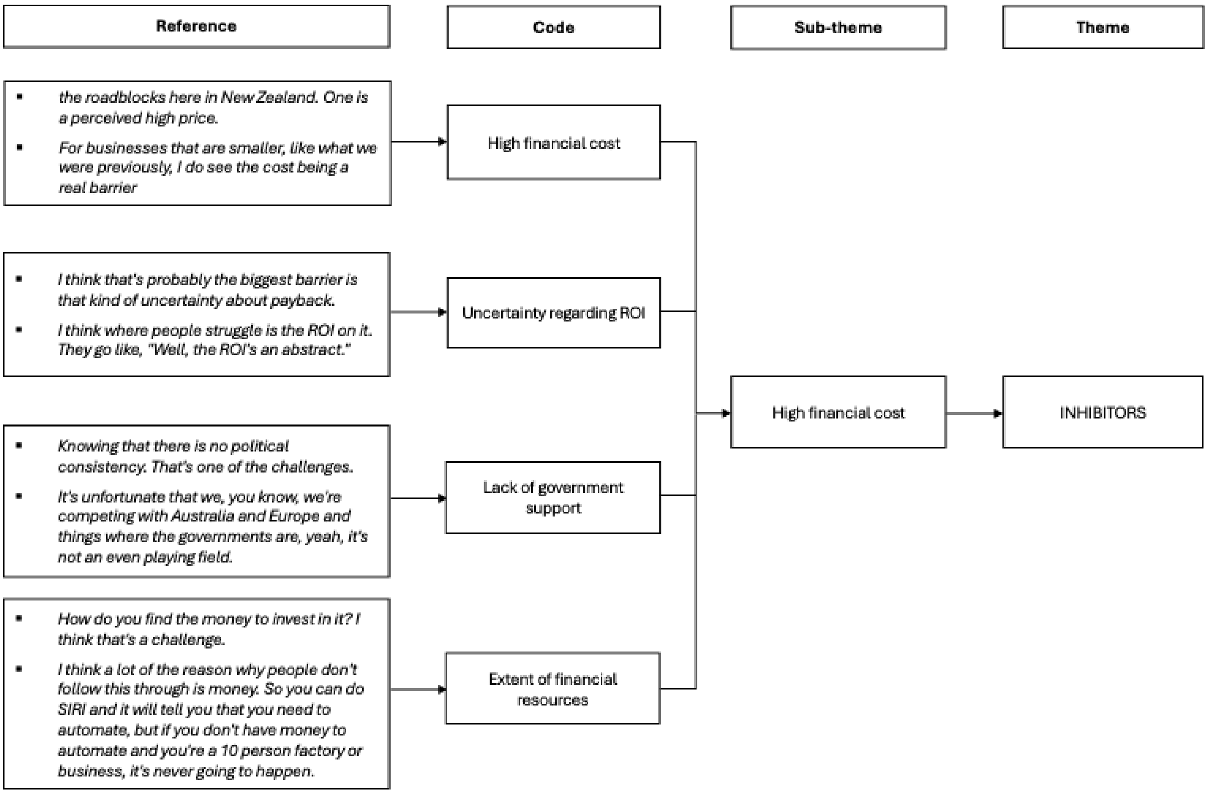
Four themes were identified prior to coding: drivers, enablers and inhibitors of I4T implementation, and I4T sustainability contribution. These *a priori* themes were 'soft' in style as they were developed from general issues identified in the literature review, in contrast with 'hard' *a priori* themes which derive directly from an existing framework or theory (King & Brooks, 2017c). The *a priori* themes represented the focus of this study and specifically related to the study's research questions (King & Brooks, 2017a). Also, at a very early stage of the coding process, a theme labelled 'NZ manufacturing characteristics' was developed inductively to encompass certain observations made by the participants which did not initially appear to fall within the *a priori* themes.

Reading through each printed transcript, anything in the text considered relevant to the research questions was highlighted using different coloured highlighter pens to differentiate between different aspects of the coding. Each highlighted text segment/reference was annotated with the heading of the theme that it most appropriately sat within. At the same a code was developed to represent the meaning of the reference or, where appropriate, an already-developed code was assigned.

A Word document was populated with each theme and, concurrent with the manual coding on each transcript, codes were added to the Word document under the relevant theme as they were developed. As additional codes were developed, some were clustered with existing codes that related to a similar issue to form a sub-theme. This led to the creation of a hierarchical list of themes, sub-themes and codes. Apart from the *a priori* themes, all other themes, sub-themes and codes were developed following an inductive/abductive approach.

Figure 3.2 provides an illustration which shows how references contributed to the development of codes and sub-themes underpinning the themes.

Figure 3.2: Development of a theme from references



After the first five transcripts were coded, the list of themes, sub-themes and codes was reviewed for potential duplication and amendments to the hierarchical position of codes was made as required. Once the review was finalised, this document formed the initial coding template (Appendix D).

The initial coding template was used to code a new subset of three interview transcripts. Again, data considered relevant to the research was highlighted and either coded with an existing code from the initial template, or a new code was developed to reflect the meaning of the reference. The process continued until the subset of three interviews were coded and all new codes had been added to the initial coding template. At the end of this round of coding, the coding template was reviewed and the opportunity taken to revise the description or hierarchical position of codes and sub-themes following an abductive approach. This resulted in a second iteration of the coding template.

The second version of the template was used to code the final subset of seven transcripts. Seven new codes resulted from this iteration which were added to the coding template. Once again, the template was reviewed and the position of codes and sub-themes revised as necessary. This resulted in a third version of the coding template.

Finally, all fifteen transcripts were reviewed against the third version of the template to check whether any additional codes were required and to ensure that all data relevant to the research questions had been coded. No new codes were developed at this stage but the position of a small number of codes was revised which resulted in a fourth iteration of the coding template. This template reflected a comprehensive analysis of the data and was the final template resulting from the manual coding process.

In addition to coding all data relevant to the research questions, the opportunity was taken to also code for some descriptive data, such as data related to the I4Ts that firms reported to use and data related to a firm's level of experience with I4Ts.

3.10.3 Analysis using NVivo

Once the manual coding was concluded, subsequent data analysis was conducted using NVivo which is a type of computer-assisted qualitative data analysis software (Lumivero, 2025). NVivo has functionality that helps researchers organise and analyse qualitative data and supports hierarchical coding at theme, sub-theme and code levels (Mortelmans, 2025).

The interview transcripts were imported into NVivo and the final manual coding template was replicated in the software to produce, what NVivo calls, a codebook. Once again, the opportunity was taken to review the position of the codes and sub-themes and amendments were made to the codebook by merging and moving codes. For example, the 'Low volume' code that originally sat within the 'NZ manufacturing characteristics' theme was moved to the 'Inhibitors' theme as this placement better reflected the researcher's interpretation of participants' comments. The complete and final codebook can be found at Appendix E.

After finalising the codebook in NVivo, the manual coding of all fifteen transcripts was replicated in the system. Once all the coding was complete, NVivo's data aggregation capability made it easy to see how many interviews a particular code appeared in and the number of times the code was used. Due to the rich body of data collected, a decision had to be taken on how to identify the themes and sub-themes most relevant to the research questions from the various clusters of codes. Following the approach taken by Riemer et al. (2025), a cluster of codes was considered to be a relevant theme or sub-theme when the cluster appeared in at least seven interviews in the aggregate. This approach is reflected in the data presented in the Findings chapter.

NVivo's framework matrix tool was a particularly useful function which was used to facilitate an in-depth cross-case analysis of the data by aggregating findings and identifying patterns in the data (Yin, 2018), and to identify quotes to illustrate and support the findings (Rockmann & Vough, 2024). Appendix F provides an excerpt of a framework matrix covering the 'High financial cost' code.

The final step in the template analysis process, interpreting the data and presenting the findings, is covered in the Findings and Discussion chapters.

3.11 Research quality

The trustworthiness of qualitative research can be assessed against four criteria proposed by Guba (1981): credibility, transferability, dependability, and confirmability. A number of the strategies proposed by Shenton (2004) were applied to this study to demonstrate the research's trustworthiness.

3.11.1 Credibility

Credibility refers to the extent to which research findings are considered believable (Guba & Lincoln, 1982). This study's credibility is supported by the use of well-established research methods, a detailed account of which was presented in this chapter. Suggestions from supervisors on how to improve the quality of the research were taken on board and incorporated into the study. Triangulation of methods and theories was used to support a holistic approach and compensate for weaknesses in any one approach. In addition, participants included users and suppliers of I4Ts as well as experts in their application, which Shenton (2004) suggests is another form of triangulation. Individuals willingly participated in the study which helped ensure that the data was given honestly, without coercion. The use of criterion sampling provides assurance that data were generated from credible sources (Nyimbili & Nyimbili, 2024). All of the participants were senior employees including a number of C-suite executives whose seniority lends further credibility to the study (Burton & Galvin, 2019). A rich and in-depth body of data were collected and the use of quotations provides evidence to address the research questions and support interpretations and conclusions. Finally, Shenton (2004) suggests that the experience of the interviewer contributes to the quality of the data collected. In this regard, although relatively new to academic research, the researcher has conducted research in corporate settings and has extensive experience of conducting semi-structured interviews with C-suite executives from their previous professional role as an onsite regulatory supervisor of financial institutions.

3.11.2 Transferability

Transferability refers to the extent to which research findings can be applied in other situations (Stenfors et al., 2020). By providing details of the context within which the study was undertaken and detailed Methodology and Findings sections, sufficient information has been provided to enable a reader to assess the transferability of this study to their own (Shenton, 2004).

3.11.3 Dependability

Dependability refers to the extent to which another researcher would be able to repeat the study (Shenton, 2004). Again, providing a detailed account of the research methodology and data analysis approach helps to support the dependability of this study (Shenton, 2004). Further, the interview guides, interview transcripts and successive coding templates have been retained and contribute to an 'audit trail' that could be reviewed as part of a "dependability audit" (Guba, 1981, p. 87).

3.11.4 Confirmability

Confirmability refers to there being a clear link between the data and the findings (Stenfors et al., 2020). Together with the interview guides, interview transcripts and successive coding templates, the coding tables and quotes presented in the Findings section provide an audit trail of information clearly linking the data to the findings.

3.12 Ethical considerations

This study was conducted with due regard to Massey University's human ethics code of conduct (Massey University, 2017). Research ethics approval was sought and obtained prior to approaching prospective participants, with the study judged to be low risk. Confirmation of ethics approval can be found in Appendix G.

As stated in section 3.6.3, all participants received an Information Sheet and a Consent Form which contained information regarding the ethical conduct of the research and advised how the participant could raise any concerns in that regard. A signed copy of the Consent Form was received from each participant before conducting the interview and additionally, verbal confirmation was obtained immediately before commencing the interview that the participant was happy for the interview to be recorded.

The research methodology chapter of the thesis, the interview guide, Information Sheet and Consent Form were reviewed by the research supervisors to ensure that ethical considerations had been addressed within the research methodology. The latter three documents were reviewed to ensure that they contained relevant and required information and were included as part of the research ethics approval application process.

Interview recordings were transferred from the portable digital recorder to a personal computer hard drive as soon as possible and the recordings deleted from the portable device to minimise the possibility of data loss. The MacWhisper transcription software was chosen as it produces high quality, automated transcripts which can be generated by and stored on a personal computer. As the data is not generated by or stored on a cloud-based service, it is less likely to be compromised by an unauthorised third party, which results in enhanced data security.

3.13 Conclusion

This chapter restated the research aim before outlining the qualitative methodological approach taken to achieve that aim within an interpretivist research approach. Ethical considerations were highlighted, as was evidence supporting the trustworthiness of the research. Rationale was given for the use of template analysis in this study, along with details of the iterative process taken to conduct the analysis. The findings from the analysis are presented in the next chapter.

Chapter 4 Findings

4.1 Introduction

As previously stated, it is important to understand what influences I4T implementation and how the technologies contribute to sustainability. Consequently, this study explored the factors that drive, enable and inhibit I4T implementation in NZ-based manufacturers, and managerial perspectives of the ways I4Ts contribute to sustainability, through the following research questions:

RQ1: What factors drive I4T implementation?

RQ2: What factors enable I4T implementation?

RQ3: What factors inhibit I4T implementation?

RQ4: How do I4Ts contribute to sustainability?

This chapter presents the key findings from the thematic analysis of data captured from 15 semi-structured interviews. In total, almost 16½ hours of interview data were collected. Interviews ranged from approximately 43 to 109 minutes, resulting in an average length of 66 minutes. Overall, 294 pages of transcribed interview data were analysed in developing the findings.

The remainder of this chapter is structured as follows. First a summary of the I4Ts each manufacturer was reported to use is presented along with an overview of each manufacturer's I4.0 maturity level. A summary of the key findings is presented in section 4.3, each discussed in greater detail in subsequent sections. Finally, concluding comments are made in section 4.8.

4.2 I4T use and I4.0 maturity level

Before presenting the findings as they relate to this study's research questions, this section provides a summary of the I4Ts each manufacturer used and an estimation of each manufacturer's I4.0 maturity level.

4.2.1 I4T use

To gain an understanding of the I4T implementation landscape, participants employed by manufacturers were shown a list of the I4Ts described in section 1.1.4 and asked which technologies their firm used. The responses are summarised in Table 4.1. The table also provides a descriptor of each manufacturer's I4.0 maturity level, derived from participants' comments, the technologies used, and the length of time the firm had been using I4Ts.

Table 4.1: Manufacturers' I4T use and I4.0 maturity level

	I4T used								I4.0 maturity level
Firm	**CC**	**ARA**	**AI**	**AM**	**IoT**	**BDA**	**AR**	**DT**	
M1	•	•	•		•	•			Advanced
M2	•	•	•	•	•	•			Intermediate
M3	•			•					Beginner
M4	•								Beginner
M5	•			•					Beginner
M6	•	•	•						Beginner
M7	•	•	•		•	•	•	•	Advanced
M8	•		•						Beginner
M9	•	•		•	•				Beginner
M10	•		•	•					Beginner
M11		•	•	•	•	•			Intermediate
M12	•	•			•				Beginner
M13	•	•				•			Beginner
	12	**8**	**7**	**6**	**6**	**5**	**1**	**1**	
	Number of firms using the technology								

Note: CC = Cloud Computing; ARA = Advanced Robotics & Automation; AI = Artificial Intelligence; AM = Additive Manufacturing; IoT = Internet of Things; BDA = Big Data & Analytics; AR = Augmented Reality; DT = Digital Twin

All manufacturers reported using cloud computing, except one who used on-site servers due to the commercially sensitive nature of their data. In the I4.0 context, cloud computing tends to be associated with big data analytics as cloud computing services are typically required to store and process the large volumes of data generated by network-enabled devices in an IoT (Zheng et al., 2021). In this study, less than half of manufacturers reported using an IoT which translated to a low reported incidence of big data production. However, all manufacturers reported generating and analysing data to some degree. As P4 put it:

> *I would say there is part of data and analytics but I wouldn't call it big data. I would call it more data and analytics.*

These findings indicated that, even though some firms are not using it to capture and analyse big data, cloud computing is an important technology that supports firms' wider business operations. This was illustrated by P8 who described how cloud computing enables colleagues to work and collaborate from multiple sites.

> *We run everything through the cloud. We have eight people [in Hamilton]. We have an office in Auckland, a department in Australia, multiple people working remotely and a few more people who are part-time remote, part-time in office. So, because of that, everyone needs access to the same information... so of course that's on the cloud. (P8)*

Manufacturers reported using advanced robotics and automation, IoT and digital twins directly in production processes. In contrast, augmented reality and additive manufacturing were used exclusively to support wider business operations rather than in the direct manufacture of products. Only M7 reported using augmented reality, which was used to deliver training. Table 4.2 lists quotes that illustrate the use of additive manufacturing outside the core production process.

Table 4.2: Quotes referencing additive manufacturing usage

Firm	Quote
M2	*We've got lots of different 3D printers that we use. We use a lot for tooling...they 3D print jigs and fixtures.*
M3	*I've been using a little bit of additive manufacturing, not for actual manufacture, just for prototyping and testing. I've got the 3D printer in the corner here, this is for printing tools more than actually printing products.*
M5	*Additive manufacturing...where we use it is for packaging type items, things like that, little caps that we put on things.*
M9	*We do model some 3D printing for some of our product ideas. It's just to aid in the design process.*
M10	*Additive manufacturing we are using, but not for manufacturing. We're using it for testing our models, testing our designs.*

AI was used both in production processes and to support the business. For example, P8 reported using AI "*largely for documentation and research…but not really at the manufacturing end*", whilst similarly for P10, AI is a tool that facilitates the completion of a range of administrative tasks.

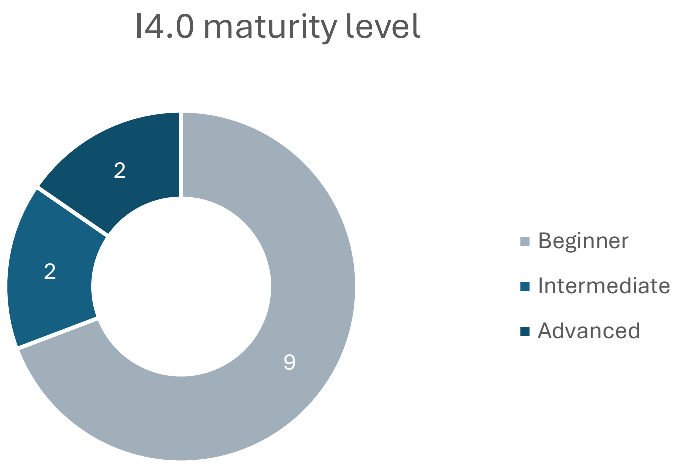
> *I use a bit of AI for analysing contracts, for analysing board papers, just to check that I've picked everything up. I use it for creating new policies and things like that. So fairly admin-type stuff. (P10)*

The quotes above illustrate that I4Ts are used to support the design and delivery of core products and to support business operations in a number of areas in addition to being used directly in manufacturing processes.

