Article

Implementing Industry 4.0 in Australia: Insights from Advanced Australian Manufacturers

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Abstract: This study explores Industry 4.0 in the Australian context, where manufacturing is dominated by smaller firms servicing the domestic market. We interviewed 20 advanced Australian manufacturers from diverse fields, capturing detailed descriptions of the Industry 4.0 implementation process. We compared the themes that emerged from their descriptions with the factors typically assessed in Industry 4.0 frameworks to draw out differences in emphasis. Consistent with these frameworks, Australian manufacturers were focused on using Industry 4.0 technologies to automate the capture, integration and analysis of data. To enable this activity, they were reorganising workforce roles and developing new skill sets. Knowledge sharing and collaborations within and across the organisation were seen to be especially important for small Australian manufacturers (with limited funding for technology investment and research and development) to maintain global competitiveness. However, while most Industry 4.0 frameworks describe supply chain applications, the development of smart products and services, and the need to adopt a strategy-led approach, relatively few participants spoke about these opportunities. Even fewer addressed the need for improved governance, standards and data security in the context of Industry 4.0. We argue that these gaps are best addressed through government policy and investment focusing beyond manufacturers, to support Industry 4.0 uplift across key domestic supply chains.

Keywords: Industry 4.0; digital manufacturing; Australian manufacturing; smart factory; advanced manufacturing; manufacturing innovation

1. Introduction

Significant global effort is being devoted to encouraging manufacturers to adopt Industry 4.0 technologies, as revealed by initiatives such as the "Industrial Internet Consortium" in the US, "China Manufacturing 2025" [1] and "Connected Industries" in Japan [2]. An international survey of Industry 4.0 researchers found that the top priority for academic research is driving and supporting practical implementation issues [3]. In this study, we capture detailed descriptions of the Industry 4.0 change process from 20 technologically advanced Australian manufacturers. We compare the themes that emerged from their descriptions with the factors typically assessed in Industry 4.0 frameworks to draw out differences in emphasis. We find that many of these differences can be understood as a response to the local economic context. The contribution of this study lies in:

- Capturing detailed descriptions of Industry 4.0 implementation from advanced Australian manufacturers;
- Identifying differences between their approaches and those described in Industry 4.0 frameworks;
- Using these differences to derive tailored recommendations for Australian government policy and broader Industry 4.0 educational initiatives.

1.1. What Is Industry 4.0?

Industry 4.0 refers to recent technological advances where the Internet and supporting technologies (e.g., embedded systems) serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organisational boundaries to form a new kind of intelligent, networked and agile value chain [4,5].

Research suggests that the integration enabled by Industry 4.0 delivers multiple benefits to manufacturers [6,7]. First, it can enable more efficient resource utilisation, through combining production with smart grids for energy savings (e.g., [8,9]). Second, Industry 4.0 supports horizontal integration that allows companies to grow their market share. It facilitates collaborative networks among enterprises so that they can combine resources, divide risks and quickly adapt to changes in the market [10]. Third, Industry 4.0 supports value creation because digital channels and smart products improve connections between the firm and its customers [11,12] enabling manufacturers to sell new services [13] and co-design products with customers [14]. Together, these capabilities enable new business models and new ways of delivering and capturing value from customers [7,15].

Because of the comprehensiveness of its impact, Industry 4.0 involves organisational and social challenges as well as technical challenges [16]. These include updating organisational business strategy to take advantage of Industry 4.0 opportunities, rethinking how the organisation operates [10], ensuring that workers have the skills required for Industry 4.0 [17], and improving governance arrangements to ensure that data sharing is achieved safely and ethically [16,18,19].

To date, adoption of Industry 4.0 has been slow. In Germany, where the concept of Industry 4.0 originated, only 4% of German manufacturers who are actively engaged with Industry 4.0 projects have achieved stage 1 maturity according to the Acatech Industry 4.0 Maturity Index [18]. A study of Indian manufacturers found that the majority of those interviewed and surveyed were aware of Industry 4.0 but did not know what the topic covered, nor had they considered its implementation [20]. One reason for the slow rate of adoption is likely to be the range of implementation actions that are required in order to achieve the benefits of Industry 4.0 [16]. The Indian study found that while the cost of technology was one barrier to the adoption of Industry 4.0, the lack of a framework and digital strategy to support adoption were also major factors impeding the uptake of Industry 4.0 [20]. Thus, capturing insights from more advanced manufacturers regarding the Industry 4.0 adoption process is critical. Furthermore, because the adoption of Industry 4.0 varies according to firm and contextual factors, an understanding of Industry 4.0 needs to be captured at both a local and a global level.

1.2. Learnings from Industry 4.0 Frameworks

Significant research effort has already been directed towards identifying the key factors and tasks that need to be managed in order to derive benefit from Industry 4.0 technologies [21]. Industry 4.0 maturity and readiness frameworks (e.g., [4,5,16,19,22,23]) provide a high-level view of key tasks and stages of Industry 4.0 adoption. To exploit the potential benefits of Industry 4.0 technologies, firms need to ensure that enabling conditions are in place. As Horvat, Stahlecker, Zenker, Lerch and Mladineo [24] illustrate, national factors such as the availability of infrastructure, the skill level of the workforce and critical mass contribute to these conditions and thereby affect the way in which Industry 4.0 is implemented, including the role of other actors (such as government) in this process. It is therefore important to investigate how the implementation of Industry 4.0 is being approached within a wide range of economies.