4.2.2 I4.0 maturity level

As noted in section 1.1.4, cloud computing, IoT and BDA are base technologies that facilitate the use of other I4Ts (Frank et al., 2019). In this study, a firm that does not have an IoT in place or is not producing big data is described as a Beginner as this indicates that the firm is at the early stages of integrating I4Ts into their operations. Firms in this category are still exploring the use of I4Ts within their organisations and typically describe manual processes for collecting and analysing data. Intermediate firms have implemented a number of I4Ts which have been deployed in recent years. Real-time data is captured which enables better process visibility and decision-making. Integration of I4Ts in these firms is ongoing. Firms described as advanced have been using I4Ts for many years and have expert knowledge of their application. Figure 4.1 shows that the majority of manufacturers in this study are at the beginning of their I4T implementation journey.

Figure 4.1: I4.0 maturity level

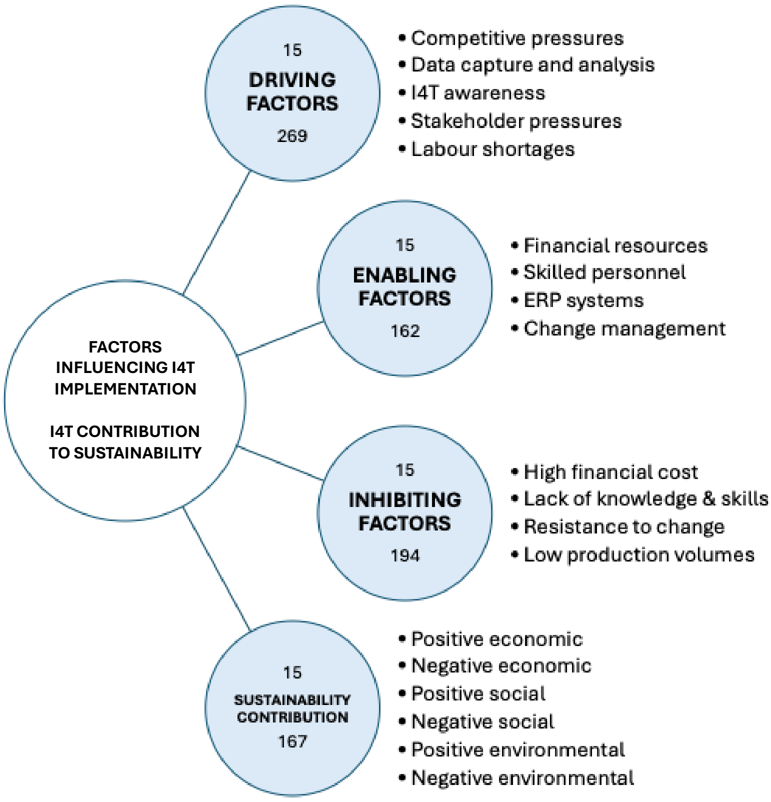


This section provided descriptive information by presenting an overview of the I4Ts each manufacturer was reported to use, along with an I4.0 maturity level reflecting the technologies used and the length of time they had been used. The following sections present the findings in relation to the research questions.

4.3 Summary and presentation of key findings

This section presents a summary of the study's key findings from the thematic analysis focused on exploring the factors that influence I4T implementation in manufacturing production operations and the contribution I4Ts make to sustainability. Figure 4.2 depicts the key findings of the study with the themes denoted by shaded circles and the corresponding key sub-themes listed by bullet point. The upper figure in each circle represents the number of interviews that the theme was coded to, while the lower figure denotes the number of references coded to the theme. Each sub-theme is discussed in greater detail in subsequent sections.

Figure 4.2: Summary of key findings



Hierarchical coding is a characteristic of template thematic analysis with "groups of similar codes clustered together to produce more general higher order themes" (King & Brooks, 2017a, p. 13). In the following sections, the codes that contribute to each sub-theme are presented for transparency in a series of tables together with the number of references attributed to each sub-theme and code. Due to coding aggregation, the number of references attributed to a sub-theme may not equal the number of references attributed to the codes within the sub-theme. This is because coding that took place directly to the sub-theme is not shown separately.

It should be noted that the analysis does not attempt to discuss each code within a sub-theme. Instead, it typically focuses on the codes considered most pertinent to the understanding of the sub-theme. Further, codes that did not contribute to a sub-theme (see section 3.10.3) are not shown in this chapter. A complete list of codes can be found in the final coding template located in Appendix E.

4.4 Drivers of I4T implementation

This section presents findings related to the first research question of this study – what factors drive I4T implementation in NZ-based manufacturers? To explore this question, participants were invited to discuss why firms implement I4Ts and what firms hope to achieve by implementing them. Five key sub-themes relating to driving factors were derived from the thematic analysis: competitive pressures, data capture and analysis, I4T awareness, stakeholder pressures, and labour shortages. The key driving factors are depicted in Figure 4.3.

Figure 4.3: Drivers of I4T implementation

4.4.1 Competitive pressures

Participants agreed that competition was a key driver of I4T implementation. The findings revealed that improving production efficiency and productivity, and keeping up with competitors, were the main sources of competitive pressure. The coding to this sub-theme is presented in Table 4.3.

Table 4.3: Competitive pressures coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers				
	Competitive pressures		**15**	**125**
		Improving production efficiency	15	78
		▪ Making better use of resources	11	24
		▪ High and consistent product quality	7	15
		Keeping up with competitors	9	11
		Improving and maintaining productivity	7	12
		Profitability & ROI	6	8
		Keeping manufacturing in NZ	3	6
		New business models	2	4

Participants highlighted improving production efficiency and productivity, by optimising resources, reducing waste and costs, and improving product quality, as key factors driving I4T implementation. For example, P7 described implementing machine vision on production lines to monitor efficiency and productivity, and prevent poor quality product reaching customers.

> *How we seal the bag is really important because if air gets in, that can deteriorate the life of the product. Also, you want a nice-looking bag going to the customer. Now we take a photo of every single bag that we produce. We've got an AI algorithm in the background that sees whether it's a good bag or a bad bag. If it's a bad bag, we kick it off the line. (P7)*

In addition to improving productivity, the findings revealed that firms were also motivated to implement I4Ts to maintain productivity levels when human resources were scarce. For example, P9 described implementing a cobot to facilitate the completion of a physically demanding and unattractive task, after it was identified that an aging workforce and recruitment difficulties threatened M9’s ability to maintain production levels and meet customer demand.

> *[The driver] was around doing more with less people. Because that's the only way we can be efficient or productive or profitable in a business that's very labour intensive.*

Participants indicated that implementing I4Ts was necessary to keep up with competitors, with comments such as "*staying relevant*" (P2), "*keep the business moving with the times*" (P9), and "*not getting left behind*" (P11) used to describe what motivated firms to implement I4Ts. Highlighting the pressure to match competitors' use of I4Ts, P5 asserted:

> *You're going to get left behind if you don't do this. If you don't focus on this stuff, you will be left behind and probably out of business within 10 years. Because you just won't be able to compete.*

Similarly, P7 highlighted that an awareness of threats in the business environment motivated M7 to use I4Ts in mitigation.

> *One of our key business risks is getting left behind… As a result, we've got a group of people who look at technology innovation quite actively, thinking about how we stay ahead.*

These quotes highlight the view that firms that do not implement I4Ts will find it difficult to compete with those that do.

4.4.2 Data capture and analysis

As highlighted in section 4.2.1, the majority of manufacturers in this study were not producing big data sets. However, data capture and analysis was identified as a key driver of I4T implementation with almost all participants indicating that their organisations want to capture data to transform it into information that can be used to drive business performance. The coding for this sub-theme is shown in Table 4.4.

Table 4.4: Data capture and analysis coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers				
	Data capture and analysis		**14**	**34**
		Increasing process visibility	10	17
		Data-informed decision-making	7	12

The findings identified that increasing visibility of the production process was an important driver among the participants in this study who wanted to be more aware of machine capability, inventory levels, and product and part locations, for example. As P10 remarked:

> *We need to be more aware of where our jobs are. The proposal is to put receiving stations throughout the workshop. Then every time we cut a piece of steel, we'll put an RFID tag on it. As that piece of steel moves through the workshop…we'll know exactly [what stage of production] we are at based on the RFID tag.*

Similarly, P9 outlined that capturing and analysing operational data would enable them to have a clearer understanding of how operations are running, and one that is based on real-time data rather than supposition.

> *So there's that need to increase … visibility into certain areas of business that we don't have visibility into, that clearly explains why we're able to achieve the gross profit that we achieved or why certain jobs are running over hours, without people just saying, "Oh, it's because of XYZ", [but not] actually having the data to back that up.*

The findings indicated that being able to make data-informed decisions was a key driver of I4T implementation for participants across all I4.0 maturity levels. For example, P8 highlighted that the potential to use data to inform decision-making across a number of areas, such as machine use, pricing, and training needs, was a driver within M8.

> *I really want more data. That's the biggest one to me about I4.0… it's getting more and better data. Not even analysing it necessarily in some super technical, big data way, just getting it. [Why? To make] better decisions.*

At the other end of the maturity scale, P7 advised that M7 took a strategic decision to establish IoT environments in its factories decades ago with the objective of leveraging data to inform decision making.

> *We've got a lot of IoT connected data, sensors and things. We collect all sorts of different data digitally to then be able to use that to drive better performance… We connect all our data sets at the data lake [and] we've got a data science team that drives a lot of our deeper analytics.*

For some firms data-informed decision-making is hampered by technologically-outdated machinery which serves as a driver to implement sensor- and network-enabled equipment. For example, P3 outlined a plan to implement network-enabled equipment to enable M3 to create dashboards from the data that could be used to enhance decision making.

> *So the plan is to connect up everything from the office to the manufacturing floor and to be able to provide feedback from the machines. Right now we're pushing data to the machines but we're not getting feedback back to the office.*

One participant highlighted that concerns regarding succession planning and business continuity was driving the firm towards I4T implementation for data capture and analysis. P9 explained that becoming a data-informed business was integral to being a more resilient business, by decreasing the amount of tacit institutional knowledge held by key employees.

> *Mainly [the driver] is around… making decisions based on data rather than gut feel. We've got people that have been in this business so long, they're running the business on their gut. But that isn't sustainable when they leave. So there's that need to increase decision-making around data.*

4.4.3 I4T awareness

Data analysis identified that having general knowledge of I4Ts and an awareness of the potential advantages of using them were factors motivating I4T implementation. The coding to this sub-theme is shown in Table 4.5.

Table 4.5: I4T awareness coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers				
	I4T awareness		**13**	**46**

The findings revealed that gaining an awareness of I4Ts motivated implementation. This was exemplified by the government agency participant who explained that awareness-raising was a key tool used to drive I4T implementation.

> *There was an awareness program... We saw the educational part as a really important part of government. Making people aware that this stuff's not too expensive, other manufacturers locally to you are using it, and they're getting benefits out of it. (P15)*

Participants highlighted a variety of ways in which I4T awareness was gained including from taking part in SIRI assessments, site visits, speaking with equipment vendors, attending trade shows, and the media. P3 explained how awareness gained by a senior executive via membership of an advisory body, prompted an investigation into I4T use within M3.

> *Our operations director is on the manufacturers advisory board. So that's how she heard about the [SIRI] assessment and that there were other companies in Christchurch that had done it… and from then we decided that was something we wanted to do.* (P3)

Seeing the technologies in action was highlighted as a key source of awareness building and motivational aid. Participants reported that seeing how other manufacturers used I4Ts helped them appreciate where the technologies could be used within their own organisation, as reflected in the following comment.

> *So [my colleague] watched this I4.0 showcase on Nautech, I think it was. And he came back and he just about ran to my desk and said, "This is fantastic. This is amazing. Look what we could do with AI." And it actually started the discussion about how can we move forward. (P10)*

Some participants reported being motivated to implement I4Ts by interacting with peers in non-competing industries, as it enabled them to get ideas about how to apply I4Ts in their organisations without sharing proprietary information with a direct competitor. For example, P7 revealed that the competitive environment makes sharing technology insights with another dairy product manufacturer problematic but that mutual benefit can be gained from interacting with firms outside of the industry.

> *So we'll work with a mining company because they're not competitive, but there's a lot of similarities. So you go talk to them and go, "What are you guys doing? What are we doing?" And we share ideas.* (P7)

4.4.4 Stakeholder pressures

The findings indicated that firms were motivated to implement I4Ts in response to stakeholder demands and requirements. Data analysis identified that complying with legal and regulatory requirements, and addressing the demands and needs of external and internal customers were the main stakeholder pressures driving I4T implementation. The coding to this sub-theme is presented in Table 4.6.

Table 4.6: Stakeholder pressures coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers				
	Stakeholder pressures		**8**	**40**
		Legal and regulatory	6	19
		▪ Employee health and safety	4	11
		External customers	5	15
		Internal customers	4	6

The findings revealed that legal and regulatory pressures experienced by firms centred on employee health and safety, and that reducing the incidence of work-related injuries drove I4T implementation. In their capacity as an international supplier of production machinery, P1's view was that, compared to their international peers, NZ-based manufacturers are more likely to adopt automation to resolve health and safety issues than to increase production because they do not need to produce more goods.

> *Most NZ manufacturers are not stretched for capacity or at their theoretical production limits. So what are the economic drivers?... [There are] different pain points in a NZ context. It's a little bit more around worker safety and ergonomics.* (P1)

Other participants highlighted that implementing I4Ts to reduce the incidence of workplace-related injuries, such as repetitive strain injuries (RSIs), was necessary to not only safeguard employees, but also to reduce their impact on productivity.

> *[Implementing] automation was very much around productivity and profitability, but [also]ergonomics. We were hurting people. So that was why it was really important to look at that. (P2)*

Similarly, P12 attested that safeguarding employees is a reason why M12 intends to implement automation to support operations as the firm grows.

> *We're looking to upgrade to equipment that can do things automatically and that's because we've had a couple repetitive motion complaints. We recognise if we're going to scale up, we can't ask an operator to pull this lever a thousand times a day. We need to automate this. (P12)*

The findings identified that meeting customer requirements is another driver of I4T implementation. P1 explained that their customers implement I4Ts to meet the quality demands of end consumers.

> *[There is] a stronger focus on overall fit and finish. So [our customers] want doors to be exactly parallel, no gaps, tighter tolerances, all in a quest to please the consumer [with] a high-quality product.*

For other firms, being able to report on regulatory compliance or sustainability issues to internal and external stakeholders drove I4T implementation.

> *A lot of our customers, including the board, are requesting information and reporting on sustainability... So now we're using automated software to monitor power, water, carbon ... and inform decision making. (P2)*

4.4.5 Labour shortages

The findings indicated that labour shortages drove firms to implement robotics and automation. The coding to this sub-theme is presented in Table 4.7.

Table 4.7: Labour shortages coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers				
	Labour shortages		**8**	**19**
		Unattractive roles	4	13

Participants highlighted an ongoing difficulty recruiting individuals into manufacturing roles with comments such as, "*Finding good people in manufacturing is still hard*" (P15), "*It's difficult to recruit the right calibre of people*" (P6), and "*It's such a struggle finding people*" (P7). Consequently, manufacturers were driven to implement robotics and automation to address the labour deficiency. As P10 stated:

> *Skill shortage can force automation. The businesses that can afford it... have been automating because they cannot find the machine operator or the welder or the fitter and turner or whatever. Or even just the factory floor staff.*

While robotics and automation were used to cover staff shortages in general, participants indicated that they were often used specifically to fulfil unattractive roles, such as physically demanding, boring, dirty, or hazardous roles, which manufacturers found hard to retain staff in, and recruit staff to. Describing their use of a collaborative robot (cobot), P9 stated:

> *So originally, the [driver for the] cobot was around polishing. Stainless steel requires a lot of polishing to get it to that food grade quality and it's a very labour-intensive task… So the idea was, how could we automate that? Because it's not a very attractive task, so it's hard to even recruit for those [roles].*

Similarly, P1 described the situation of a customer in the food processing industry, who had difficulty retaining staff needed to wash large containers under high pressure and at relatively high temperatures for sanitation purposes. Ultimately, M1 developed an automated solution for the customer with robots able to work in the unpleasant conditions for long periods.

Some participants asserted that implementing I4Ts might help the manufacturing sector mitigate labour shortages by increasing the sector's attractiveness to younger, technologically literate people. For example, P5 explained that they found it easier to recruit high school leavers into roles where I4Ts are used compared to traditional, more manual manufacturing roles, stating:

> *There is an element of this that is not necessarily about workforce shortages… It's that element that talent will migrate to these things and talent is going to migrate away from businesses that aren't doing these things.*

This view was echoed by P15, who felt that manufacturers needed to respond to the expectations of potential employees.

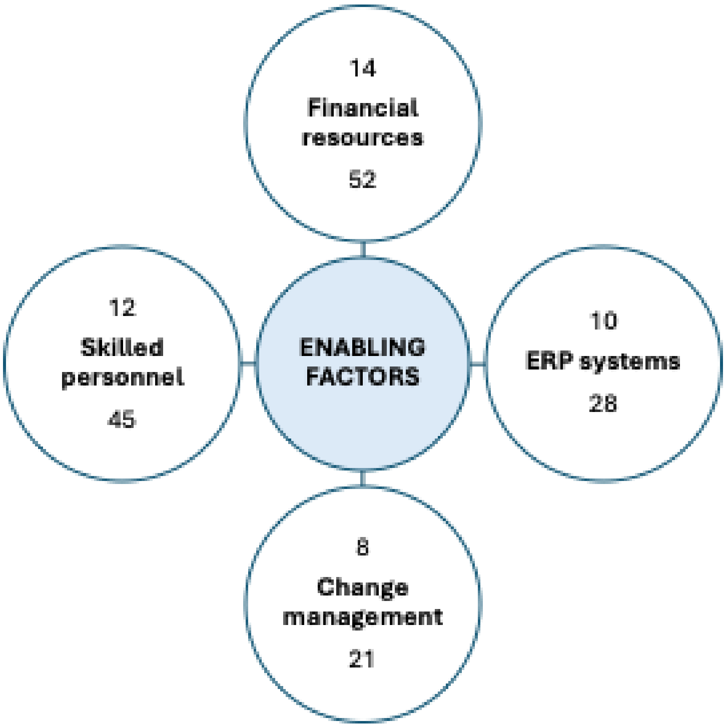
> *With the new round of workforce coming through, they walk onto a site and you give them paper drawings and they're looking at you going, "Where's the electronic version?... How backward are these people?"...Employers need to catch up with what the incoming workforce is looking for.*

These quotes highlight how socio-cultural pressures drive firms to implement I4Ts.

4.5 Enablers of I4T implementation

This section's findings address the second research question of this study – what factors enable I4T implementation in NZ-based manufacturers? To explore these factors, participants were invited to discuss what helps manufacturers implement I4Ts. As depicted in Figure 4.4, the key sub-themes derived from the analysis were financial resources, skilled personnel, Enterprise Resource Planning (ERP) systems, and change management.

Figure 4.4: Enablers of I4T implementation



4.5.1 Financial resources

The findings identified that financial resources are an essential enabler of I4T implementation. This sub-theme also captures factors that reduce the amount of financial resource firms need to implement I4Ts, such as sources of indirect financial support and the falling cost of I4Ts. The coding for this sub-theme is shown in Table 4.8.

Table 4.8: Financial resources coding

Theme	Sub-theme	Codes	Frequency across interviews (N=15)	Number of references
Enablers				
	Financial resources		**14**	**52**
		External funding and support	11	36
		▪ Government	8	28
		▪ Partnerships	1	3
		Falling cost of I4Ts	6	6
		Internal funding sources	3	5

When asked what helps firms implement I4Ts, participants identified financial resources and other forms of financial support as essential enablers, responding that "*access to capital*" (P11), "*resource and cash*" (P8), and "*capital and incentives*" (P13) were required.

Only two manufacturers, M7 and M11, were described as having sufficient internal financial resources to self-fund I4T implementations. All other manufacturers relied on external sources of funding and support. The government was identified as a particularly important source of external funding and support. Participants highlighted how government subsidies had enabled their firms to commence I4T implementation initiatives. A number of participants mentioned that grants obtained from Callaghan had helped their organisations commission SIRI assessments, which kick-started their implementation initiatives, as the following quotes illustrate.

> *One of the earliest things that kicked off our I4.0 journey was a SIRI assessment that we did through an organisation called LMAC. I think Callaghan subsidised about 40% [of the cost]. (P9)*

> *So [our implementation journey] started with the SIRI assessment. We got one of the grants from Callaghan to do the assessment with LMAC. (P3)*

While participants acknowledged the value of government-subsidised programs such as those delivered via Callaghan, they also felt that the government could do more to encourage I4T implementation by reducing the financial burden on firms in the initial investment phase. Speaking as a member of a manufacturing industry body, P1 suggested that capital investment and tax incentives might ease the financial burden of I4T implementation.

> *[Among my peers there] is a wish that our government would do more about incentivising the capital outlay for machinery or the technologies. So whether that's a different write-off schedule for tax purposes… or grants or funding or lower interest loans… Ways to make it more palatable to spend that money. (P1)*

Regarding incentives, participants singled out accelerated depreciation of capital assets as a means to incentivise investment in machinery and equipment. By increasing cash flow and reducing manufacturers' tax burden in the early years following a capital investment, accelerated depreciation leaves more money available to firms and is a tool used to incentivise investment in new capital assets. According to P15, "*Accelerated depreciation is probably the biggest thing that government could do [to support manufacturers]*."

Some participants highlighted that the cost of I4Ts is falling, making them accessible to more firms. For example, servo-driven machinery enables a high level of precision and is typical in I4T-enabled production systems employing advanced robotics and automation. Comparing its price to traditional hydraulic-actuated machinery, P1 stated, "*It's more expensive initially, but like a lot of technologies, the prices are coming down.*" Similarly, P8 asserted that the costs for robotics "*are actually coming down quite significantly*" which meant that M8 would be able to purchase a cobot that had previously been considered too expensive.

4.5.2 Access to skilled personnel

The findings revealed that having access to personnel with relevant skillsets enables I4T implementation. While a small number of participants mentioned consultants or business partners, manufacturers typically trained existing staff and onboarded experienced new hires to access skilled personnel. The coding to the sub-theme is presented in Table 4.9.

Table 4.9: Access to skilled personnel coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Enablers				
	Access to skilled personnel		**12**	**45**
		Training and upskilling	6	12
		▪ Apprenticeships	3	5
		Experienced employees	4	12
		▪ Manufacturing-targeted immigration policies	3	3
		Partnerships	2	6
		Consultants	2	4

Participants highlighted the importance of people in I4T implementation, and that implementation initiatives falter when firms fail to appreciate the importance of having access to personnel with the skills needed to interact with I4Ts. As P14 pointed out:

> *A robot does nothing unless you program it and give it something to do. [I can] think of manufacturers that have done the hard bit and bought the*

> *machine…and then the machine sits there doing nothing…[because]… they haven't alongside buying the machine, decided to bring the skills in or pay for the skills externally.*

The findings identified training and upskilling of existing staff as key activities firms need to undertake to ensure that employees have the skills required to enable I4T implementation. For example, P5 asserted that upskilling of staff was integral to M5 being able to implement I4Ts.

> *As an organisation, we wouldn't have been ready five years ago. We didn't have skilled enough staff in order to do this stuff. So there has been an upskilling of staff that was needed to get to the level to be able to do this.*

The findings identified apprenticeships as a tool used by the manufacturing sector to develop a pipeline of skilled individuals able to implement and maintain I4Ts. Participants noted that apprenticeships are particularly useful to attract and develop individuals who may not be willing, or whose circumstances might not enable them, to attend university. Explaining why M1 provides a four-year, accredited apprentice program, P1 stated:

> *The factories of the future need a very diverse skill set. Problem solving, thinking on your feet. And a lot of our young people could be doing that. You don't necessarily need a degree, just some guidance, some training, some experience.*

All the participants who commented on apprenticeships felt that the NZ government should do more to enhance the status and availability of apprenticeships, as doing so would increase the pool of skilled individuals available for employment in the manufacturing sector, which would further enable I4T implementation initiatives.

While upskilling existing employees and nurturing new talent through apprenticeships were identified as important activities, the findings also identified that experienced employees enable I4T implementation. Participants highlighted that hiring recruits with overseas experience was an essential part of ensuring that their organisation had the skills required for I4T implementation. As P5 stated:

> *Who has that exposure to advanced manufacturing and brings best-in-class ability? It's mostly immigrants, because we don't have a large industry of that here. So it's people who have worked for a Boeing or have worked for a big automotive supplier, and now they've ended up in NZ. And we love to hire them.*

Similarly, P14 felt that attracting senior managers with experience of I4Ts from overseas to work in NZ manufacturers would provide a level of confidence and direction that would energise and accelerate the pace of I4T implementation, and was "*probably the only way to make a real difference.*" Linked to attracting skills and experience to NZ, some participants suggested that immigration policies could be amended to address the specific needs of the manufacturing industry and facilitate greater access to skilled personnel. P11 stated that NZ "*doesn't make it easy in immigration*" which hampers M11's ability to find the skills needed to support I4T initiatives. P14 suggested that a "*fast track*" for professionals with I4T skills could be developed in a similar way that overseas medical professionals have a fast-tracked route into NZ's healthcare sector.

4.5.3 ERP systems

Ten of the thirteen participants employed by manufacturers mentioned using Enterprise Resource Planning (ERP) systems in connection with I4T implementation. The findings identified that ERP systems enable I4T implementation by supporting data capture and the development of big data, which is also a base technology upon which other I4Ts are built (Frank et al., 2019). The coding to this sub-theme is presented in Table 4.10.

Table 4.10: ERP systems coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Enablers				
	ERP systems		**10**	**28**

An ERP system allows firms to capture data produced across various business functions, such as production operations, accounting, sales, HR, and the supply chain, and share the data freely around an organisation, eliminating information silos (Muscatello et al., 2003). By enabling data capture from across the organisation, the findings identified that ERP systems develop firms' capability to build big data sets. Participants advised that the data captured from ERP systems was typically transferred to data warehouses or data lakes, which firms subsequently analysed to track production, monitor operational efficiency and facilitate real-time decision-making.

P11 outlined how moving to a "*cutting edge*" ERP system enabled full vertical integration of M11's information technology and operational technology systems. This meant that the firm, which manufactures products consisting of thousands of components and has multiple sites, was able to use the data captured by the ERP system to accurately track where in the production cycle products were, which helped the firm meet customer expectations of product delivery in full and on time.

> *The big data part is really all around the ERP system... Being linked together, everybody's got visibility of what's going on. We can see where everything is and how things are moving. (P11)*

P13 explained that their ERP system enables data-capture from network-enabled equipment which is used to analyse performance against KPIs and inform decision-making.

> *We have a lot of automated reporting extracted from our ERP… The most modern pieces of equipment that we have are all connected. We extract data from them... [and] we have two guys dedicated to data analytics who provide the reports that we need.*

Participants whose firms were not yet producing big data sets also highlighted how ERP systems enable data capture and analytics. For example, P5 stated that M5 is "*getting towards big data and analytics*" and described expectations that a new two-tier ERP system would enable them to integrate data from new business acquisitions, in different locations, into a single source of information. P5 highlighted that the new ERP system "*is not only more efficient at capturing data, but lets you do more with it*".

4.5.4 Change management

Participants described taking action to mitigate resistance from colleagues to the changes that result from I4T implementation. Consequently, this study identified change management as an enabler of I4T implementation. The coding to this sub-theme is presented in Table 4.11.

Table 4.11: Change management coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Enablers				
	Change management		**8**	**21**

Participants highlighted that I4T implementation is an involved process that goes beyond the physical installation of equipment and software, to include managing colleagues' expectations, and apprehensions about the impact of intended changes. As P9 stated:

> *It takes a lot longer than you think when you get into it. It sounds quite simple on the surface… You just connect it up and… away it goes. But it's not. It's managing expectations, and change management, and all that kind of stuff.*

Participants stressed the need to prepare colleagues for I4T implementation by including them in the change process and ensuring the reasons for change are understood. P15 pointed out that, in their experience advising manufacturers on I4T implementation, firms often fail to realise the benefits projected on paper because they fail to adequately include employees in the change process. P2 echoed this sentiment, who described surveying employees to capture concerns, and then addressing those concerns to mitigate resistance.

> *[Employees] did an online survey that meant I could dissect the information. That was really key for us, for buy in, and to make sure that people weren't concerned that we were getting quotes through for automation. …Without buy-in from people on the factory floor, [bringing in automation] is pointless.*

Participants highlighted training's role in equipping employees with the skills and capabilities needed to effectively use I4Ts once they were physically implemented. Sometimes training was not focused on how to use a particular I4T, but instead on increasing employee confidence and capability in using digital technologies in general. For example, P11 described how having a predominantly older workforce meant that M11 had to prepare employees to use touchscreens in the workplace, by first providing them with basic digital skills training using consumer digital technologies such as tablets and associated apps.

> *We took our old boys on the machines through a digital training program, which is basically about taking the fear out of using a computer. We knew that when we brought ERP in, those guys would be having to do things on screens. So when it happened, they were confident.*

Sometimes, firms used training to develop champions, that is, employees who viewed I4T implementation positively and could help colleagues through the change process. For example, P6 described how M6 trained a cross-section of employees on the uses of AI and automation, who were then able to share their experiences with colleagues and alleviate the fear that their implementation was designed to cut jobs.

> *The whole idea was these champions could then go out into the factory and say, "You don't need to worry. If they're bringing in a fantastic modern machine that does this and this, it's not to replace us, it's to work with us and help us." And that was pretty successful.*

4.6 Inhibitors of I4T implementation

This section addresses the third research question of this study – what factors inhibit I4T implementation in NZ-based manufacturers? To explore this topic, participants were asked to outline what makes I4T implementation difficult. Four key sub-themes related to inhibiting factors were derived from the data: high financial cost, lack of skilled personnel, resistance to change, and low production volumes. These are shown in Figure 4.5.

Figure 4.5: Inhibitors of I4T implementation

4.6.1 High financial cost

The findings revealed that the financial cost of acquiring and implementing I4Ts is a factor that inhibits implementation. Also included in this sub-theme are findings related to factors that exacerbate the financial burden on firms implementing I4Ts. After the high financial cost, the main factors contributing to this sub-theme were uncertainty regarding return on investment, lack of government support and the extent of an organisation's financial resources. The coding to this sub-theme is presented in Table 4.12.

Table 4.12: High financial cost coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Inhibitors				
	High financial cost		**15**	**73**
		Uncertainty regarding ROI	8	14
		Lack of government support	6	13
		▪ Policy instability	4	9
		Extent of financial resources	6	12
		Automating dextrous tasks	3	4
		Lack of strategic approach	2	5
		Maintenance	1	3

The findings identified that high acquisition costs inhibit I4T implementation and that the cost may be particularly prohibitive for smaller firms. Participants reported acquisition costs ranging from $10,000 to $500,000 and upwards depending on the technologies being implemented. Participants agreed that the cost to acquire I4Ts is a factor that inhibits implementation, providing comments such as, "*The problem is that it's pretty capital intensive*" (P13), "*Cost is obviously a big [barrier]*" (P3), "*It's very expensive*" (P2), and "*It's still not cheap*" (P10). In their capacity as a provider of automated machinery, P1 advised that high acquisition costs deter many NZ manufacturers.

> *If we start talking to somebody about $250,000, $300,000, for many NZ companies that still draws out a big gulp. That's a lot of money for many NZ companies to even think about.*

Participants claimed that high acquisition costs is an inhibitor particularly felt by smaller manufacturers, with P1 further noting, "*That huge outlay of cash in one go is a big issue for the smaller NZ companies*." P5 supported this opinion, stating, "*For businesses that are smaller, I do see the cost being a real barrier*."

Closely linked to the issue of cost is the extent of an organisation's financial resources. The findings identified that, irrespective of a firm's size, insufficient funds inhibit I4T implementation. As P2 noted:

> *You can do SIRI and it will tell you that you need to automate, but if you don't have money to automate… it's never going to happen.*

The findings revealed that investors' focus on return on investment (ROI) inhibits the acquisition of I4Ts when the ROI is difficult to calculate. Participants reported the need to be able to justify the expense of acquiring new technologies, with anticipated ROI mentioned by many as a specific hurdle that needed to be met. Participants noted that the ROI associated with I4Ts is not always easy to calculate which means that obtaining authorisation to purchase them can be problematic. As P4 stated:

> *Private organisations are always going to want to see the return on investment. It's very simple. You have invested money, you want to see a return. [But with] some of the innovations, the return is unknown.*

Likewise, P3 stated that I4T implementation at M3 stalled due to difficulty justifying the expense during the ongoing downturn in the construction industry.

> *With new technology it's hard to forecast what kind of benefit you would get. If you're going to spend $10,000 to $20,000 implementing something, how do you know that's going to pay back, and how long?... I think that's probably the biggest barrier, that uncertainty about payback.*

The findings identified that a lack of government support contributes to the inhibiting effect of high acquisition costs. Participants asserted that successive NZ governments have not done enough to support the manufacturing industry and enable it to compete in international markets. For example, P2 stated that, "*It's not an even playing field*", when competing with manufacturers based in Australia and Europe where government support for manufacturing is perceived to be strong.

Participants also opined that the political framework in NZ, with general elections held at a maximum of every three years, does not support I4T implementation, as policy changes from one administration to the next make it difficult for firms to plan future investments. For example, P10 noted that government funding "*would make [investment] much easier, but the funding comes and goes*". Elaborating on this issue, P13 stated:

> *Knowing that there is no political consistency, that's one of the challenges… It means that if Government One tells us, "Oh, yes, we are supportive of this"… after three years I may have a new government saying, "Oh, no. That idea from the previous [government] is gone now." ... So we cannot rely [on government*

> *policy]. When we build our plans, we look five, ten years ahead. We don't look three years ahead.*

Participants cited Callaghan as an example of a government-funded body that is no longer available to support and fund I4.0 initiatives. As the following quotes illustrate, participants were concerned about the impact removal of this support would have on the ability of firms to initiate future I4T implementation projects.

> *A lot of [our funding] came through Callaghan and now Callaghan's being disbanded. So that's a problem for manufacturers. (P2)*

> *The SIRI assessment was really the first step. And now with Callaghan gone, I don't know what's going to happen...That's going to be a big loss for us. (P12)*

4.6.2 Lack of knowledge and skills

The findings in this section highlight that ignorance of I4Ts, limited understanding of I4.0, and skills shortages inhibit I4T implementation. The coding to this sub-theme is presented in Table 4.13.

Table 4.13: Lack of knowledge and skills coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Inhibitors				
	Lack of knowledge and skills		**13**	**53**
		Lack of knowledge of I4Ts	6	10
		Poor perception of manufacturing	6	8
		What is Industry 4.0?	5	7
		Lack of apprentices and graduate engineers	4	10
		Lack of experienced individuals	4	5
		Low English literacy levels	2	4

Participants indicated that a general lack of knowledge about relevant technologies inhibits I4T implementation. For example, when asked what made implementation difficult at M3, P3 responded:

> *The hardest part is knowing where to start.…Not knowing what's out there, what technology is available, and what solutions there are, is certainly a big barrier.*

While acknowledging that their own organisation was well placed in terms of technology awareness, P7 felt that an issue facing many NZ firms is that they lack an awareness of I4Ts and an understanding of the benefits that might be gained from using them.

> *Companies in NZ aren't exposed to a lot of the technologies out there, that might be relatively cheap, that they could implement. Getting that exposure, understanding, and knowing how to get value from technology... would be helpful.*

In addition to a lack of knowledge about individual technologies, participants raised that a lack of knowledge about the I4.0 concept in general hampers implementation efforts. For example, P10 felt that the term 'Industry 4.0' created a barrier because its technological breadth and lack of a single definition makes it a challenging concept for busy executives to immediately understand, which creates indifference towards learning more about it.