Our goal in this study was to capture advanced Australian manufacturers' insights into the Industry 4.0 implementation process and examine how well they aligned with existing Industry 4.0 frameworks that were informed by research carried out in larger manufacturing economies. We did not attempt to carry out a systematic review of Industry 4.0 frameworks, but an analysis of eight of the more widely adopted frameworks (see Table 1) reveals six attributes that are commonly identified as part of the Industry 4.0

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transformation process. Based on the way in which these attributes are described in the frameworks, we define them as follows:

Strategy and leadership: The adoption of Industry 4.0 and investment in Industry 4.0 initiatives is informed by a strategy detailing how the organisation will realise value from Industry 4.0. Senior leaders are committed to Industry 4.0, diverting resources to support initiatives and providing central co-ordination for Industry 4.0 initiatives.

Organisational culture and structure: The organisational culture reflects a focus on continuous learning, innovation and knowledge sharing. The organisational structure is flat, supporting decentralised decision-making and flexible structures and processes.

Digital integration: Integrated data, modelling and technology connects functions both within the organisation and across the supply chain in near to real time.

Governance, safety and security: Actions to protect data quality, worker safety, cyber-security and intellectual property are implemented. Relevant Industry 4.0 standards are adopted.

Workforce: The organisation invests in building Industry 4.0 skills within the workforce. Work roles are redefined to reduce repetitive tasks and enable people to work more autonomously and collaboratively.

Smart products and services: Products are customised and technology embedded within products creates service-based business models for products.

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Table 1. Attributes represented in Industry 4.0 frameworks.

Source of the Framework	Attributes Represented					
	Strategy and Leadership	**Organisational Culture and Structure**	**Digital Integration**	**Governance, Safety and Security**	**Workforce**	**Smart Products and Services**
Lichtblau et al. [4]	Strategy and Organisation		Smart factory Smart operations			Smart products Data driven services
Pirola, Cimini and Pinto [25]	Strategy		Processes Technology Integration		People	
Singapore Smart Industry Readiness Index [22]		Structure and management	Processes (operations, supply chain, product lifecycle) Technology (automation, connectivity, intelligence)		Talent Readiness	
Veile, Kiel, Muller and Voigt [16]	Financial feasibility	Corporate culture and communication Company organisation	Preparing the implementation of Industry 4.0 solutions Handling and integrating Industry 4.0 solutions	Safety and security	Personnel	
Sony and Naik [5]	Readiness of organisational strategy Top management involvement and commitment		Level of digitisation of the organisation Extent of digitisation of supply chain	IT system security and cloud-based data management to product data (a component of digitisation of supply chain)	Employee adaptability with Industry 4.0	Smart product and services
Schumacher, Erol and Sihn [19]	Strategy Leadership	Culture	Operations Customers Technology	Governance	People	Products

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Table 1. *Cont*.

	Attributes Represented					
Source of the Framework	Strategy and Leadership	Organisational Culture and Structure	Digital Integration	Governance, Safety and Security	Workforce	Smart Products and Services
Santos and Martinho [23]	Organisational strategy	Organisational structure and culture	Smart factories Smart processes		Workforce	Smart products and services
Schuh, Anderl, Dumitrescu, Kruger, Hompel [18]		Organic internal organisation Dynamic collaboration within the value network Willingness to change Social collaboration	Self-learning information processing Information system integration Structured communication		Digital capability	

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The implementation of Industry 4.0 represents a form of open innovation in that innovation within the firm is driven by external factors (the emergence of new technologies) [26]. Furthermore, the implementation of Industry 4.0 is affected by local factors such as the economic environment, market environments, cultural backgrounds and overall conditions [16]. Although Industry 4.0 frameworks are intended to provide general guidance, the concept was initially developed in Germany, and most of the research to date has been carried out in countries with larger and more diverse manufacturing companies. Australian manufacturing has traditionally been constrained by its small domestic market and geographic distance from larger markets [27]. Australia's manufacturing sector is highly concentrated in the processing of natural resources (e.g., food and beverages, basic metals and fabricated metal products)—sectors where localisation creates a competitive advantage [28]. It is also dominated by small to medium-size enterprises [28] and plays a relatively minor role in global production sharing [29]. All these factors, lack of diversity, domestic focus and the dominance of small to medium enterprises will influence the way in which Australia experiences Industry 4.0. However, given the low level of uptake of Industry 4.0 in Australia to date, differences between the factors identified in Industry 4.0 frameworks and Australian manufacturers' conceptualisation of Industry 4.0 may also reveal knowledge gaps where information and awareness-raising is needed to support the successful adoption of Industry 4.0.

Thus, our goal in this study was two-fold. First, we sought to capture the knowledge and experience of advanced manufacturers regarding the changes involved in adopting Industry 4.0 within the Australian context. From this, we sought to identify practical strategies that could be used to support Australian manufacturers to derive greater benefit from Industry 4.0 technologies.

2. Materials and Methods

To capture manufacturers' insights into the changes required to adopt Industry 4.0, we carried out in-depth, semi-structured interviews with 20 Industry 4.0 experts within advanced Australian manufacturing organisations (including three researchers/consultants who work on Industry 4.0 projects with advanced Australian manufacturers). This sample size compares favourably with other qualitative research studies investigating Industry 4.0 adoption [16,25]. The use of qualitative, semi-structured interviews meant that we could flexibly explore participants' conceptualisation of the changes involved in successfully adopting Industry 4.0 [30]. The benefit of this flexible approach was that it allowed us to capture the experience and knowledge of real-world experts in their own words and discover what factors they gave greatest emphasis to.

2.1. Participants

Our goal was to capture insight from highly advanced manufacturers from each of the major fields of manufacturing in Australia. Focusing on the nine largest manufacturing sub-divisions (by employment) in Australia and working with key government and peak bodies for Australian manufacturing (the Australian Department of Industry, Science, Energy and Resources, Swinburne University Factory of the Future, Australian Industry Group and the Advanced Manufacturing Growth Centre), we developed a list of 107 highly advanced Australian manufacturers (including international manufacturing companies with operations in Australia). From this list a target sample of 50 manufacturers was chosen, designed to provide balanced representation across manufacturing sub-divisions and a mix of small and large manufacturers operating across urban and regional locations in Australia (see Tables 2 and 3). Of the 50 manufacturers that we contacted, 40% agreed to participate. Most of the interview participants were employed as either a general manager, managing director or CEO. In some cases, the original contact for the manufacturer asked to involve other representatives of the organisation in the interview so the interviews provided input from 23 individuals from 20 manufacturing (or manufacturing-service

provider) organisations. Although there is a high proportion of small manufacturers in Australia, the sample had a relatively large number of medium and large manufacturers (13 of the 20 manufacturers came from organisations with more than 200 employees). The relatively high proportion of large manufacturers in our sample reflects the fact that larger manufacturers tend to be more technologically advanced.

Table 2. Representation across manufacturing subdivisions.

Manufacturing Subdivision	Number of Manufacturing Firms Represented
Fabricated Metal Product Manufacturing	2
Food Product Manufacturing	2
Furniture and Other Manufacturing	2
Machinery and Equipment Manufacturing	2
Polymer Product and Rubber Manufacturing	2
Primary Metal and Metal Product Manufacturing	2
Transport Equipment Manufacturing	2
Pulp, Paper and Converted Paper Product Manufacturing	1
Wood Product Manufacturing	1
Manufacturing Service Providers (researchers, consultants)	4

Table 3. Representation across Australian States and Territories.

State or Territory	Number of Manufacturing Firms Represented
VIC	6
QLD	5
International	3
WA	3
NSW	2
SA	1

2.2. Interview Process

All interviews were carried out by one of the three authors of this paper, either by telephone or videoconference. Each interview commenced by checking for informed consent, capturing background information from participants and then sharing a definition of Industry 4.0. We used a definition that was developed by the Australian government agency who provided funding to support the research and are responsible for administering Australia's "Manufacturing Modernisation Fund":

> *The Department of Industry, Science, Energy and Resources (DISER) describes Industry 4.0 as the use of automation and connectivity in manufacturing. This includes linking technologies such as robotics and sensors with data and analysis tools, to support a business in creating value in its productivity (by understanding or optimising operations and supply chains in a real-time, automated or agile manner) and product and service offerings (by informing the strategic direction or choices of the business, including the evaluation of new business models and strategies).*

After providing this definition and checking that participants were comfortable with it (all said that they were), the interview then focused on the following key questions:

- What changes would we be likely to see within a manufacturing firm as a result of adopting Industry 4.0?

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- What attributes would indicate that a manufacturer is more (or less) advanced in their use of Industry 4.0 technologies?

These two questions were posed to participants in all of the interviews, with follow-up questions used to explore the topics that emerged from participants' initial responses and capture more detailed descriptions of the changes and attributes associated with implementation of Industry 4.0. Adopting this semi-structured approach allowed the focus of the interviews to vary according to the way in which each participant thought about the Industry 4.0 implementation process.

A third question was posed at the end of the interview (asking what metrics might be used to monitor adoption of Industry 4.0). This question was designed to inform a specific departmental initiative and respondents' answers to this question were not analysed for the current study. Interviews took between 20 and 60 min to complete but most interviews lasted for at least 45 min. With the permission of the research participants, the interviews were recorded and transcribed.

2.3. Data Analysis

The interview transcripts were analysed using a constant comparison analysis method [31]. This inductive approach was used to ensure that we captured emergent constructs introduced by respondents rather than restricting our analysis to predefined attributes. First, each interview was coded by the researcher who conducted the interview. As the researcher read through the transcripts, the text was broken into smaller, meaningful chunks that were labelled with codes. During this phase of the analysis, the researchers met regularly to compare notes about the codes that they were using and the themes that they were observing. After this first round of coding, the first author reread all of the transcripts and codes to identify higher-order themes in the data. This process ensured that all codes grouped under the same theme reflected the same constructs and themes were labelled appropriately.
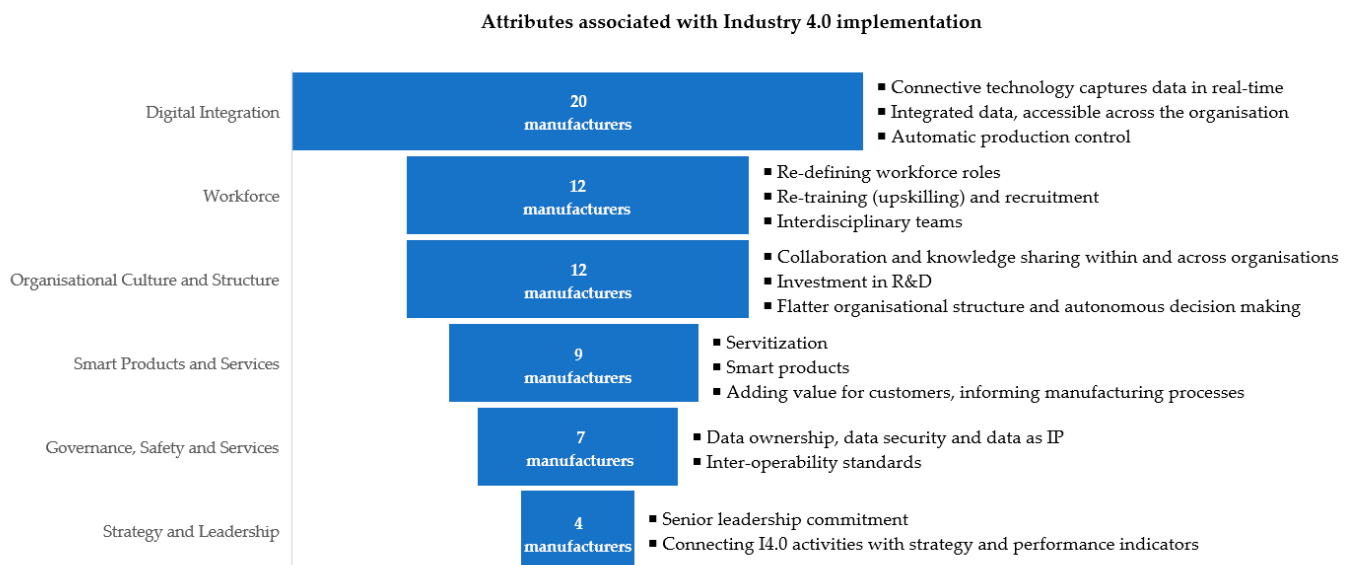
The third stage of our analysis involved contrasting these themes with the attributes derived from our review of Industry 4.0 frameworks. In this analysis, the researchers examined the alignment between the themes that emerged from deductive coding of the interviews and the descriptions of these attributes in the eight Industry 4.0 frameworks listed in Table 1. We used this analysis to identify commonalities and differences between Australian manufacturers' description of Industry 4.0 implementation and the attributes derived from the Industry 4.0 frameworks.