> *A lot of business owners and managers don't hear the phrase 'Industry 4.0' and think, "I know exactly what that is."…That uncertainty breeds nervousness, you know, "I'll step back. I don't really want to know." …We use labels and phrases to make things easy, but sometimes it has the opposite effect. It becomes a barrier.*

The findings indicated that skills shortages at various levels, from employees at the beginning of their careers through to experienced senior executives, inhibits I4T implementation. Some participants partly attributed the lack of skills to the perception of the sector as unclean, technologically backward and poorly paid. As the following two quotes highlight, participants observed that manufacturing is associated with the First Industrial Revolution, which makes it less attractive to prospective employees compared to other sectors, and decreases the pool of skilled individuals available to implement I4Ts.

> *So many people think of factories as being the factories of the 1800s or early 1900s. They don't think of factories as being cool, clean, high tech, and interesting, which is a shame. (P1)*

> *A lot of people think industrial revolution, dark, dingy sort of things. But now we have automation, it's light and bright. (P2)*

Participants lamented the lack of vocational routes into the manufacturing sector and raised issues related to a lack of graduate engineers, including too few engineers graduating from NZ universities, and graduate engineers leaving NZ for jobs abroad soon after graduation. P13 highlighted the variation between engineering degrees, questioning whether current programs equip students with the skills needed to interact with I4T-enabled systems.

> *Because they can select a lot of their modules, there's a lot of discrepancies with the students coming out of university. Some were exposed [to digital technologies], some not. Yet they have the same degree at the end. But the same degree doesn't mean the same skills.*

Participants highlighted that NZ's manufacturing sector lacks individuals with previous experience of and exposure to I4Ts. For example, P8 compared NZ to China, stating that China emphasises STEM education and produces millions of engineering graduates each year. However, in NZ:

> *We don't have many people with the knowledge and skills to come into a company and say, "Here's some stuff you can automate, here's some options, and here are the costs. (P8)*

Concern about maintaining I4Ts after they are implemented was identified as an inhibiting factor. Participants suggested that for manufacturers lacking the in-house skills needed to maintain I4Ts, the prospect of paying for third-party assistance on an ongoing basis deters implementation. P1 described the perceived cost of ongoing I4T maintenance as "*a roadblock to gaining more acceptance*" and referenced past conversations with clients.

> *[Maintenance cost] does scare some businesses, where they feel, "Okay, you've helped me with automation, but now I'm going to be paying every year for expensive people to come in and keep this machinery running [because] I don't have those skills in my business."*

One participant had a contrary view regarding there being a lack of personnel with the skills to implement I4Ts. Whilst acknowledging that a lack of previous experience inhibits I4T implementation, P14 refuted that a skills gap exists in NZ, asserting that the skills are available and can be acquired by firms willing and able to pay.

> *I think the skills are there if you know what you're looking for, and can be outsourced as well. There's lots of contractors and companies able to help you*

on that journey rather than having to hire it. So if you're genuine about making transformation happen, the skills are there, and you can go buy them.

4.6.3 Resistance to change

Implementing I4Ts inevitably involves a change to processes and procedures. The findings identified that resistance to change inhibits I4T implementation. No single element dominated this sub-theme with participants highlighting a number of factors contributing to I4T implementation being resisted. The coding to this sub-theme is shown in Table 4.14.

Table 4.14: Resistance to change coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Inhibitors				
	Resistance to change		**11**	**27**
		Due to disruption	4	4
		Due to having to learn something new	4	4
		Due to potential job losses	2	3
		Due to lack of competition	1	3
		Due to machinery payback period	1	3

The findings identified that employees feeling uncomfortable with new technologies can inhibit I4T implementation. Participants described colleagues being "*concerned about Industry 4*" (P2), "*afraid of change*" (P4), and "*mentally scared of the technology*" (P11) as factors that led to resistance to I4T implementation. Some participants mentioned employee concerns about robotics and automation taking jobs. Others noted that concerns about the disruption that might occur when I4Ts are implemented leads to resistance. For example, P7 noted that even when a new technology is expected to have a positive impact on an employee's role, resistance to its implementation might still occur due to the perceived disruption it would cause.

Like you can have a great idea that you go, "This is a cool new technology, it will save you all this time." But whether it's positive or negative, when we've got people in our factories who are just focused on making sure that process goes well, anything new is disruptive. Whether it's good or bad, it's disruptive. (P7)

Participants also noted that the prospect of having to learn about a new process can inhibit I4T implementation. For example, P14 noted that pressures on senior management time may lead to them deferring investment in I4Ts.

> *Everybody's just so busy all the time. There are so many distractions for a leadership team across health and safety and business development. To try and take the time to learn something new, in the sense of all the things there are to learn about if you're going to automate a process, is just a real challenge.*

The findings also identified that a lack of competition in the domestic market creates resistance to implementing I4Ts. In their role at a government agency, P15 has interacted with a number of manufacturers regarding I4T implementation. They observed that manufacturers serving only the domestic market are subject to weak competition due to NZ's geographic remoteness. These manufacturers are consequently reluctant to invest in new technologies because they make money as they are. As P15 put it:

> *I meet a lot of small business owners who say, "Technology's not for us. I make money, why should we change?"*

One participant highlighted that manufacturers resist implementing I4Ts because they have already invested millions of dollars in conventional machinery that they are reluctant to replace, because the machinery is functional and has not yet generated sufficient net cash flow to cover the original cost of investment.

> *The bulk of our machines are expensive and it takes a long time to get that money back… So I think the biggest problem with implementation is the fact that, when you have machines ranging from half a million dollars to four or five million dollars, you're going to keep them for 20 years. (P8)*

4.6.4 Low production volumes

Participants noted that, compared to counterparts in other countries, NZ manufacturers tend to produce low volumes of goods. The findings revealed that this characteristic particularly inhibits the implementation of automation. The coding to this sub-theme is given in Table 4.15.

Table 4.15: Low production volumes coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Inhibitors				
	Low production volumes		**10**	**21**

Participants commented that NZ manufacturing operations tend to be small scale with low production volumes, as illustrated by the following quotes.

> *In NZ we tend to focus on low volume, high complexity manufacturing, because that's how we compete with the Chinas and Moroccos of the world. (P2)*

> *For the manufacturers in NZ, that is our niche - things that are low volume. (P5)*

The findings identified that low production volumes inhibits automation implementation because low volumes make it harder for manufacturers to build a business case for automating a process. As a provider of custom, automation solutions, P1 stated that finding customers in NZ was "*a challenge*" because:

> *Most manufacturers are relatively small scale, not stretched for capacity... and typically operate at a lower capacity relative to global manufacturers. (P1)*

P4 outlined that low production volumes at M4 creates a barrier to implementing automation stating, "*We don't have enough volumes, we're not selling enough. Why [would we] push towards that?*" A similar observation was made by P3 when they explained why putting locks into window frames was conducted manually at M3.

> *There are machines that automate it, but it's really high capacity. At the moment, we're making 80-ish windows a week. We'd have to be doing 200 probably, to make it worth it in terms of automating.*

4.7 I4T contribution to sustainability dimensions

This section addresses the fourth research question of this study – how do I4Ts contribute to sustainability? To explore this subject, participants were asked for their views on how I4Ts make both positive and negative contributions to economic, environmental and social sustainability dimensions. Table 4.16 shows that almost twice as many positive references regarding I4Ts and sustainability were coded compared to negative.

Table 4.16: Sustainability sentiment coding

Sentiment	Frequency across interviews (*N*=15)	Number of references
Positive	14	106
Negative	14	57

This finding was exemplified by P14 who stated:

> *I've got to admit, I've not really thought about the downsides [to] sustainability. Maybe that's quite telling. You know, me working in this industry and not giving too much thought to the sustainability impacts of encouraging technology adoption.*

The findings derived from participants' reflections on the contribution I4Ts make to sustainability are presented in the following sections, starting with contributions to economic sustainability, then social and environmental sustainability contributions. In each case, positive contributions are addressed first, followed by a presentation of the negatives. Table 4.17 provides a summary of the coding to each dimension, which shows that fewer participants commented on how I4Ts contribute to environmental sustainability compared to economic and social.

Table 4.17: Summary of the sustainability dimensions coding

Sustainability dimension	Frequency across interviews (*N*=15)	Number of references
Economic	15	64
Social	14	60
Environmental	10	43

4.7.1 Contribution to economic sustainability

The findings revealed that I4Ts make a positive contribution to economic sustainability by enabling firms to enhance their efficiency and productivity. Negative contributions related to costs and profitability of investments. Table 4.18 shows that a slightly higher number of participants made a negative comment regarding I4T use and economic sustainability compared to positive.

Table 4.18: Economic sustainability coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Sustainability contribution				
	Positive economic		**12**	**32**
		Efficiency and productivity	12	32
	Negative economic		**14**	**32**
		Acquisition & implementation costs	12	17
		Uncertain or long-tailed ROI	6	8
		Third-party dependency costs	4	6
		Equipment disposal costs	1	1

Participants claimed that I4Ts enable their organisations to compete with countries such as China and Mexico, that historically benefitted from low labour costs which, in part, enabled them to produce and price goods at a lower cost compared to NZ. The competitive advantage associated with low labour costs is diminished when NZ manufacturers competing internationally use the same technologies as competitors. As P5 asserted:

> *Everyone's using the same German and Japanese equipment to make this stuff. It's all the same software that we have access to. It's all the same big data tools. So [China's] competitive advantage is actually slipping away from them… It levels the playing field and helps us be more efficient.*

Participants reported that I4Ts help their organisations be more efficient and productive, which leads to greater profitability. For example, P11 stated:

> *The technologies enable us to keep up with the growth. We've managed to keep the volume up and [employee] numbers have gone down, so what does that equal? That's pure profit.*

Similarly, P2 reported that after establishing a data lake as a single repository for all the organisation's data, implementing sensors on machinery and equipment for additional data collection and using AI to help analyse the data, M2 was able to monitor operational efficiency more effectively which led to an increase in profitability.

> *What's happened is the profitability of the company's got a lot better because of the data. Because of how we're using it. It's been the game changer.*

Participants spotlighted advanced robotics and automation as a technology that contributes to increased productivity and efficiency because, unlike humans, they can operate continuously, for many hours, without fear of RSIs or mental fatigue. P2 described the productivity benefits of using a robot to conduct a highly repetitive task.

> *[The robot produces] a lot more. It doesn't go to the toilet and it runs on two shifts for 18 hours, which a person can't. And [does] that uniformly. We won a lot more work introducing this.*

Participants also highlighted the cost benefits that come from improving efficiency and productivity. For example, when discussing the use of digital twins to improve the energy efficiency of large pieces of commercial equipment P7 stated, "*there's probably significant dollars associated with how much we reduce costs there*".

The negative contribution that I4Ts make to economic sustainability closely mirrors the main inhibitor identified in this study: the financial costs associated with acquiring and implementing I4Ts and uncertainty whether investment in I4Ts would be profitable. The presentation of these factors can be found in section 4.6.1. In addition, as outlined in section 4.6.2, participants noted that maintaining I4Ts requires expertise which firms may not possess in-house. The findings indicated that this adds to implementation costs when manufacturers depend upon third parties to update, maintain and repair I4T-enabled systems and equipment. As P8 remarked:

> *I really, really would like a machine that I can fix… But as we increase the complexity of everything, this decreases the ability of people to repair and maintain them, which inevitably increases the costs.*

4.7.2 Contribution to social sustainability

Data analysis identified that I4Ts help firms positively influence the workplace experience of their employees, provide job and skill development opportunities, and may increase the number of skilled, highly paid jobs. Conversely, the findings identified the potential for job losses as the main negative contribution. Coding is presented in Table 4.19.

Table 4.19: Social sustainability coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Sustainability contribution				
	Positive social		**12**	**41**
		Improving employee safety and satisfaction	10	22
		Upskilling and reskilling existing staff	5	7
		Job creation	5	6
		Improving access to training	3	6
	Negative social		**8**	**19**
		Job losses	7	14
		Reducing employee engagement	2	4
		Injury potential	1	1

The findings revealed that I4Ts can increase workplace safety and create better work environments for employees in general. Participants noted that the introduction of automation had "*made things cleaner*" which "*made people feel like they're in a better space*" (P11) and had the potential to "*reduce frustration*" (P12) because employees would spend less time dealing with avoidable errors. P10 stated that implementing RFID tags and sensors on components and finished goods would "*make work easier for people*" because:

> *They're not wasting energy, travelling backwards and forwards, trying to find something. [They'd] simply know where it is. That's a positive.*

Participants noted that automation can be used to assume repetitive and mundane tasks, reducing the risk of employees experiencing physical and/or psychological harm, leading to improved health outcomes (Häusser et al., 2014). For example, when asked about potential, positive social sustainability outcomes from using I4Ts, P14 responded:

> *Some examples would be health and safety benefits, [reducing] repetitive strain injuries and so on. If you automate the process, [you're] obviously having a positive impact.*

Participants highlighted that automation frees colleagues to focus on more interesting, value-added tasks which has both individual and organisational benefits. For example, P6 opined:

> *If you have a bunch of people doing something that's repetitive or boring, you can release them to go and do something more value added for the business. To be able to utilise that experience and smartness and capability in other more technical aspects, is a benefit to the business and a benefit to the person.*

The findings identified that I4T implementation leads to an upskilled workforce as employees develop new skills required to operate and interact with I4Ts through training and practical experience. Asked how the introduction of I4Ts had positively affected colleagues, P11 responded, "*Upskilling. They get new skills. I think that's a major one right off the bat.*"

Firms also used to meet individual employees' specific training needs. Participants highlighted that AR and AI can be used to meet the training needs of people who struggle with communication or have low levels of English language proficiency. P11 asserted that incorporating AI into their training processes led to "*a huge shift in understanding*" among employees at M11, which resulted in fewer work-related injuries.

> *The genius of AI is that we can put [training material] into different languages instantly. Tongan, Samoan, Filipino, Mandarin, whatever one we want. It takes out the English as a second language barrier. So when it comes to the health and safety side… [employees] now understand what good is and what bad is… (P11)*

Similarly, M9 proposed using AR to make training more inclusive.

> *Because we've got a focus around neurodiversity and people that are quite dyslexic and very visual, AR could be a means for us to make the training a bit easier for them. (P9)*

The findings also identified the potential for I4T use to create jobs. For example, P2 explained that after implementing robotics and automation, M2 developed the capability to fulfil additional contracts which led to the creation of 60 new jobs. In addition to increasing the number of roles available, participants expected I4T implementation to lead to a change in the type of jobs available, with the expectation that more highly skilled, highly paid jobs would be created. For example, P5 stated that roles working with robots are, "*just better, higher paying jobs*" than traditional manufacturing jobs, while P13 anticipated that lower skilled roles "*are going to be replaced by the higher skill levels*".

In contrast to the above, the findings also identified the potential for job losses, at both firm and industry level, due to I4Ts. The potential impact of automation and AI on jobs was highlighted by participants with comments such as, *"[Automation] is going to take away jobs*" (P8) and "*Jobs that are very manual, an AI or robot can easily replace*" (P4).

The findings revealed the potential for individual job losses when employees struggle to be retrained with the skills necessary to interact with I4Ts. As P2 explained:

> *To be brutally honest, some people really struggle. We had two production managers that had been here for a long time, and they had to go in the end because — your mindset has to be open to change. And not everyone can do it, unfortunately.*

Although participants acknowledged the potential for individual job losses, the findings suggested that widespread job losses due to I4Ts were not prevalent because the manufacturing sector struggles to find staff at all levels. Consequently, if an individual role becomes redundant, it appears that firms tend to retrain and reskill employees to take on new roles created as a consequence of I4T implementation. Speaking from an industry-wide perspective, P15 explained:

> *There is no doubt that some people lose jobs as part of these programs. My observation is people get redeployed ... or [firms] reskill. Because finding good people in manufacturing is hard to do, so [firms] redeploy them. I haven't seen massive job losses from [firms] adopting technology and automation.*

From an individual firm perspective, P7 acknowledged that automation is replacing people in certain roles, but made the point that this is in response to not being able to find people to fill the roles.

> *Less and less people want to work in a factory. So as we put in a bit of technology and maybe need one or two less people, that doesn't mean that people are out of work. We haven't had to make people redundant, because it's such a struggle finding people. We just need to [be able to work with] less people.*

4.7.3 Contribution to environmental sustainability

The findings revealed that I4Ts were most often associated with either increasing or reducing consumption and waste. The coding is presented in Table 4.20, which shows that references to positive contributions were identified more often in interview transcripts compared to negative references.

Table 4.20: Environmental sustainability coding

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Sustainability contribution				
	Positive environmental		**9**	**36**
		Reduced consumption	7	17
		Waste reduction	7	15
		Reduced CO_2 emissions	2	4
	Negative environmental		**3**	**7**
		Increased consumption	3	4
		Increased waste	3	3

The findings revealed that I4Ts enable manufacturers to monitor water and energy usage and take action to reduce consumption. For example, P2 stated:

> *So we're monitoring power, water, carbon, the usual sort of things, but using software and…having sensors on things – making sure that it's giving us the data so we can monitor it and improve.*

Similarly, P7 described how digital twins drive energy efficiency at M7.

> *Our biggest energy consumers are our dryers and evaporators. We use digital twin and other technologies to look at how we can increase the energy efficiency of our assets, so they consume less energy [and produce] less emissions.*

The findings also indicated that I4Ts have a role to play in reducing waste. By using combinations of I4Ts such as sensing technology, AI and digital twins, manufacturers were able to monitor production lines more closely, which helped limit the production of defective components and products. For example, P1 asserted that using I4Ts to identify defects early in production processes reduces the number of finished products going to landfill.

> *I think a big part of where things like IoTs and sensing technology comes in [is having] multiple inspection points to catch defects as early as possible and*

> *then reject that part. Traditional manufacturing inspects the finished product. [But] then you're scrapping the whole thing.*

Similarly, P7 explained how using machine vision enabled M7 to quickly identify and remediate defective products and processes which helped to reduce waste.