To convey which themes were most commonly mentioned in manufacturers' descriptions of the Industry 4.0 change process, we report the number of times each theme was mentioned. Although there were multiple participants in some of these interviews, responses were aggregated to provide a firm-level count. We adopted this approach so as not to give greater emphasis to the data captured from firms where multiple individuals took part in the interviews.

3. Results

Figure 1 illustrates how many manufacturers spoke about each of the Industry 4.0 attributes derived from existing frameworks. All the manufacturers that we interviewed understood that digital integration was a core component of Industry 4.0 transformation but some other attributes (the introduction of smart products and services, the need to develop governance, safety and security arrangements and the role of strategy and leadership in guiding the transformation) were not even mentioned by most of the manufacturers that we interviewed.

Attributes associated with Industry 4.0 implementation

Digital Integration — 20 manufacturers
- Connective technology captures data in real-time
- Integrated data, accessible across the organisation
- Automatic production control

Workforce — 12 manufacturers
- Re-defining workforce roles
- Re-training (upskilling) and recruitment
- Interdisciplinary teams

Organisational Culture and Structure — 12 manufacturers
- Collaboration and knowledge sharing within and across organisations
- Investment in R&D
- Flatter organisational structure and autonomous decision making

Smart Products and Services — 9 manufacturers
- Servitization
- Smart products
- Adding value for customers, informing manufacturing processes

Governance, Safety and Services — 7 manufacturers
- Data ownership, data security and data as IP
- Inter-operability standards

Strategy and Leadership — 4 manufacturers
- Senior leadership commitment
- Connecting I4.0 activities with strategy and performance indicators

Figure 1. Manufacturers' descriptions of Industry 4.0 attributes.

Below, we review each theme, providing quotes from the interviews to illustrate the way in which manufacturers described each of these elements of the Industry 4.0 implementation process. We compare their descriptions with those from the Industry 4.0 frameworks.

3.1. Digital Integration

Digital integration (the label we use to encompass elements from existing frameworks such as "smart factories", "smart operations", "vertical integration" and "horizontal integration") is one of the key elements of Industry 4.0 frameworks and it was also the dominant theme in the interviews. Participants' descriptions of the changes involved in implementing Industry 4.0 centred around automating the capture, integration and analysis of data within the factory. For most manufacturers, this data capture and analysis was focused on activity occurring within the factory and it was used to allocate resources more efficiently. While the specific technologies used by manufacturers would vary, all Industry 4.0 manufacturers would be working towards achieving automated, real-time data capture across all processes and functions, making it accessible across the organisation.

> *. . . you've got feeding of information from each of the different segments, so instantly you can say, well, what are you currently reporting on and how real-time is that information . . . that tells me how well integrated the Industry 4.0 is . . . .* [12]

At more advanced stages of Industry 4.0 adoption, the data captured is used for automatic production control, to enable optimisation of resources and predictive maintenance. This is the "intelligence" component of Industry 4.0 [22]. Six of the Australian manufacturers were using (or envisaged using) Industry 4.0 for automatic production control.

> *. . . we have a lot of sensors. Basically, all our controls are automated through PLCs, our first layer of data, and we access that via human interfaces . . . it's bringing all that data together into something meaningful and something that the operators can understand so they can see what's going on and see what decisions the computer is making and they can step in if they need to. But most of the time they can leave it on automatic.* [16]

While digital integration is enabled by technology, manufacturers reported that the use of technology would, and should, vary since the types of technologies that would add value depend on a manufacturer's business model and manufacturing processes. Nevertheless, the assumption was that a manufacturer adopting Industry 4.0 would be using some combination of Industry 4.0 technologies. Table 4 lists the technologies that

manufacturers mentioned and the frequency with which each was mentioned across the interviews. Robotics, modernised software, sensors and additive manufacturing were most commonly associated with Industry 4.0 adoption, whereas only one manufacturer spoke about simulations and digital twins.

Table 4. Industry 4.0 technologies mentioned by Australian manufacturers.