> *If we produce better quality bags, there's less bags getting wasted. If there's a lot of wrinkles on bags, they have to get thrown away. So if you catch that early on, you fix your process and there's less bags being thrown away.*

The findings indicated that firms gave less consideration to the ways I4Ts negatively contribute to environmental sustainability, with only three out of the fifteen participants mentioning negatives. For example, while the economic and social impact of implementing new machinery formed part of their decision-making process, consideration of negative environmental contributions was not a focus for P13 who stated:

> *We focus on the capabilities of the machine to deliver the products we need, and [that it's] a safe machine for the people working on it…. Will we look at its carbon footprint or power consumption? The answer is, it would be seen as a nice to have. It won't be a high priority.*

When participants did consider the negatives of I4T use, the findings identified that increased productivity may lead to increased consumption and waste. For example, P15 stated that, "*The more productive [manufacturers] become, the more resources they use...which of course causes more waste.*" Similarly, P14 stated that I4T use increases the use of resources, and suggested that the I4.0 concept encourages industrial consumerism, leading to increased waste.

> *Ironically, [using I4Ts involves] using more energy to monitor your machines. And buying screens and computers and tablets to [monitor] them, that also use more energy… I'd be terrified if you peeled back the curtain on manufacturers' e-waste. I imagine it has shot up dramatically in recent years.*

P10 proposed that increased productivity achieved by increasing output might not be met with increased demand, which again would lead to an increase in waste. They also noted the increase in energy and water requirements that accompanies the demand for AI.

> *The environmental downside of AI is the energy budget. Somebody's got to build a massive data centre and power it 24 hours a day and keep it cool.*

4.8 Conclusion

This chapter began by presenting descriptive information regarding the I4Ts used by the manufacturers in this study and gave an assessment of their I4.0 maturity level. The substantive part of the chapter presented the key findings from fifteen semi-structured interviews conducted to explore factors influencing I4T implementation and I4Ts' contribution to sustainability. The findings revealed various drivers, enablers and inhibitors of I4T implementation, and identified more positive than negative references from participants regarding I4Ts and sustainability. Compared to economic and social sustainability, fewer participants commented on the negative contributions I4Ts make to environmental sustainability. These findings are interpreted and discussed in the following Discussion chapter.

Chapter 5 Discussion

5.1 Introduction

This study explored the factors influencing I4T implementation in NZ-based manufacturers and managerial perspectives of the positive and negative contributions I4Ts make to sustainability. This chapter discusses the empirical findings presented in the previous chapter in relation to the research questions and existing literature, drawing on INT and DCT to guide the analysis. The key findings regarding factors influencing I4T implementation are incorporated into an integrative I4T implementation framework, that shows how the study's themes relate to INT and DCT.

The remainder of this chapter is structured as follows. It begins with a discussion of the factors driving I4T implementation, followed by a discussion of enablers and inhibitors in section 5.3. I4Ts' contribution to sustainability are discussed in section 5.4. The final section draws on the discussion in preceding sections to propose an integrative framework for I4T implementation.

5.2 Drivers of I4T implementation

The first question in this study sought to identify factors driving manufacturers to implement I4Ts. The findings are consistent with extant research, which found that factors related to competitive pressures (Horváth & Szabó, 2019; Intalar et al., 2024), data capture and analysis (Skalli et al., 2024; Sony et al., 2021), I4T awareness (Ghobakhloo et al., 2022; J. Graham, 2024), stakeholder pressures (J. Graham, 2024; Khin & Kee, 2022), and labour shortages (Leesakul et al., 2022; Sureeyatanapas et al., 2023) are key drivers of I4T implementation. This finding suggests that, despite its geographical remoteness from major competitive markets and small domestic size, NZ manufacturers are influenced by the same factors that motivate counterparts in dominant manufacturing nations such as Germany (Kiel et al., 2017; Müller et al., 2018).

Drivers can be categorised as external or internal. External drivers reflect environmental forces that influence organisational behaviour (DiMaggio & Powell, 1983), and are typically outside the organisation’s control (Correia Simões et al., 2020). Internal drivers derive from an organisation's leadership and employees, and are typically within the organisation's control (Riemer et al., 2025). In this study, the competitive pressures, stakeholder pressures, and labour shortages sub-themes fell within the external drivers category, while the data capture and analysis, and I4T awareness sub-themes were categorised as internal drivers.

5.2.1 External drivers

The findings support the relevance of INT to this study by indicating that manufacturers implement I4Ts in response to coercive, mimetic, and normative pressures, which is consistent with previous studies (Correia Simões et al., 2020; Dubey et al., 2019). However, data analysis identified only two references to normative pressures, whereas references to mimetic and coercive pressures were much more prevalent. This suggests that normative pressures to implement I4Ts are weak among NZ manufacturers. Two explanations are proposed for this finding. The first relates to the manufacturing sector having no professional governing body or, due to its heterogenous nature, no single industry body representing all manufacturers (MBIE, 2025a). The second relates to the observation made by one participant that NZ engineering degrees do not necessarily provide students with exposure to I4Ts. The lack of sector-specific rules/regulations, a single unifying industry body promoting the use of I4Ts, or engineering degrees with compulsory modules on digital technologies, limits the degree to which professionalisation occurs in the sector (DiMaggio & Powell, 1983), which may account for the apparently weak normative pressure on manufacturers to implement I4Ts.

5.2.1.1 Influence of mimetic pressures

The findings indicated that firms of all sizes and across all I4.0 maturity levels were motivated to implement I4Ts to keep up with competitors and mirror the benefits gained by competitors from improved production efficiency and productivity, such as reduced costs, increased profit and consistent product quality. This finding aligns with drivers identified in the literature (Horváth & Szabó, 2019; Müller et al., 2018) and suggests that mimetic forces play a key role in driving NZ manufacturers towards I4T implementation. DiMaggio and Powell (1983) hypothesised that uncertainty can lead firms to copy the actions of other firms deemed to be more knowledgeable or successful, and noted that strong mimetic forces occur "when organizational technologies are poorly understood" (p. 151). As noted in section 4.6.2, participants indicated that a lack of knowledge about, and exposure to, I4Ts meant that they were not always sure how to proceed with implementations, which may explain the identification of mimetic influences in this study.

5.2.1.2 Influence of coercive pressures

The influence of coercive forces was identified in this study, as evidenced by firms implementing I4Ts to meet legal and regulatory requirements and to address labour shortages. With regard to meeting legal and regulatory requirements, firms were driven to implement robotics and automation to address employee health and safety issues. This was a novel finding with regard to driving factors, contrasting with previous studies that identified compliance with product and environmental regulations as drivers of I4T implementation (J. Graham, 2024; Skalli et al., 2024). A possible explanation for employee health and safety driving I4T implementation might be found in the sector's workplace injury claim rate, which was the highest of all sectors in 2023, and remained in the top three in 2024 (Stats NZ, 2024a, 2025b). Unlike in other major industries where the injury claim rate has been declining, manufacturing's claim rate has remained relatively steady over the last seven years (Stats NZ, 2024a). It may be that NZ manufacturers are driven to implement robotics and automation to reduce the number of work-related injuries within their industry, not only to address legal and societal expectations regarding employee safety, but also to mitigate the impact that work-related injuries have on productivity, efficiency and ultimately profit (Kim & Park, 2021). For example, in their case study of an Italian manufacturer, Braccini and Margherita (2019) found that automating labour-intensive and repetitive tasks enabled the firm to reduce the risk of work-related injury, which reduced lost time incidents, leading to increases in productivity and profitability.

This study is consistent with previous studies in finding that manufacturers are motivated to implement I4Ts, such as advanced automation and robotics, to mitigate the impact of labour shortages and maintain productivity (Horváth & Szabó, 2019; Leesakul et al., 2022). The findings also align with Graham (2024) in revealing that some manufacturers felt that implementing I4Ts helps them attract and retain staff. Viewed through an INT lens, this suggests that NZ manufacturers are responding to coercive pressures when they implement I4Ts to make their organisations more attractive to a young, digitally literate workforce. This is because it reflects manufacturers' response to the cultural expectations of a young workforce to work in environments where digital technologies are used (Racolţa-Paina & Irini, 2021).

5.2.2 Internal drivers

5.2.2.1 Data capture and analysis

The study revealed that data capture and analysis was a key driver of I4T implementation for firms of all sizes and maturity levels. Participants highlighted the desire to analyse operational data to increase process visibility and enhance decision-making, which was a finding consistent with the literature (Horváth & Szabó, 2019; Sony et al., 2021). Given that the majority of firms in the study were not generating big data sets (see 4.2.1), this finding suggests that even firms generating small amounts of data recognise the benefit of being able to capture and analyse it. This is supported by Vahn (2014) who stated, "even doing small data analytics … can generate a great deal of value" (p. 9).

This finding also suggests that manufacturers in this study were primarily concerned with gathering and interrogating data to generate information about their internal business environment. This finding can be viewed from a DCT perspective, indicating that participants capture and analyse data to sense internal opportunities and threats to organisational objectives, for example, to sense how processes might be made more efficient or to identify orders at risk of not being fulfilled. This finding is supported by van Rijmenam et al. (2019), who contend that data analytics is a dynamic capability, and that descriptive and predictive analytics have particular value in helping managers better understand their business environment, leading to enhanced decision-making and competitive performance.

The study also found that business resilience, in the form of mitigating the loss of tacit/implicit institutional knowledge, was a driver for data capture and analysis and therefore of I4T implementation. Enhancing business resilience through data capture and analysis may be of particular importance in the NZ context where 91% of manufacturers have fewer than twenty employees (Stats NZ, 2025c), because small enterprises are at particular risk of losing tacit organisational knowledge (Adesina & Ocholla, 2024). By converting implicit institutional knowledge to explicit institutional knowledge, data capture and analysis enables experience-based decision-making to be exchanged for data-informed decision-making (van Rijmenam et al., 2019), which helps ensure that organisational information is not lost when employees leave.

5.2.2.2 I4T awareness

The findings indicated that being aware of the benefits, and seeing how other firms derived benefit from I4T use, was a key force driving their implementation, which aligns with previous studies conducted by Khin and Kee (2022) and J. Graham (2024). Although this study classifies I4T awareness as an internal driver, its influence on I4T implementation can be viewed from an INT perspective, because the study found that I4T awareness appeared to motivate firms to copy the actions of their peers, to derive the same benefits from I4T implementation. Consequently, it appears that I4T awareness can lead to mimetic isomorphism. Further, the awareness-raising activities of Callaghan can be viewed as a source of coercive pressure from the government (Zhou & Zheng, 2023).

The study identified a variety of ways in which participants gained not only an awareness of the benefits of I4Ts, but also an awareness of the threats to their organisations' survival from not using I4Ts. Viewed through a DCT lens, the means by which firms developed awareness of I4Ts are examples of microfoundations of the sensing dynamic capability by which firms identify opportunities and threats (Teece, 2007). This finding aligns with Ellström et al. (2022), who found that adopting routines such as networking, and communicating with peers outside of an organisation's own sector, were key to inspiring digitalisation initiatives.

5.3 Enablers and inhibitors of I4T implementation

In common with Ghobakhloo et al. (2021) and Müller et al. (2024), the findings identified that the same factor could enable I4T implementation when it was available to a firm, and inhibit it when absent. Therefore, to aid a more cohesive discussion of the two themes, the enabling and inhibiting factors identified in this study are discussed together in this section. Consequently, this section discusses findings related to the study's second and third research questions: what factors enable and inhibit I4T implementation in NZ-based manufacturers.

The remainder of this section is structured as follows. Factors related to financial resources, knowledge and skills, and organisational change were identified as having the capacity to both enable and inhibit I4T implementation and are discussed first. This is followed by a discussion of two factors, ERP systems and low production volumes, which were identified as enablers and inhibitors respectively in this study, but not identified in the literature review. The section concludes with a discussion of two factors, senior management support and technology integration, that were identified in the literature review but not in this study.

5.3.1 Financial resources

The findings indicate that high financial costs associated with I4T implementation act as an inhibiting factor, while having access to financial resources is an essential enabler. These findings are consistent with previous studies which reported that having access to financial resources (Ghobakhloo et al., 2022; Khin & Kee, 2022) are factors that help firms implement I4Ts, while high investment cost and lack of financial resources are factors that inhibit implementation (Ghobakhloo et al., 2021; J. Graham, 2024). Financial resources enable firms to not only purchase I4Ts but also to support the various activities that accompany I4T implementation, such as training and hiring staff, and managing organisational change (Kiel et al., 2017). From a DCT perspective, financial resources are essential for a firm to seize the potential benefits of I4Ts (Vu et al., 2023). The varied costs of I4T implementation represent a significant investment and, as the findings highlighted, cost inhibits I4T implementation because financial resources are limited for firms of all sizes.

The present study found that the high financial cost of I4Ts is a factor that influences investment decisions across all firms and only large manufacturers reported having sufficient financial resources to not have to rely on external government funding and support to. This finding aligns with Intalar (2024), and Khin and Kee (2022), whose studies including SMEs and large-sized manufacturers found that SMEs relied on government funding to support I4T implementation.

With regard to government funding and support, participants in the present study highlighted the role that Callaghan played in providing funding for SIRI assessments. From an INT perspective, government funding is a source of coercive pressure, intended to motivate I4T implementation by reducing the financial burden on firms (Zhou & Zheng, 2023). While it was evident that government funding had helped some firms implement I4Ts, other firms had not been able to access the funding due to its limited nature. Consequently, participants felt that government support of I4T investment was lacking, which inhibited I4T implementation. This finding accords with Rojas-Berrio et al. (2022) and Skalli et al. (2024) who suggested that lack of government financial support inhibited I4T implementation by Colombian and Moroccan manufacturers respectively. The participants in the present study felt that government financial support should be enhanced to include capital investment and tax incentives. If more manufacturers were exposed to a coercive pressure to implement I4Ts, such as through capital investment and tax incentives that could be accessed by any eligible manufacturer when completing their tax return, it may result in a more widespread implementation of I4Ts. In this regard, it is noteworthy that the NZ government introduced a form of accelerated depreciation called 'Investment Boost' in May 2025 (Inland Revenue, 2025), which means firms pay less tax on eligible assets in the year of acquisition.

Financial support from the government reduces the amount that firms have to contribute towards the cost of I4T implementation but would not usually cover the entire cost. Therefore, firms need to find additional financial capital to meet the full investment cost. This study found that manufacturers are typically required to produce a positive ROI calculation to obtain funding approval from finance providers. This requirement inhibits I4T implementation because the intangible benefits that come from I4T use, such as data-enhanced decision-making, enhanced customer satisfaction, and competitive advantage, are not easy to quantify, which makes an ROI calculation difficult to produce (Coyle, 2006). This finding aligns with Horváth & Szabó (2019), who identified that profitability concerns significantly hampered I4T implementation by Hungarian manufacturers.

From an INT perspective, pressure to provide a favourable ROI to secure funding can be viewed as coercive pressure from finance providers on manufacturers to conform to the expectation that investments will produce a financial return. However, focusing on ROI purely from a financial perspective ignores the potential for I4T investments to generate other forms of ROI, such as social ROI, which measures the social and environmental value created by an investment in addition to the economic value (Corvo et al., 2022). As discussed in section 5.4, this study identified that I4Ts make positive contributions to economic, environmental and social sustainability. Therefore, I4T investment has the potential to generate positive social ROI.

The negative impact of short parliamentary terms on I4T investment was not mentioned in the reviewed literature, which suggests this finding may be specific to the NZ context. Indeed, among liberal democracies, NZ has the shortest maximum parliamentary term at only three years (OpenAI, 2025). Participants' views that frequent policy changes inhibit I4T implementation are supported by the United Nations Industrial Development Organisation (UNIDO) which states, "Inconsistency and a short-term focus of industrial policy undermine the success of any industrial policy strategy, which requires long-term planning horizons" (UNIDO, 2024, p. 55).

5.3.2 Knowledge and skills

The study identified that having access to personnel with relevant knowledge and skills is a crucial enabler of I4T implementation, and that a lack of knowledge and skills inhibits a firm's ability to implement I4Ts. These findings are consistent with previous studies which reported having access to skilled personnel helps firms implement I4Ts (Khin & Kee, 2022; Leesakul et al., 2022), while a lack of skilled personnel and I4T awareness inhibits I4T implementation (Hamzeh et al., 2018; Horváth & Szabó, 2019; Rojas-Berrio et al., 2022).

Participants reported acquiring skilled personnel in a variety of ways, including by training and upskilling existing employees, and hiring experienced personnel with the requisite skills, either as employees or as consultants. Viewed through a DCT lens, skilled personnel enable firms to implement I4Ts to achieve strategic goals. Training, upskilling, hiring experienced personnel, and developing partnerships are examples of the microfoundations firms employ to leverage human resources to seize the opportunities presented by I4Ts (Leemann & Kanbach, 2022). These actions also respond to the threat posed to strategic objectives of not having sufficiently skilled and knowledgeable personnel, which this study identified as an inhibitor of I4T implementation. By training, upskilling, and hiring staff with relevant skills, firms improve their digital maturity, which Warner & Wäger (2019) identified as a reconfiguring DC fundamental to successful I4T implementation.

Experienced personnel play an additional role in enabling I4T implementation by strengthening a firm's sensing DCs. The findings identified that firms welcomed the opportunities for cross-pollination that arise when new recruits bring relevant overseas work experience with them. Through cross-pollination, experienced personnel enhance a firm's absorptive capacity, which is defined as "a firm's ability to internalise external knowledge" (Harris & Le, 2019, p. 290). From a DCT perspective, the findings suggest that experienced personnel enable I4T implementation by increasing a firm's absorptive capacity to identify or sense which I4Ts might be relevant to it, and how to make better use of the organisation's existing I4Ts. This finding aligns with Graham and Moore (2021), who found that a firm's absorptive capacity influences I4T adoption. However, due to its geographic remoteness from major industrialised nations and relatively small size, NZ's manufacturing sector has limited opportunities to benefit from the cross-pollination of knowledge and ideas that occurs when employees move from one organisation to another (Müller et al., 2024). Consequently, the findings identified that NZ manufacturers are not generally exposed to the potential benefits of I4T implementation through cross-pollination, which contributes to the finding that a lack of knowledge inhibits I4T implementation.

The findings identified that apprenticeships are an important tool to develop skilled personnel. This finding supports Sureeyatanapas et al. (2023), who stated that the introduction of an I4.0 apprenticeship program in the Thai manufacturing industry might enable its implementation. Further, UNIDO supports apprenticeships, stating that they are a key tool in modern industrial policymaking that should be used to strengthen the skills and capabilities needed to accelerate progress towards sustainable industrialisation (UNIDO, 2024). This supports the study's finding that apprenticeships enable I4T implementation through skill development.

In common with the study conducted by Leesakul et al. (2022) in the UK, the present study identified that the NZ manufacturing sector suffers from a negative perception, which deters prospective employees with relevant skills and exacerbates the sector's skills shortage. As noted in section 5.2.1.2, some participants felt that implementing I4Ts would help the sector overcome its poor perception by promoting a cleaner, more high-tech image. However, given the low level of I4T implementation, the sector may find it difficult to change this perception in the short-term and instead it will fall to individual manufacturers to promote their own digital credentials.

The findings revealed that the manufacturing sector's negative perception might be fuelled by the term 'Industry 4.0' which some participants perceived as an inhibiting factor. The study found that the term may create a barrier in two respects. First, participants reported that manufacturing and factories are often associated with the First Industrial Revolution, which evokes images of dull, dirty, and dangerous workplaces. As previously noted, this makes the sector unattractive to the younger contingent of the workforce. Therefore, using the word 'Industry' to describe the application of digital technologies in the manufacturing sector, might trigger negative perceptions in the minds of people that the sector wants to attract. Second, participants felt that the term is unclear and does not explain what it is, which may lead to people 'back away' when they hear the term because they are unable to grasp what it means. Indeed, as Culot et al. (2020) identified, the I4.0 concept has many definitions, is termed differently in different countries and may encompass over 1000 technological components which are continually evolving. Consequently, there might be better engagement from prospective employees and manufacturers, if the benefits of I4Ts were promoted under a term more attractive and accessible than 'Industry 4.0'.

5.3.3 Change management and resistance to change

The study identified that I4T implementation involves not only technological and physical aspects of integrating new technologies into existing work environments, but also managerial aspects of addressing employees' apprehensions about the impact I4Ts might have on the way they work. Consequently, the study found that effective change management helps smooth the transition to I4Ts by helping employees adapt to new ways of working. Conversely, employee concerns about I4Ts can lead to resistance to their implementation, which this study identified as an inhibiting factor. These findings are consistent with previous studies, which reported that managing change helps firms implement I4Ts (Leesakul et al., 2022; Veile et al., 2020), and minimise the resistance that can inhibit implementation (Horváth & Szabó, 2019; Tay et al., 2021).

From a DCT perspective, effective change management helps firms deal with the threat that resistance to change poses to I4T implementation by reconfiguring the organisation and its resources in ways that enable implementation. For example, the findings identified that firms used champions to change sceptical employees' perceptions of automation and AI, which facilitated implementation. Training formed part of firms' change management efforts and was a way firms reconfigured human resources to prepare employees for I4T implementation. This finding aligns with Vu et al. (2023), who identified change management as a key reconfiguring DC among Bolivian and Vietnamese manufacturers implementing I4Ts.

The findings revealed a variety of reasons why I4T implementation was resisted, a number of which, such as disruption, potential job losses, and employee reluctance to learn new procedures, are covered by extant literature (Horváth & Szabó, 2019; Sony et al., 2021). The literature tended to view resistance to change from the perspective of the employee, considering how I4T implementation impacts employees and leads to resistance. However, the present study identified two reasons why business owners in particular might resist change, both of which can be examined through the lenses of INT and DCT. The first reason relates to the lack of competition in the domestic market (IMF, 2025). The findings suggest that NZ's geographic remoteness and relatively small domestic market protect manufacturers from foreign competition and, as noted in section 1.2, competition in the domestic market is weak. Therefore, it may be that manufacturers serving only the domestic market do not sense competitive pressures, which means they identify neither opportunities nor threats related to I4T implementation. Consequently, they do not develop seizing or reconfiguring DCs, which results in no organisational change and maintenance of the status quo. The second reason relates to firms' existing investments in machinery and equipment (M&E). The findings identified that manufacturers may resist implementing I4Ts because existing M&E is still functional. Manufacturers who are able to meet customer requirements with existing M&E, may sense little opportunity to be gained from replacing M&E still considered fit for purpose with I4Ts. In this regard, the findings suggest that there might be particular resistance to I4T implementation in manufacturers where significant investment has been made in existing M&E.

5.3.4 ERP systems

The findings identified that ERP systems enable firms to capture organisational data, which was identified as a key driver of I4T implementation (see 5.2.2.1). Further, by enabling the development of big data, ERP systems also enable the implementation of other I4Ts that rely on data to perform, such as AI and advanced robotics (Frank et al., 2019). ERP systems was not identified as an enabler of I4T implementation in the literature review that informed this study, and was initially viewed as a novel finding. However, a further review of scholarly literature identified one study that supports the finding. Castillo-Vergara et al. (2025) developed a model to test the relationship between firms' digital capability, I4.0, and innovation performance based on data from 536 Chilean SMEs. From their findings the authors conclude that digital management systems, such as ERP systems, facilitate the adoption of base technologies, such as cloud computing and big data, which aligns with the finding of the present study. While there appears to be a lack of extensive scholarly literature identifying that ERP systems enable I4T implementation, the researcher notes that grey literature does recognise the connection (Achieve-ERP, 2024; Hennik Research, 2025). This may indicate an opportunity for future academic research in an apparently under-developed area.

5.3.5 Low production volumes

The study identified low production volumes as an inhibiting factor particularly with regard to automation. This was a novel finding not previously identified in the literature, which suggests that this inhibitor may be specific to the NZ context. The findings suggest that low production volumes may be a specific characteristic of the NZ manufacturing sector that inhibits automation implementation because the low volumes make it difficult for firms to build a business case for automation. As highlighted in Chapter 1, as much as 80% of NZ manufacturers serve the domestic market only. Coupled with the low production volumes, this suggests that the vast majority of manufacturers are generating product sufficient to satisfy NZ's small domestic market and which generate an acceptable return to the manufacturer. Consequently, firms may have little incentive to incur the expense of implementing automation if there is unlikely to be demand for increased output. Again, this can be viewed through INT and DCT lenses, if it is assumed that manufacturers are not experiencing sufficient institutional pressure to produce more goods. Consequently, from a DCT perspective, no opportunities or threats associated with producing more goods are identified, and the manufacturer continues their current mode of operations.

This characteristic may create tension between the government's desire for manufacturers to increase their productivity to benefit wider society (New Zealand Productivity Commission, 2023), and the appetite of individual manufacturers to increase their productivity beyond the level at which they are currently comfortable. If a manufacturer serving only the NZ domestic market were able to achieve higher productivity by producing more goods with the same input, it may not be able to find a buyer for the additional goods given the size of the market, which would not be economically sustainable in the long term. Alternatively, the same manufacturer could also increase productivity by producing the same level of goods using less input. In terms of raising productivity, this should be the preferred option for manufacturers serving the domestic market only. However, this option would require the manufacturer to invest time and other resources in identifying where and how input levels could be reduced, which there may be little appetite for if they are generating the income they need from current activities.

5.3.6 Senior management support and technology integration

In contrast to the literature (see section 2.5.4), senior management support for I4T implementation was not identified as a key enabling factor in this study because it was mentioned by only two participants. One possible explanation for this might be that the participants did not think to highlight the influence that senior management might have on I4T implementation because that influence could be implied from their participation in the study.

Also in contrast to the literature (see section 2.6.5), technology integration was not identified as a key inhibiting factor in this study. The final coding template shows that technology integration was coded as an inhibiting factor in six interviews. Consequently, following the criteria described in section 3.10.3, technology integration was not identified as a key inhibiting factor. A reason for this factor not being mentioned by more participants, may be due to the majority of manufacturers in this study being categorised with a Beginner I4.0 maturity level, which may indicate they had not been exposed to the challenges of technology integration at the time of the interviews.

5.4 I4T contribution to sustainability

The study found that I4Ts make positive and negative contributions to economic, environmental, and social sustainability. The findings revealed almost twice as many positive references to I4Ts and sustainability than negative, which suggests participants perceived I4Ts more favourably than negatively with regard to sustainability.

5.4.1 Economic sustainability

With regard to economic sustainability, participants reported benefits of increased efficiency and productivity, such as reduced costs, increased profitability, and increased competitiveness in global markets, which aligns with the prevailing view of extant literature (Cricelli & Strazzullo, 2021; Ghobakhloo et al., 2021). However, the findings revealed concerns about the high financial cost of I4T implementation and whether I4T investment would be profitable, findings which again align with the literature (Birkel et al., 2019; Ghobakhloo et al., 2021). The study also revealed that the financial cost of I4Ts does not end when they are implemented, because firms need to factor in the costs of third-party maintenance and repair if they do not have the required skills in-house. On the whole, the findings suggest that firms face a dilemma, whether the potential positive economic sustainability outcomes of I4T implementation outweigh the negative.

5.4.2 Social sustainability

The findings identified that I4T use enables firms to create a better work environment for employees, provides employees with opportunities to acquire new knowledge and skills, and may increase the number of highly paid jobs. These findings align with previous research such as those conducted by Felsberger and Reiner (2020), and Braccini and Margherita (2019).

As discussed in section 5.2.1.2, NZ's manufacturing sector has a poor workplace injury record. The findings identified that that implementing automation can result in positive physical and psychological benefits for employees, by relieving them from dull and repetitive tasks that may induce stress and repetitive strain injuries (Häusser et al., 2014). This finding is consistent with previous studies by Papetti et al. (2018), and Braccini and Margherita (2019). Maintaining a healthy workplace also has an economic impact. Participants highlighted difficulties finding people to fill manufacturing roles. Consequently, it makes sense for a firm to safeguard the well-being of existing employees, so that it does not incur the financial cost of, for example, compensating injured employees, hiring and training new employees to replace those lost through illness and injury, or decreased profitability due to reputational damage (Kim & Park, 2021).

In common with the literature (Braccini & Margherita, 2019; Felsberger & Reiner, 2020), the findings indicate that I4T implementation leads to an upskilled workforce because employees develop new skills through training and on-the-job experience. Significantly, the findings revealed that I4Ts such as AR and AI can be used to give employees with low literacy levels or communication challenges, an equal opportunity to receive and understand training material. This is a novel finding not previously identified in the literature which suggests the finding may be specific to the NZ context. The finding is significant in the NZ context because the manufacturing sector is a leading employer of Māori and Pacific peoples (MBIE, 2023), and unfortunately, the work-related injury claim rate is disproportionately high among Māori and Pacific peoples employed in manufacturing (EMA, 2024). Together with cultural barriers, inadequate training, and poor communication of safety procedures are associated with the sector's poor injury claim rate (EMA, 2024). Data indicates that literacy levels among Māori and Pacific peoples are low (Alkema, 2020), consequently, by removing language-based barriers to learning, using AR and AI to deliver training increases social equity in the workplace by making training more inclusive and, particularly where training relates to health and safety issues, leads to a safer work environment for all employees, by increasing understanding of health and safety procedures across the organisation. Consequently, the findings suggest that AR and AI might be usefully employed to increase understanding of training, thereby reducing the work-related injury rate in the sector and reducing the economic cost of injuries on society.

The findings identified that I4T use created jobs by enabling firms to meet additional customer demand, and may change the mix of manufacturing roles, with lower skilled roles replaced by roles requiring higher skill levels. These findings are consistent with the literature (Felsberger & Reiner, 2020; Grybauskas et al., 2022). The findings also identified the potential for job losses due to, for example, automation assuming low skill, repetitive tasks, AI being used for analytical tasks, and individuals being unable to adapt to using I4Ts. Again, these findings align with the literature (Brougham & Haar, 2017; Leesakul et al., 2022). However, the findings identified that I4Ts are not currently causing widespread job losses. While individual job losses do occur as a result of I4T implementation, it appears NZ manufacturers use I4Ts to complete tasks they have not been able to recruit for, rather than to replace employees. As noted earlier, labour and skills shortages mean that firms struggle to meet their human resource requirements, which may explain why they prefer to retain, retrain, and reskill employees and avoid redundancies. This finding is congruent with the multiple case study conducted by Margherita and Braccini (2020), which found management deployed I4Ts to improve productivity rather than to reduce their workforce.

5.4.3 Environmental sustainability

The findings identified fewer references to I4Ts' contribution to environmental sustainability compared to economic and social, which suggests manufacturers may be less engaged with environmental sustainability than economic and social. This finding is somewhat supported by insights from Callaghan (2025a), which revealed that NZ manufacturers taking part in smart factory assessments exhibited low engagement with environmental sustainability, with the large majority having no environmental policy, and no formal plans to reduce emissions, waste, or energy and water use.

The findings identified that I4Ts help firms make a positive contribution to environmental sustainability by helping them monitor resource usage and emissions during production processes and highlighting where reductions can be made, which is consistent with extant research (Javaid et al., 2022). Further, reducing resource consumption reduces the overall cost of resources to an organisation, which makes a positive contribution to economic sustainability (Cricelli & Strazzullo, 2021).

Only a few participants highlighted I4Ts' negative contribution to environmental sustainability, which suggests that firms may be unaware of, or have not fully considered the potential for negative environmental outcomes from using I4Ts. The findings highlighted that manufacturers might use more resource when they use I4Ts to increase productivity. They also revealed that the need for ancillary equipment, such as monitors, computers, and tablets that enable manufacturers to interact with the I4Ts, increases industrial consumption and may result in increased energy use. These findings align with Dieste et al. (2023), who concluded that I4Ts can increase consumption and waste. Further, the findings identified that purchasing ancillary equipment might lead to more electronic waste (e-waste), which Birkel et al. (2019) identified as an under-acknowledged ecological risk of I4T implementation. This finding may be particularly important in the NZ context because, when viewed as a geographic region, Australia and NZ generate more e-waste per capita than any other (United Nations, 2025), and the majority of waste generated by NZ manufacturing goes to landfill (Aurecon et al., 2024). Consequently, this suggests that the NZ government and manufacturing sector may need to consider how to pursue I4.0 and concurrently deal with redundant I4Ts and ancillary equipment in an environmentally sound way.

5.5 Integrative I4T implementation framework

This study took a novel approach by synthesising INT and DCT in its exploration of the factors that influence I4T implementation. This synthesis was depicted in the conceptual framework shown in Figure 2.1. Based on insights gained from the previous discussion, the conceptual framework was developed into the integrative framework shown in Figure 5.1. The integrative framework shows a manufacturer (the firm), the key themes of the study – drivers, enablers, and inhibitors of I4T implementation, and sustainability – and their relation to the theoretical lenses of INT and DCT. The integrative framework combines these interrelated components to propose a novel perspective on I4T implementation and resultant sustainability outcomes.

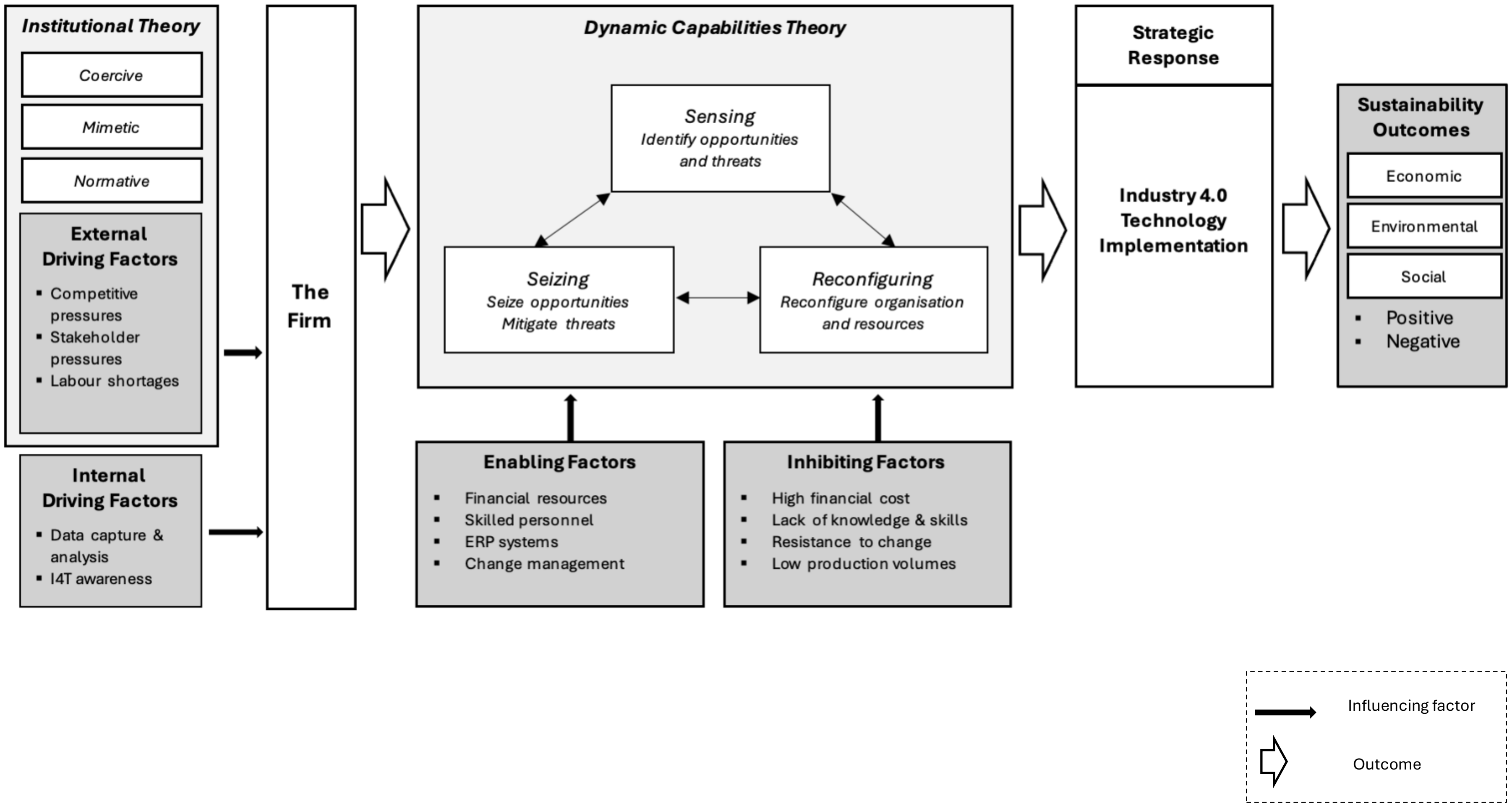
First, the framework reflects the study's findings that internal and external drivers motivate firms to implement I4Ts. Drawing on INT (DiMaggio & Powell, 1983), the framework shows the firm is subject to coercive, mimetic and normative institutional pressures present in their external operating environment. Essentially, these pressures influence the decisions that firms make regarding their structure, practices and strategies (DiMaggio & Powell, 1983). Based on the empirical findings (see Chapter 4), this study confirms that INT provides some explanation for a firm's motivation to implement I4Ts. However, the findings also identified internal drivers of I4T implementation. Internal drivers are not addressed by INT but are recognised in the framework to reflect the study's findings. The influence of internal and external factors in driving technology implementation was recognised by Correia Simões et al. (2020), in their study of factors influencing cobot adoption.