Technology Terms	Number of Manufacturers
Robotics	9
Modernised software (for enterprise resource planning, product lifecycle management, collaboration design and manufacturing)	6
Sensors	5
Additive manufacturing/3D printing	5
Augmented reality/Virtual reality	4
Artificial intelligence	4
Cloud computing	3
Simulations	1
Digital twin	1

Digital integration also involves sharing the real-time data generated by Industry 4.0 technologies across the supply chain to support better production planning, transport management, risk management and ultimately, optimisation of costs, time and resources [4,5]. Yet only 13 of the 20 manufacturers explicitly described Industry 4.0 in terms of connecting data across the supply chain, and these applications of Industry 4.0 were mentioned briefly and primarily in the context of global supply chains.

> . . . *if I've got more connectivity in my supply chain then I can more readily have my finger on the pulse, and can be getting early warning of problems that need to be managed and addressed through that level of connectivity . . . I'm getting data that's analysed off a machine, or out of a supply chain that tells me that they're on or off track, I've got a quality problem or I don't, then I'm more able to manage that compressed timeframe that I've actually got left*. [11]

3.2. Workforce

Industry 4.0 frameworks that we reviewed [5,16,18,19,22,25] identify workforce management (especially reskilling and upskilling) as a key activity required to derive benefit from Industry 4.0. Relevant workforce management activities range from redefining roles (based on changes to work processes enabled by Industry 4.0 technologies) [16], promoting learning as a continuous process [22,25], providing Industry 4.0 training and learning opportunities [16,18,25] and creating a more multi-skilled and interdisciplinary workforce [16,18,22]. Schuh et al. [18] also focus on the importance of employees being aware of the importance of IT security, particularly the value of data as intellectual property, possible data leaks and the reasons for them.

Twelve of our participants spoke about the need for redefinition of workforce roles and development of new skill sets to support successful adoption of Industry 4.0. Adopting Industry 4.0 reduced the need for production workers who could perform manual or routine tasks, since these tasks would be automated. Consequently, they were investing in retraining their existing workers and/or recruiting new workers. Some manufacturers believed it was desirable to hire new, younger workers. They emphasised the need for workers who were oriented towards continuous improvement rather than maintaining existing ways of doing things.

I'll be looking for young mechatronics engineers, people who are also not constrained in their thinking by 30 years of work experience and this is the way we do it. [11]

Other manufacturers (*n* = 9) were focusing on building specific skills or combinations of skills. The types of skills that manufacturers mentioned they were seeking to build within their organisation were mechatronics, computer science, automation systems, data analysis, electrical engineering and industrial engineering.

. . . less production and more systems analysis and instrumentation people . . . you need those industry instrumentation technicians to maintain and keep the plant running. [12]

Alongside upskilling and reskilling the workforce, three manufacturers reported that the nature of roles and teams in their organisation were changing. The implementation of Industry 4.0 was resulting in traditional boundaries (e.g., between office and factory floor workers) eroding, with roles becoming more integrated and teams becoming more interdisciplinary.

. . . they're working digitally then they're outside on the floor monitoring the robot. So, it's actually blurring the lines . . . they seem to have this cross-disciplinary skill set where part of what they do is working with robots and . . . Industry 4.0 technology and part of what they do is design. [14]

3.3. Organisational Culture and Structure

Many of the Industry 4.0 frameworks also identify changes to organisational culture and structure as a necessary component of Industry 4.0 adoption. For example, a culture of autonomy and flexibility is required if workers are to be able to participate in the creation of the new solutions that Industry 4.0 enables [23]. In the study by Veile et al. [16], German manufacturers described this change as requiring a systematic change approach, led by management towards more open information exchange, entrepreneurial spirit, failure tolerance and a creative environment. They also described intra- and inter-firm changes to the organisation of the company, directed towards more flexibility and agility within the organisation. This included implementing different types of cooperation and more horizontal and vertical connection of the value chain.

The Australian manufacturers that we interviewed also reported that Industry 4.0 required innovation and culture change, although only three of them spoke about making changes to organisational structure. Participants variously described the culture required to support Industry 4.0 as future-oriented, growth-oriented, accountable, empowered and innovative. As in the German study [16], there was a focus on knowledge sharing and collaboration both within the organisation and with other companies. A collaborative culture was seen to be particularly important in the Australian economy because Industry 4.0 requires significant investment and Australian manufacturing is dominated by small and medium-sized enterprises (SMEs).

There are so many SMEs in Australia that to be globally competitive we kind of have to team together and share knowledge and skills, and so I think that's a big part of what we are trying to do is tap into ways that we can discover and understand this new knowledge as a kind of collaborative team. [14]

Consequently, manufacturers who were adopting Industry 4.0 were seeking to collaborate and share learnings with other organisations that were engaging with Industry 4.0.

. . . that's critical . . . to be connected with other people who have (a) similar level of implementation, or at least the same stage of implementation of (the) Industry 4.0 concept. [19]

Several manufacturers (*n* = 6) reported that firms were investing in research and development and collaborations with universities as part of their Industry 4.0 adoption process.

> ... *a significant commitment to R&D development including in-house test facilities* ... *to be able to develop cutting-edge stuff you have to be able to solve the problems that nobody's solved before, which means that you have to take your engineering hypothesis and turn it into a product that meets industry standards.* [7]

Three manufacturers added that adoption of Industry 4.0 should also lead to a flatter organisational structure as a result of workers being enabled (through access to joined-up data and decision support systems) to make decisions more autonomously.