Next, the framework illustrates that the firm uses its DCs to respond to the driving factors, which can be viewed as opportunities or threats (Teece, 2007). At this point, the framework aligns with Demeter et al. (2020), in proposing that the firm has to become aware of the drivers by deploying its sensing DCs first. After that, it uses any combination of sensing, seizing and reconfiguring DCs to formulate a response to the driver. As stated in section 2.8.2, this is not a linear process and is likely to involve the firm iteratively deploying its DCs as it develops its strategic response to the driving factors (Leemann & Kanbach, 2022).

As shown in the framework, enabling and inhibiting factors influence the deployment of a firm's DCs. For example, the findings identified that financial resources help a firm seize opportunities and reconfigure resources by enabling it to acquire I4Ts and bring skilled employees into the organisation. Conversely, the findings revealed that resistance to change is an inhibiting factor that prevents firms from seizing opportunities when, for example, employees are hostile to retraining or to using I4Ts that would enable the firm to increase its productivity. Teece (2007) noted that firms often fail to seize identified opportunities due to, for example, lack of financial resources or resistance to change. Based on empirical findings, the framework develops this idea further, and proposes that a firm will enhance each dynamic capability if it is able to develop enabling factors and limit inhibiting factors.

Next, the framework shows that the firm decides on a strategic response as a result of deploying its DCs, which it hopes will lead to it gaining or maintaining a competitive advantage (Teece et al., 1997). In this study, and as shown in the framework, the strategic response to a particular set of institutional pressures and internal drivers was I4T implementation. Finally, based on the study's empirical findings, the framework illustrates that both positive and negative sustainability outcomes result from I4T implementation.

Figure 5.1: Integrative framework for I4T implementation leading to sustainability outcomes



5.6 Conclusion

This chapter discussed the findings derived from fifteen semi-structured interviews and linked them to the literature and theory. First, internal and external drivers of I4T implementation were discussed, linking with INT which highlighted the influence of mimetic and coercive pressures. Second, the enablers and inhibitors of I4T implementation were analysed and factors specific to the NZ context were identified. Third, the contribution that I4T use makes to sustainability dimensions was discussed, highlighting both positive and negative outcomes across all three dimensions. Finally, an integrative framework of I4T implementation was presented, using INT and DCT to illustrate the roles driving, enabling and inhibiting factors play in I4T implementation. The framework illustrates that enabling and inhibiting factors influence NZ manufacturers' ability to deploy DCs, which they do in a strategic response to external institutional forces and other internal drivers. As such, the framework suggests that I4T implementation is less about the technology itself, but more about how firms use I4Ts as tools to seize opportunities and mitigate threats by reconfiguring assets to achieve strategic goals and ultimately to gain or maintain competitive advantage.

Chapter 6 Conclusion

6.1 Introduction

This study explores factors influencing I4T implementation in NZ-based manufacturers and managerial perspectives of the positive and negative contributions I4Ts make to sustainability. This chapter comprises six sections. A brief overview of the study follows this introduction. Then, the key research findings are summarised in section 6.3. Section 6.4 presents the implications of the study, and its limitations are outlined in section 6.5. Suggestions for future research are made in the final section.

6.2 Overview of the study

This study endeavours to contribute to the body of knowledge regarding I4T implementation in manufacturing entities, by adopting institutional and strategic management perspectives to explore influencing factors and sustainability outcomes in a NZ context. To achieve this aim, the following research questions were developed:

RQ1: What factors drive I4T implementation?

RQ2: What factors enable I4T implementation?

RQ3: What factors inhibit I4T implementation?

RQ4: How do I4Ts contribute to sustainability?

A qualitative, predominantly abductive approach was taken to address the research questions. Primary data were collected from fifteen semi-structured interviews with senior manufacturing executives and I4.0 consultants who had knowledge of organisations' I4T implementation initiatives and an awareness of sustainability issues. Secondary data obtained from company websites, and publicly available I4.0 case-studies about the participant firms, were analysed to complement and triangulate with primary data. Two organisational theories, INT and DCT, were used to guide the data analysis and develop a framework to understand I4T implementation. INT was used to explore the influence of external pressures, while DCT was used to explore connections between driving, enabling and inhibiting factors. An integrative framework of I4T implementation leading to sustainability outcomes was developed based on the study's findings.

6.3 Key research findings

6.3.1 Drivers of I4T implementation

The study found that various external and internal factors motivated NZ manufacturers to implement I4Ts. Competitive pressures, stakeholder pressures and labour shortages were the main external factors driving I4T implementation, while data capture and analysis and I4T awareness were the key internal drivers.

Viewed through an INT lens, mimetic and coercive institutional pressures were the primary external drivers. Normative pressures to implement I4Ts appeared to be weak among NZ manufacturers. This is likely due to the limited opportunities for professionalisation to occur in the sector. With respect to mimetic pressures, factors related to competition were foremost, with firms implementing I4Ts to copy the benefits enjoyed by competitors. The influence of mimetic forces may reflect manufacturers' lack of knowledge about I4Ts and their implementation, which may lead them to copy the actions of peers deemed to be more knowledgeable or successful.

Legal and regulatory requirements, external customer demands and labour shortages were examples of coercive pressures identified in the study. Manufacturers were driven to implement robotics and automation to address employee health and safety concerns. This appears to be a novel finding, which may reflect an attempt by manufacturers to improve the industry's poor work-related injury claim rate and mitigate the impact of labour shortages on their ability to operate. Further, the findings revealed that labour shortages motivated manufacturers to implement I4Ts to cover vacant positions, and to meet prospective employees' expectations of working in environments where digital technologies are used.

Regarding internal drivers, the study found that data capture and analysis was a key driver for manufacturers of all sizes, reflecting a desire to enhance their decision-making capabilities by having a better understanding of the internal business environment. Additionally, the findings indicated that seeing how other manufacturers benefit from their use drives implementation. This suggests that NZ manufacturers are influenced by their peers' experiences, which tallies with the finding that mimetic pressures play a key role in driving I4T implementation.

6.3.2 Enablers and inhibitors of I4T implementation

The study identified several factors that enable and inhibit I4T implementation, and found that some factors act as both enablers and inhibitors. Drawing on the relationship of the findings to the theoretical lenses, the study revealed that enabling and inhibiting factors influence firms' ability to develop DCs.

Having access to financial resources and other forms of financial support enabled firms to meet the high financial costs associated with I4T implementation, such as acquisition costs, and costs related to training, hiring staff, and making organisational changes. These costs inhibit implementation because firms of all sizes have limited financial resources. Most firms in the study needed government support to help with implementation initiatives although frequent policy changes meant that firms did not feel they could rely on that support being available when required.

Because interacting with I4Ts requires skills different from those used with conventional manufacturing equipment, having access to skilled personnel was a key enabler of I4T implementation, while a lack of knowledge and skills was identified as an inhibiting factor. Training, upskilling and hiring experienced staff were typical ways firms acquired skilled personnel. Apprenticeships were identified as a tool to develop skilled personnel, although concerns were raised that the government does not do enough to support them. Concerns were also raised whether engineering degree programs equip graduates with the skills needed to interact with I4Ts. Personnel with previous I4T experience were valued by firms due to their potential to enhance firms' absorptive capacity and steer I4T implementation initiatives.

Implementing I4Ts leads to changes in the way that an organisation operates, which some employees may find challenging. The findings identified change management and resistance to change as an enabler and inhibitor of I4T implementation respectively. Appointing champions of change and providing training were two key ways firms prepared employees for I4T implementation and mitigated resistance to change. Lack of competitive pressure and existing investment in functional machinery may make business owners reluctant to change their current way of working.

The study found that low production volumes inhibit automation implementation. This was a novel finding not previously identified in the literature, which suggests this inhibitor may be specific to the NZ context. Low production volumes inhibit automation implementation because the cost of implementation is difficult to justify for the low-volume manufacturers that dominate the sector. This finding is also significant because it identifies a tension between the government's desire for manufacturers to increase their productivity and the manufacturing sector's ability to do so, given the size of the domestic market and availability of financial resources.

The study also identified that the term 'Industry 4.0' may inhibit I4T implementation by perpetuating an association of manufacturing with the First Industrial Revolution, which may exacerbate the labour shortages experienced by the sector, and ERP systems enable implementation by helping firms capture organisational data.

6.3.3 I4T contribution to sustainability dimensions

The study found that I4Ts make positive and negative contributions to economic, environmental and social sustainability. The findings suggest that participants hold a more positive than negative view of the contribution I4Ts make to sustainability, and that manufacturers' engagement with the environmental dimension is lower than with the other two. Economic benefits derived from I4Ts' ability to enhance firms' efficiency and productivity. The high financial costs associated with I4T implementation represented the primary negative contribution to economic sustainability.

Turning to social sustainability, the potential for job losses was identified as the main negative contribution; however, it appears that widespread job losses are uncommon. The use of automation can lead to cleaner work environments and positive physical and psychological outcomes for employees by reducing stress and repetitive strain injuries. Training and upskilling were identified as positive outcomes from I4T use and one which could also result in the creation of new, more highly skilled roles. Further, the use of AR and AI can make training more inclusive when they are used to give employees of differing language abilities an equal opportunity to receive and understand training material. This benefits the individual employee and may also lead to a safer work environment for all employees. That social equity in the workplace can be enhanced through the use of AR and AI was a significant finding which may be specific to the NZ context.

Regarding environmental sustainability, the findings identified that I4Ts make positive contributions by helping firms monitor resource usage and emissions during production processes, highlighting where interventions can be made to make reductions. Conversely, I4Ts may negatively contribute by increasing productivity and industrial consumerism, leading to an increase in resource use and increased waste. In general, participants seemed less aware of the potential for negative environmental outcomes from using I4Ts.

6.4 Implications

Theoretical, practical and policy-related implications can be drawn from the findings of this study.

6.4.1 Theoretical implications

To the best of the researcher's knowledge, this study is the first to apply INT and DCT to explore the driving, enabling and inhibiting factors influencing I4T implementation. The study presents a framework that lays the theoretical foundation for a new approach for conceptualising I4T implementation from an institutional, strategic management perspective, thereby making a significant theoretical contribution to the literature. Further, adopting INT and DCT in one study answers calls for future research from Gölgeci et al. (2017), and Liu et al. (2020).

This study provides an exploration of the drivers, enablers and inhibitors of I4T implementation in NZ and contributes empirical data on NZ firms' specific experiences, thereby enriching the body of knowledge on I4T implementation in manufacturing entities. Further, by identifying negative sustainability outcomes resulting from I4T implementation, and not focusing only on the positives, the study answers calls from Bohnsack et al. (2022), and Liu et al. (2020), for research considering the positives and negatives of using digital technologies.

6.4.2 Implications for practice

This study provides manufacturers with valuable insights regarding I4T implementation. First, manufacturers can use the findings from this study to inform their own I4T implementation initiatives by having a better understanding of the factors that helped and hindered their peers. Second, by considering and balancing the potential benefits and drawbacks identified in this study, manufacturers can seek to optimise the benefits of I4T use, and proactively plan for and mitigate potential negative consequences. Third, manufacturers can take low-cost steps to improve training outcomes and increase workplace safety for all employees, by using AI to translate standard operating procedures and health and safety instructions into the languages used by their workforce. Fourth, manufacturers should be mindful that the number of people in the workforce who expect to work in environments where digital technologies are used, will continue to grow. Therefore, firms should consider implementing I4Ts to attract and retain staff.

6.4.3 Implications for policy makers and industry bodies

The findings from this study have implications for policymakers and industry bodies, in developing policies and initiatives that support the implementation of digital technologies in the manufacturing sector to enhance its future productivity and sustainability.

First, mimetic institutional pressures are a key driver of I4T implementation. To drive further implementation, industry bodies should promote examples of successful initiatives, and case studies should be publicised, particularly of implementations involving small manufacturers.

Second, government funding and support via Callaghan Innovation played a huge role in enabling firms' I4T implementation initiatives. With Callaghan's disestablishment, the government must give serious consideration to how it will support manufacturing digitalisation going forward, particularly in light of national productivity and sustainability goals.

Third, to achieve its objective of increasing the productivity of the manufacturing sector through I4T implementation, government must devise a mechanism to reach and influence the majority small- and medium-sized manufacturers.

Fourth, manufacturers of all sizes are likely to benefit from the insights that can be gained from operational data, and data is the fuel that drives other I4Ts. Therefore, policies and initiatives might focus first on helping manufacturers extract data from their operations, rather than on technologies such as automation.

Fifth, government should be mindful that the drive for increased productivity should not come at the expense of the environment. If manufacturers are encouraged to replace old, but functional, machinery with new I4Ts, due consideration must be given to ensuring that mechanisms exist to enable redundant machinery and ancillary equipment to be disposed of in an environmentally sound manner.

Sixth, the study found that I4Ts positively contribute to social and environmental sustainability. Sustainability and digitalisation initiatives appear to be at low levels in the manufacturing sector. Consequently, there is an opportunity for government and industry to pursue a triple transition agenda which "places the interlinkages and interconnections of the environmental, digital, and social aspects of development at the core" (OECD, 2023, p. 14).

Seventh, industry bodies should collaborate with academia to ensure that courses prepare students with the skills required by a future, digital manufacturing sector, and government should provide more support for apprenticeships.

Eighth, the use of the term 'Industry 4.0' in communications may be alienating. Future initiatives should abandon 'Industry 4.0' and refer to 'digital manufacturing' and 'digital manufacturing technologies' instead, focusing on the benefits of individual technologies rather than on the I4.0 concept. Using 'digital' rather than 'industry' would also reflect the experience of the younger workforce (Racolţa-Paina & Irini, 2021), and may help counter some of the negative perceptions around manufacturing. Further, pan-industry knowledge-building and collaboration would be enhanced by using a term that is as equally well understood in, for example, the mining sector as it is in the manufacturing sector.

Finally, if it were possible to produce, I4T implementation would benefit from a sector digitalisation policy that spanned successive governments.

6.5 Limitations

While this study contributes to the body of knowledge by providing valuable and novel insights, it is subject to limitations.

First, this study captured rich and in-depth data from its participants. However, given that it was a NZ-based, qualitative study with a small sample size the findings are not generalisable and readers should make their own assessment of the findings' applicability in other contexts.

Second, the study explored digital technology implementation and associated sustainability contributions in the manufacturing sector. Therefore, the identified drivers, enablers, inhibitors, and sustainability contributions may differ in other sectors, such as retail or hospitality.

Third, semi-structured interviews were conducted only with business owners and senior personnel. Valuable insights into I4Ts' contribution to environmental and social sustainability might have been gained from interviews with employees who work more closely with I4Ts or in areas directly affected by I4T implementations.

Fourth, the study was conducted by a single researcher, which raises the potential for inherent bias in the data interpretation. Various approaches were adopted to maintain and evidence research quality and rigour. For example, to evidence confirmability, a comprehensive research database has been maintained that provides an audit trail clearly linking the data to the findings. However, it is acknowledged that the findings may not be totally free of single researcher bias.

6.6 Suggestions for future research

The study revealed a number of novel findings which may be specific to the NZ context, such as the impact of low production volumes on automation implementation, the inhibiting nature of short parliamentary terms, the use of AI and AR to increase learning and inclusion in the workplace, and the contribution ERP systems make to I4T implementation. Any of the novel findings might form the basis of future study.

The findings revealed paradoxical tensions related to I4Ts, such as their capacity to create and eliminate jobs, or to increase and decrease consumption and waste. This suggests that scope exists to consider the relationship between I4Ts and sustainability through a paradox theory lens.

The study adopted a qualitative, cross-sectional research design which explored managerial experience and perspectives regarding I4Ts' contribution to sustainability. A longitudinal study adopting a quantitative or mixed-methods approach could provide a quantifiable analysis of sustainability contributions before, during and after an I4T implementation to, for example, evaluate the environmental impact of replacing traditional machinery with I4Ts or assess changes in employee well-being.

Regarding productivity, NZ is often compared to other small advanced economies such as Denmark and Singapore (Skilling, 2020). A comparative study involving other small advanced economies, looking perhaps at influences on I4T implementation and industrial digitalisation policy, might provide useful insights that could be applied in the NZ context to further I4T implementation in its manufacturing sector.