3.4. Smart Products and Services

The adoption of Industry 4.0 is both enabled by and directed towards the creation of smart products and services. These aspects of Industry 4.0 adoption were mentioned by nine manufacturers (approximately half of the sample). Six spoke about creating service delivery opportunities through the adoption of Industry 4.0 and six spoke about shifting to smart products.

Smart products have add-on functionalities (e.g., product memory, self-reporting, integration, localisation, assistance systems, monitoring) as a result of embedding technologies in the product [23]. These functionalities not only inform decisions during the manufacturing process but enable manufacturers to deliver new services and collect usage data that can inform sales support, maintenance and product development decisions.

> ... *that change in the product offering is probably also a big factor that a lot of people don't really focus on, on what can I do differently with my product now that I have connectivity available, now that I have data available, what can that mean in terms of my offering, whether it's going from product to service or adding service or using data from products in the field to feedback into what I'm actually producing.* [17]

However, smart products do not just represent an opportunity to value add with the product. They create the opportunity to deliver new value to customers through servitisation [5]. Four stages of servitisation have been identified in the literature [32], beginning with traditional services such as installation and repair. At the second stage, Industry 4.0 solutions are used to lift these traditional service offerings, for example, by creating products that communicate proactively to avoid breakdowns. The third stage of servitisation involves offering novel services enabled by ICT, such as remote monitoring and supervision services that optimise the operation and function of the core product. At the most advanced stage, a condition-monitoring system is integrated into the machine as a digital supporting component. The Australian manufacturers who were thinking about servitisation offered examples that corresponded with the second and third stages.

> ... *the good brands will have this module available that you can get the most out of the system and get the benefits that they promise when they sell the equipment* ... *As soon as you're selling a solar system, you'll now start to sell it with, "we will manage it and we will help you to get the best out of the system and we'll tell you when to clean it, or we'll organise the people who come and clean it".* [16]

> *I think it's product liftings or references to analytics as a service, or insights from data as part of the product that this manufacturer is selling. So, if someone is a pump manufacturer, they're not just making a pump, you're now seeing that they are offering pump analytics or they have a portal where you can leave it and compare performance(s) of the family of pumps.* [9]

3.5. Governance, Safety and Security

Governance, safety and security are also commonly identified within Industry 4.0 frameworks. Because Industry 4.0 brings about an increase in connectivity and data sharing, data storage, data governance and the protection of data interfaces are critical [16,18,19]. Integration of information systems increases the risk of cyberattacks.

Only two of our participants mentioned data security or cyber-physical security architectures as a differentiator of companies that were adopting Industry 4.0. One of these participants explained the need to give greater focus to data sharing and IP as follows.

(security and privacy) . . . I think that's fundamentally now the cornerstone of everything we think about . . . besides obviously privacy and laws and acts around data regulation et cetera. I think more and more . . . Data is our IP rather than something physical we may have had in the plant . . . you can't just think about serving a process, you've got to think about in a secure way, and you've got to think about protecting your IP, and it's no longer okay just to trust, I think, it's a zero-trust approach. [23]

Engaging with Industry 4.0 also requires greater focus on protection of IP and data [19]. The issue of maintaining data ownership was raised by one participant.

. . . data sovereignty, I think is a big one as well. So, a lot of people are offering products— where the cloud-based data . . . you never actually own your own data. So, you've got to—maybe you pay a monthly subscription to access your own data, but then it's very hard then to grab that data and do something else with it when you plug in the next module as well. [8]

Governance of Industry 4.0 should also consider the suitability of technological standards [18,19]. Very few of the manufacturers in our study were aware of Industry 4.0 standards. Only one participant (a consultant) mentioned engagement with technology standards as an important aspect of Industry 4.0.

. . . if you want to achieve the operating model of Industry 4.0 and all the benefits of Industry 4.0, it is not possible to do without interoperability standards . . . what's happening in manufacturing is . . . you basically buy the whole system from one vendor and that means you get their scheduling software, you get their enterprise management software, you get their tracking, you get their quality, all that stuff, all in one package . . . But if you can't integrate those systems and just have the modular components to integrating by using these standards and be able to rapidly change them out when the new thing comes along, you're never going to get the benefit of what Industry 4.0's striving to do . . . That's a huge, massive benefit of Industry 4.0 and interoperability, being able to rapidly change our technologies, when something better or most cost-effective comes along. [18]

3.6. Strategy and Leadership

Most Industry 4.0 frameworks emphasise the importance of having a strategy-driven approach to the adoption of Industry 4.0. Early adoption may involve investing in pilot studies or small-scale Industry 4.0 initiatives but the decision to invest in Industry 4.0 should be based on a well-developed strategy, with performance indicators that reflect the strategic goals that the organisation wishes to achieve from the investment [4,16,22,25]. These frameworks also note the need for high-level leadership support and dedicated revenue and resourcing to support the transformation process [19,25].

Only four manufacturers spoke about the need to connect Industry 4.0 activities with the organisation's strategy and performance indicators. One said:

Leadership . . . can actually provide indicators . . . around how successful a business will be in terms of adopting Industry 4.0 . . . does the business have an articulated strategy, is that strategy well understood by everybody in the business? . . . What's driving the strategy, is the strategy mainly focused on operations . . . or is it actually focused on future growth? . . . Does it articulate how digitalisation would assist the business to achieve the

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next set of outcomes it wants to achieve? Does the strategy contain articulation of skills that are required to do that . . . do they measure the outcomes of these initiatives? [5]

However, this participant's understanding of the requirement to connect Industry 4.0 initiatives with organisational strategy was unusual. It seemed that most of these advanced Australian manufacturers were currently adopting an exploratory approach rather than a strategically directed approach to the adoption of Industry 4.0. Across the twenty interviews, only one participant spoke about having a formal Industry 4.0 strategy and roadmap to direct and guide the Industry 4.0 transformation process. Three manufacturers noted that senior leadership commitment to Industry 4.0, reflected in the dedication of effort resources to enable the transformation, was also necessary for success.

Industry 4.0 is not just a single person within the organisation . . . it needs to be really driven as a sort of whole of organisation approach, at least from a vision and a view as to how you're going to achieve it. If you have one person sitting in the corner trying to roll out Industry 4.0, then that's really not going to succeed from our experience . . . whether it's getting driven by, and supported by, management is probably the biggest clue, and when I say management that's . . . upper level of management across all areas of the organisation. [21]

Thus, of all the Industry 4.0 attributes, manufacturers were least aware of the importance of strategy, performance indicators and leadership to drive, guide and enable Industry 4.0 adoption.

3.7. Additional Attributes

Since the study was designed to reveal unique aspects of the Australian experience with Industry 4.0 adoption, we also looked for themes from the interviews that were not represented in the Industry 4.0 frameworks. In line with the Industry 4.0 frameworks [18], many participants commented on the fact that the types of Industry 4.0 technology and smart products and services that manufacturers adopt will vary depending on their business model and business processes. This theme does not represent a new attribute of Industry 4.0 maturity, but it does reinforce the importance of each manufacturer having a strategy and measures of success to guide their Industry 4.0 decisions. Another theme that emerged in the interviews was a concern about the lack of technological maturity, scale and awareness of the majority of Australian manufacturers, which was seen as a major barrier to widespread adoption of Industry 4.0. Again, this theme reinforces the importance of attributes such as leadership support, workforce and organisational culture rather than representing a new attribute. We concluded that, while Australian manufacturers gave different emphasis to the set of attributes represented in Industry 4.0 frameworks, they did not identify any unique attributes associated with Industry 4.0 in the Australian context.

4. Discussion

This study was designed to reveal aspects of the Industry 4.0 transformation that were unique to the Australian manufacturing context. Our interviews with advanced Australian manufacturers revealed that most were focused on achieving digital integration, upskilling and reskilling the workforce, promoting a culture of innovation and collaboration, and developing smart products and services. However, they appeared to be giving little focus to strategy and leadership to support and guide the Industry 4.0 implementation process. In addition, they did not appear to be focusing on the need for improved governance and security controls to support the data integration and sharing that is integral to Industry 4.0. They also appeared to be primarily focused on applying Industry 4.0 to improve processes and decision making within the factory and far less on supply chain applications of Industry 4.0.

A key differentiator for Australian manufacturing is scale and distance [29]. The small scale and domestic focus of most Australian manufacturers may have contributed to the fact that advanced Australian manufacturers are focusing on vertical integration

rather than horizontal integration. In this respect, our findings align with research carried out with smaller-scale Italian manufacturers who were most advanced in terms of the digitisation of internal process and data collection, sharing and management inside the company [25]. Another factor that may be influencing the implementation of Industry 4.0 in Australia is lack of digital maturity. Our manufacturers were chosen because they were technologically advanced, so it is quite likely that the other actors in their supply chains are not yet digitally mature enough to engage with Industry 4.0. According to the 2021 IMD World Competitiveness report [33], Australia's digital competitiveness has been declining in recent years, with Australia ranked 20 out of the 64 countries they assessed. When only some of the actors in the supply chain are digitally integrated, benefits such as improved production planning, smart logistics and supply chain management will only be partially realised [4]. Well-resourced and dominant players in the supply chain may be able to influence and support other actors to engage with Industry 4.0 but in the Australian context, where there are relatively few large players, this leadership to enable Industry 4.0 adoption across the supply chain may be lacking. This leadership gap increases the need for policy, investment and education to support broader adoption of Industry 4.0, not just by manufacturers but by all actors within the manufacturing supply chain.

Another under-represented aspect of Industry 4.0 transformation was the attribute that we labelled governance, safety and security. Only a few manufacturers were thinking about the new governance requirements (e.g., interoperability standards, cybersafety and data as intellectual property) that are necessary to ensure that potential negative impacts of data sharing and new technologies are managed. While manufacturers understood that data and connectivity are central to Industry 4.0, they did not appear to be aware of the importance of standards as an enabler of interoperability and flexibility. Similarly, only two manufacturers spoke about the need to focus on cybersecurity when implementing Industry 4.0. Yet security issues and incompatibilities related to IoT standards and interfaces are recognised as key challenges in the successful adoption of Industry 4.0 [34,35]. As well as reducing dependency on a particular machine, tool or software, these systems enable agile information flow and data exchange transition between different information systems, while also supporting IT security by providing proactive measures to maintain security and adapt in response to changing circumstances [18]. Furthermore, addressing security and interoperability requires coordination at sector and industry levels, as well as investment in hardware, factory and network security [34–36]. Consequently, government and advisors need to provide greater support for investment, collaboration and knowledge-sharing to support adoption of standards and improved cybersecurity across the manufacturing supply chain.

The other need that this research reveals is strategy and leadership to guide and support implementation of Industry 4.0. Only four of our manufacturers spoke about the need for strategy to guide Industry 4.0 transformation. In contrast, 50% of manufacturers in the Italian study of Pirola et al. [25] had an Industry 4.0 strategy in place. Sony and Naik [5] identify strategy as one of the most important determinants of an organisation's readiness for Industry 4.0 because Industry 4.0 has such comprehensive impacts. Industry 4.0 creates the opportunity to redefine the company's product/service offering and its relationship with customers [25]. While pilot studies focused on pain points within the existing manufacturing process can be a useful entry point for Industry 4.0 transformation, there is a danger in focusing too much on improving existing processes when the real opportunity lies in transforming the system. Australian manufacturers are not alone in this regard. The latest McKinsey digital manufacturing global expert survey found that most manufacturers' Industry 4.0 initiatives are focused on pilot studies that target incremental improvements rather than driving their adoption of Industry 4.0 strategically [37]. Our findings suggest that manufacturers should be better informed about the importance of having a strategy to guide their Industry 4.0 transformation.