The study explored the influences on I4T implementation by gaining insights from participants whose organisations had implemented at least one I4T. Given NZ's low I4T adoption rate, it might be useful to conduct a study among manufacturers who have not yet implemented I4Ts, as they may be influenced by different drivers, enablers and inhibitors.

The conceptual model could be expanded to include a theory that explicates internal drivers, for example, integrative stakeholder theory. Further, quantitative surveys or a mixed-methods approach could be adopted to operationalise the framework and test its relationships with a larger number of participants.

This study provided an initial exploration of the relationship between the use of digital technologies and sustainability. Future studies might focus on the incorporation of a triple transition agenda (OECD, 2023), incorporating digitalisation, social sustainability, and environmental sustainability into organisational objectives to support achievement of the SDGs.

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Appendix A: Information Sheet

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

MASSEY BUSINESS SCHOOL

INFORMATION SHEET

Introduction

Kia ora. My name is Vanessa Wood and I am a Post-Graduate student pursuing a Master of Business Studies degree at Massey University. For the final part of my degree I am undertaking a research project that explores the experiences of New Zealand-based manufacturers who have implemented Industry 4.0 technologies. This document provides information about my research project:

> *Exploring the drivers, challenges and impacts of Industry 4.0 technology implementation in New Zealand manufacturers*

Project Description

The aim of my research is to explore the implementation of Industry 4.0 technologies in manufacturing operations and production processes. Specifically, I would like to gain an understanding of the following:

- The reasons why manufacturers implement Industry 4.0 technologies
- How the technologies are being used
- The difficulties manufacturers face when implementing Industry 4.0 technologies
- How the use of Industry 4.0 technologies impacts sustainability (people, planet, profit) in manufacturing operations and production processes

Benefits of the study

Through this research, I hope to highlight the benefits and impacts of digital technologies on (sustainable) manufacturing, raise awareness of the issues NZ manufacturers face when implementing them and suggest some practical solutions.

Participant Identification and Recruitment

I am seeking interviews with senior individuals employed by manufacturers that have implemented at least one Industry 4.0 technology. Participants should have solid knowledge of their firm's Industry 4.0 technology initiatives and an awareness of sustainability issues.

Invitation to participate

You are invited to be part of this research project to share your experiences, perceptions and views of Industry 4.0 technology implementation within your organisation, and the impacts the technologies might have had on your firm's sustainability performance.

Interview procedure

Participation in this study will involve a one-to-one, in-person interview of open-ended questions lasting approximately one hour. Further information may be required from participants after the interview, particularly to follow up on any aspects of the interview that require clarification.

Data Management

I will record all interviews and transcribe them verbatim for analysis. The privacy of participants will be rigorously upheld by ensuring all participants remain unidentifiable in any reports or publications. The findings of my research project will be reported in a written thesis. Transcripts and audio recordings will be kept in a secure location and their content will remain confidential, however quotes may be used anonymously as part of the thesis. The thesis will be available for participants to view after it has been submitted to Massey University. Findings may also be published in an academic journal in the future, maintaining anonymity of all participants.

Your Rights as a Participant

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question.
- ask for the recorder to be turned off at any time during the interview.
- withdraw from the research project (including during the interview).
- ask any questions about the research project at any time during participation.
- provide information on the understanding that your name will not be used unless you give permission to the researcher.

Ethical Conduct

This research project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz

Project Contacts

If you have any queries or require any further information about this research project to help with your decision to participate, please do not hesitate to contact me or my supervisors:

Researcher: Vanessa Wood (vanessa.wood.2@uni.massey.ac.nz)

Supervisors: Dr Aymen Sajjad (a.sajjad@massey.ac.nz)
Dr Shafiq Alam (s.alam1@massey.ac.nz)

Participant Consent Form

Participants must complete a consent form. Please submit the consent form via e-mail to vanessa.wood.2@uni.massey.ac.nz

Appendix B: Consent Form

MASSEY UNIVERSITY
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UNIVERSITY OF NEW ZEALAND

MASSEY BUSINESS SCHOOL

PARTICIPANT CONSENT FORM

Researcher: Vanessa Wood

Research project: Exploring the drivers, challenges and impacts of Industry 4.0 technology implementation in New Zealand manufacturers

Participant declaration

I have read the Information Sheet and received an explanation of the research project details. My questions have been answered to my satisfaction and I understand that I may ask further questions or seek further clarification at any time.

I willingly grant permission for the interview to be recorded, with the clear understanding that my responses will remain confidential to the researcher and any summarised information will remain anonymous in any publications.

By providing my physical/electronic signature below, I acknowledge that I have read and understand the conditions outlined in the Information Sheet, and that I voluntarily consent to participate in the research project.

Signature:____Date:______________

Full Name – printed:____

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.

Appendix C: Interview Guide

Interview guide

PART A: Preliminaries

Introduction [3 mins]

1. Introduce myself and thank the interviewee for their participation
2. Remind them of the aim of the study (RQs)
3. Remind them of their rights - open-ended questions to allow you to talk freely. No right or wrong answer, looking for your experiences and perceptions
4. **GET CONSENT FORM SIGNED IF NOT ALREADY RECEIVED & VERBAL PERMISSION TO PROCEED**

PART B: The interview

Background information [5 mins]

5. What does the firm manufacture?
6. What are your role and responsibilities at the firm? How long have you been here?
7. How many people does the firm employ?

I4.0 technology implementation [25 mins]

8. Where would you say you are on your digital transformation journey? When did it start?
9. Which I4.0 technologies has the firm implemented – SHOW LIST
10. Which technology did you start with?
11. How/where is the firm using these technologies?
12. How does the firm find out about the (relevant) technologies?
13. Why did the firm decide to adopt I4.0 technologies (driver/influence)?
14. What did the firm hope to achieve by implementing these technologies?
15. What kind of support, internal or external, helped the firm implement the technologies?
16. What things made implementation difficult (before/during)?
17. How did you overcome these difficulties?
18. What resources did the firm have to develop or acquire to facilitate implementation?

19. In general, what changes have you had to make to accommodate the transformation?

20. Does the firm plan to implement any other I4.0 technologies in the short term? If yes, what and why? If no, why not?

I4.0 technology impact (people, planet, profit) [20 mins]

21. In general, what have the benefits been/what do you hope the benefits will be?

22. How have the technologies contributed to the firm's financial or commercial performance?

23. How have the technologies helped the firm reduce its impact on the environment?

24. How have people, inside or outside your organisation, benefitted from the implementation?

25. What are the downsides/negative impacts on people, planet, profit of I4T implementation?

26. Is there anything I haven't covered that you think is relevant or you would like to add?

Appendix D: Initial coding template

1 Drivers

- 1.1 Competition
  - 1.1.1 Keeping manufacturing in New Zealand
  - 1.1.2 Profitability
    - 1.1.2.1 Increasing production efficiency
    - 1.1.2.2 Improving productivity
    - 1.1.2.3 Reducing cost
  - 1.1.3 Emulating competitors/peers
  - 1.1.4 Proving value added services
- 1.2 Responding to stakeholder demands/requirements
  - 1.2.1 Improving traceability
  - 1.2.2 Improving quality
  - 1.2.3 Reducing cost
  - 1.2.4 Sustainability reporting
- 1.3 Reducing production errors and defects
  - 1.3.1 Improving product quality
  - 1.3.2 Reducing waste (raw materials, resources, time)
- 1.4 Workforce availability
  - 1.4.1 Difficulty filling undesirable roles
  - 1.4.2 Reliance on seasonal workers
- 1.5 Increasing visibility of operations
  - 1.5.1 Making better use of data – fast and informed decision making
  - 1.5.2 Inventory control
- 1.6 Improving employee safety

2 Enablers

- 2.1 Financial resources
  - 2.1.1 Internal funding sources
  - 2.1.2 External funding sources
    - 2.1.2.1 Government funding and support
    - 2.1.2.2 Partnerships
  - 2.1.3 Accelerated depreciation of productive assets
  - 2.1.4 Falling cost of I4Ts
- 2.2 Human resources
  - 2.2.1 Skills/capabilities
    - 2.2.1.1 Training
    - 2.2.1.2 Apprenticeships
    - 2.2.1.3 Partnerships
    - 2.2.1.4 Champions
  - 2.2.2 Partnerships
- 2.3 Champions – people driving the initiative
- 2.4 Employee engagement
- 2.5 Formal assessment of current digital capability, e.g. SIRI
- 2.6 Strategic/holistic/connected thinking
- 2.7 Acquiring knowledge about the technologies

3 Inhibitors

- 3.1 High financial cost
  - 3.1.1 Lack of financial resources
  - 3.1.2 Lack of government support
  - 3.1.3 Acquiring and implementing I4Ts
  - 3.1.4 Uncertainty regarding return on investment
  - 3.1.5 Maintaining I4Ts (perception vs reality)
  - 3.1.6 Automating complex or dextrous tasks
  - 3.1.7 Lack of strategic thinking/piecemeal approach
- 3.2 Implementation complexity (interoperability)
- 3.3 Workforce availability
  - 3.3.1 Poor perception of manufacturing as a career choice
  - 3.3.2 Lack of graduate engineers
  - 3.3.3 Lack of apprentices/skilled, non-graduates
- 3.4 Poor project management
  - 3.4.1 Lack of communication of change
  - 3.4.2 Not identifying and involving key stakeholders
- 3.5 Lack of leadership/ownership
- 3.6 Resistance to change
  - 3.6.1 Due to fear of the unknown/having to learn something new
  - 3.6.2 Due to lack of competition
- 3.7 Low English literacy levels
- 3.8 Lack of knowledge about the technologies
- 3.9 Regulatory burdens

4 Sustainability contribution positive

4.1 Economic

4.1.1 Ability to win and fulfil more contracts through productivity improvements

4.1.2 Increased profitability

4.2 Environmental

4.2.1 Reducing resource use

4.2.1.1 Raw materials

4.2.1.2 Energy

4.2.1.3 Using data to monitor resource usage

4.2.2 Reducing CO_2 emissions

4.3 Social

4.3.1 Increasing social equity

4.3.1.1 Increasing workplace literacy

4.3.1.2 Improving access to training

4.3.2 Upskilling and reskilling existing staff (not made redundant)

4.3.3 Improving employee safety and satisfaction

4.3.3.1 Automation assuming repetitive or boring tasks

4.3.3.2 Documentation and instructions in employee's first language

4.3.3.3 Employee empowerment? (info at shopfloor level rather than with mngt)

4.3.4 Job creation

4.3.4.1 Jobs created due to manufacturing capacity improvements

4.3.4.2 Higher skilled, higher paid roles in the economy

5 Sustainability contribution negative

5.1 Economic

5.1.1 Costs

5.1.1.1 Acquisition/implementation

5.1.1.2 Maintenance

5.1.1.3 Uncertain ROI

5.2 Environmental

5.2.1 Increase in productivity leads to increased resource usage

5.2.2 Increase in productivity leads to increased waste generation

5.3 Social

5.3.1 Reduction in available manufacturing roles

5.3.2 Job losses

5.3.3 Reducing employee engagement (with each other and role)

6 NZ manufacturing characteristic (What makes NZ different/how it competes?)

6.1 Low volume/small scale

6.1.1 Not maximising manufacturing capacity

6.2 Niche products

6.3 Innovative "number 8 wire" mentality

7 What is Industry 4.0?

Appendix E: Final coding template

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Drivers			**15**	**269**
	Competitive pressures		**15**	**125**
		Improving production efficiency	15	78
		▪ Making better use of resources	11	24
		▪ High and consistent product quality	7	15
		Keeping up with competitors	9	11
		Improving and maintaining productivity	7	12
		Profitability & ROI	6	8
		Keeping manufacturing in New Zealand	3	6
		New business models	2	4
	Data capture and analysis		**14**	**34**
		Increasing process visibility	10	17
		Data-informed decision-making	7	12
	I4T awareness		**13**	**46**
	Stakeholder pressures		**8**	**40**
		Legal and regulatory	6	19
		▪ Employee health and safety	4	11
		External customers	5	15
		Internal customers	4	6
	Labour shortages		**8**	**19**
		Unattractive roles	4	13
		Business continuity	4	5

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Enablers			**15**	**162**
	Financial resources		**14**	**52**
		External funding and support	11	36
		▪ Government	8	28
		▪ Partnerships	1	3
		Falling cost of I4Ts	6	6
		Internal funding sources	3	5
	Access to skilled personnel		**12**	**45**
		Training and upskilling	6	12
		▪ Apprenticeships	3	5
		Experienced employees	4	12
		▪ Manufacturing-targeted immigration policies	3	3
		Partnerships	2	6
		Consultants	2	4
	ERP systems		**10**	**28**
	Change management		**8**	**21**
		Assessment of digital capability	4	6
		Leadership	4	5
		Strategic thinking	3	5

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Inhibitors			**15**	**194**
	High financial cost		**15**	**73**
		Uncertainty regarding ROI	8	14
		Lack of government support	6	13
		▪ Policy instability	4	9
		Extent of financial resources	6	12
		Automating dextrous tasks	3	4
		Lack of strategic approach	2	5
		Maintenance	1	3
	Lack of knowledge and skills		**13**	**53**
		Lack of knowledge of I4Ts	6	10
		Poor perception of manufacturing	6	8
		What is Industry 4.0?	5	7
		Lack of apprentices and graduate engineers	4	10
		Lack of experienced individuals	4	5
		Low English literacy levels	2	4
	Resistance to change		**11**	**27**
		Due to disruption	4	4
		Due to having to learn something new	4	4
		Due to potential job losses	2	3
		Due to lack of competition	1	3
		Due to machinery payback period	1	3
	Low production volumes		**10**	**21**
		Technology integration	6	11
		Regulatory burdens	2	6
		Lack of leadership	2	2
		Ignoring key stakeholders	1	1

Theme	Sub-theme	Codes	Frequency across interviews (*N*=15)	Number of references
Sustainability contribution			**15**	**167**
	Positive economic		**12**	**32**
		Efficiency and productivity	12	32
	Negative economic		**14**	**32**
		Acquisition and implementation costs	12	17
		Uncertain or long-tailed ROI	6	8
		Third-party dependency costs	4	6
		Equipment disposal costs	1	1
	Positive social		**12**	**41**
		Improving employee safety and satisfaction	10	22
		Upskilling and reskilling existing staff	5	7
		Job creation	5	6
		Improving access to training	3	6
	Negative social		**8**	**19**
		Job losses	7	14
		Reducing employee engagement	2	4
		Injury potential	1	1
	Positive environmental		**9**	**36**
		Reduced consumption	7	17
		Waste reduction	7	15
		Reduced CO_2 emissions	2	4
	Negative environmental		**3**	**7**
		Increased consumption	3	4
		Increased waste	3	3

Summary sustainability dimension coding	Frequency across interviews (*N*=15)	Number of references
Economic	15	64
Social	14	60
Environmental	10	43

Sustainability sentiment coding	Frequency across interviews (*N*=15)	Number of references
Positive	14	106
Negative	14	57

Appendix F: Framework matrix excerpt

	PARTICIPANT						
	M1	**M2**	**M3**	**GA1**	**M4**	**C1**	**M5**
High financial cost	A perception that it's more expensive than it is, than it needs to be the roadblocks here in New Zealand. One is a perceived high price. But it is a recurring theme that I hear that, again, coming up with $400,000, $500,000 is just insurmountable to some, all in one go	from what I've been told by a lot of industry experts and things, is that a lot of people go down this path and go, right, we're going to do a project, and we're going to look at it, but because of the costs involved, or you don't have someone driving it, it stops the first robot we put in was half a million dollars the robotics is cool. It's very expensive There's automation that we would love to bring in, but it's just cost prohibitive at the moment.	cost is obviously a big one	in relation, people aren't necessarily as expensive, if you know what I mean. So you could throw 10 people on a conveyor line and be quite agile, whereas buying a robot's quite expensive and you can't depreciate it as fast. So the business case sort of leans you towards the people, which makes you less productive.	Now, the problem is a lot of the research, they are just a small part of the business. So if you actually want to expand to the whole business or actually implement that, it will cost you a lot of money.	Perceived cost barrier and actual cost barrier People believe that some of these systems are really expensive So that's the perceived cost barrier for some technologies. And then, yeah, I guess an actual cost barrier for others, the ones that are naturally probably all, well, not always, but generally are capex intensive. So automation, purchasing a robotic arm, that kind of thing.	For businesses that are smaller, like what we were previously, I do see the cost being a real barrier Some of these smaller firms, especially ones with aging owners, you know, the owner's 60 years old, and he goes, “Geez, $250,000. I'm working on my retirement here. I'll just limp along for another five years and then sell the business.”

Appendix G: Ethics approval letter

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

14/01/2025

Dear: Vanessa Wood

Re: Low Risk Notification - 4000030064 - Exploring the drivers, challenges and impacts of Industry 4.0 technology implementation in New Zealand manufacturers

Thank you for submitting a low risk notification for your research/teaching/evaluation.

This email is to acknowledge receipt of the low risk notification and to inform you that the details of your project have been recorded in our database for inclusion in the annual reports to the Health Research Council Ethics Committee (HRCEC) and the Massey University Research Committee (URC).

You may proceed with your research, though it is advisable to provide a couple of weeks before commencing, as all low risk notifications are checked for completeness and clarity by a Research Ethics Advisor. You may be contacted if your application is incomplete and/or further clarification is required.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis.

If a sponsoring organisation, funding authority (e.g., the Health Research Council) or a journal require evidence of ethical approval from a Human Ethics Committee (with an approval number), you need to complete a full Massey University Human Ethics application to be reviewed and approved by one of our Human Ethics Committees. Applications must be submitted and approved prior to the commencement of the research.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro ViceChancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact the Research Ethics Office, email humanethics@massey.ac.nz. "

Please include the following statement on all public documents (e.g., information sheet, consent form) related to your project:

> ***This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.***
>
> ***If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.***

I wish you all the best in your research, teaching or evaluation activities and appreciate your thoughtful consideration of ethics principles and practices.

Ngā mihi nui,

Professor Tracy Riley

Acting Chair, Research Ethics Chair's Committee

Research Ethics Office, Research and Enterprise
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