One factor that Australian manufacturers emphasised in their description of Industry 4.0 adoption (which received less attention in the Industry 4.0 frameworks that we reviewed)

was the importance of engaging in collaboration and knowledge sharing with universities and other manufacturers involved in Industry 4.0 initiatives. The need to collaborate was explained in terms of the relatively small size of most Australian manufacturers, meaning that they could not support dedicated research and development functions. Instead, Australian manufacturers aimed to benefit from sharing experience and learnings with other advanced manufacturers, either informally or through established networks and forums. This finding is useful in that it suggests that networks and forums to facilitate this knowledge sharing and collaboration are likely to be especially valuable in countries such as Australia where small to medium manufacturers are prevalent. It suggests that those Australian manufacturers who are embracing Industry 4.0 are doing so in an open innovation mode, seeking to benefit from external ideas and collaborations rather than relying on internal expertise and ideas [26]. Furthermore, Industry 4.0 promotes open innovation because supply chain applications of Industry 4.0 technologies require the sharing of knowledge, resources and innovations with partners [38].

We did not sample randomly from the population of Australian manufacturers and our findings are not meant to be representative of the whole sector. Rather, they provide a window into the thinking and experiences of Australian manufacturers who have already engaged with Industry 4.0. It is likely that levels of knowledge and engagement with Industry 4.0 are far lower in the broader population of Australian manufacturers. We also acknowledge that if we had adopted a different approach (e.g., specifically asking them about each attribute from the Industry 4.0 frameworks) participants might have demonstrated greater knowledge of these attributes than was captured from these interviews. Nevertheless, we believe it is valuable to gain insight into manufacturers' naturalistic conceptualisations of Industry 4.0 transformation since these are likely to reflect their real-world decisions and behaviours. Survey measures that allow manufacturers to self-rate their Industry 4.0 maturity or readiness prompt respondents about relevant Industry 4.0 activities. Asking manufacturers to describe how they were approaching the implementation of Industry 4.0 provides better insight into their priorities and knowledge. It therefore provides useful guidance for policymakers and advisors regarding aspects of the Industry 4.0 transformation process that require greater focus in information and education initiatives.

Managerial Insights and Practical Implications

This study, exploring the experiences of early adopters of Industry 4.0 in Australia, offers crucial learnings for manufacturers, government and educators. We found that:

- Manufacturers were adopting an exploratory rather than a strategy-driven approach to implementing Industry 4.0.
- Australian manufacturers are focusing on implementing Industry 4.0 within the factory, rather than across the supply chain.
- Australian manufacturers do not seem to be focused on the governance arrangements and standards that are necessary to support interoperability and protect the greater range of data being collected, integrated and shared via Industry 4.0 technologies.
- Knowledge sharing and collaboration were seen to be critical enablers of Industry 4.0 transformation in the Australian context since they can mitigate the limitations of small scale and low involvement in global production networks.

These findings reveal multiple opportunities for strengthening Industry 4.0 adoption in Australia. First, participants appreciated the role that existing industry bodies played in supporting education and knowledge sharing but they wanted the government to do more to support this effort. They reported that the criteria for government co-investment in research and development collaborations with universities (e.g., the amount of funding required from the manufacturer, the requirement that projects should create new jobs, the ineligibility of software development projects) are too stringent in the context of Industry 4.0. They also suggested that the government could incentivise knowledge sharing by requiring manufacturers to participate in networks or knowledge sharing to access this funding.

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The other gaps that we identified in Australian manufacturers' approach to Industry 4.0 are likely to be interrelated. For example, established governance arrangements, standards and security controls are necessary to implement supply chain applications for Industry 4.0, which depend on all actors in the supply chain being able to share data in an ethical, efficient and secure manner. Thus, Industry 4.0 policy and interventions focused on improving knowledge-sharing, strategy, governance and security across manufacturing supply chains (rather than simply within manufacturing firms) could well have a compounding effect on the success of Industry 4.0 initiatives in Australia. Finally, there is a dearth of information to assist manufacturers in determining how best to combine the range of Industry 4.0 technology and capability within their specific operating environment. Without such information, it is difficult for manufacturers to adopt a strategy-led approach to Industry 4.0. Future research effort needs to be directed towards exploring the interrelationships between manufacturers' business models, the technologies that they are adopting and the types of outcomes that they achieve from these investments.

5. Conclusions

Industry 4.0 frameworks provide a useful lens for analysing how advanced Australian manufacturers are approaching Industry 4.0 implementation and where this effort can be strengthened. Even amongst advanced Australian manufacturers, the implementation of Industry 4.0 is being approached in an exploratory and limited manner. In the absence of very large domestic manufacturers with the scale and influence to drive the adoption of Industry 4.0 across the supply chain, the role of government in facilitating this effort is vital [24]. This government effort should exploit existing demand for collaboration and knowledge sharing by investing in research, education and networks, with particular focus on Industry 4.0 strategy, governance and supply chain applications. Importantly, these initiatives should not focus solely on manufacturers. Instead, it would be more effective to design Industry 4.0 policy and incentives to support Industry 4.0 adoption across key domestic supply chains.

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