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An investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia

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ABSTRACT

As supply chains recover from the impact of COVID-19, a sudden acceleration of interest in digitalization and automation is expected, as firms increasingly look towards digital technologies as sources of innovation in the wake of an extreme disruption. The purpose of this study is to utilize the experience of supply chain practitioners, to ascertain the current level of adoption of a number of key Industry 4.0 technologies, understand what preparatory measures are being taken by firms to ensure they are digitally-ready to utilise Industry 4.0 technologies, recognise how and where these technologies are likely impact supply chains, and investigate whether organisational size is a factor in technology adoption. This empirical study utilises primary data from a descriptive survey of supply chain practitioners working across a range of industry sectors and different stages in the supply chain. Whilst the findings from this research indicate that some Industry 4.0 technologies are still in the early stages of adoption, amongst Australian supply chain organisations, they clearly show which technologies are anticipated to have the greatest impact, what sectors that impact will most likely occur in, and which specific improvements they are expected to drive. Larger firms were found to be more digitally-ready than smaller firms, and a number of significant gaps were identified between expected impact and expected investment, meaning little spend is currently projected for certain technologies that are expected to have a significant impact.

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1. Introduction

Prior to the COVID-19 pandemic, a global survey of 1,116 supply chain professionals concluded that emerging digital technologies and innovations are ‘driving massive changes and improvements in supply chain’ (Deloitte, 2018, p. 3). They were predicted to completely disrupt our traditional ways of working, by creating a ‘smoothly running, self-regulating utility that optimally manages end-to-end work flows and requires very little human intervention’ (Lyall et al., 2018, p. 2). Supply chains are becoming increasingly sophisticated in the way they connect business partners, promote collaboration, diffuse innovation, enable data-driven decision making, and track movements in real time.

Digital technologies are one of the key components for driving operational and supply chain innovation (Arlbjørn et al., 2011), as platforms for generating and exchanging vast amounts of data, which catalyses improved value creation across all sectors (Kache and Seuring, 2017; LaValle et al., 2011). Supply chain managers need to be increasingly aware of the capabilities of new technologies, if they are to keep pace with the growing demands of today’s customers, who want everything cheaper, faster and more personalised (Deloitte, 2018; GSCI, 2017; Montgomery, 2018), and the disruption they cause can quickly leave behind those who don’t adapt their digital strategies accordingly (Waller and Fawcett, 2013). In an increasingly digital world, the extent to how ‘digitally ready’ an organisation is to benefit from the increasing capability of emerging digital technologies, the better outcomes they can expect in the long term (Cisco, 2018). This has never been more important than it is today, as supply chain firms recover from the COVID-19 global pandemic, and increasingly look towards digital technologies as a mechanism for improving long-term performance, agility and resilience (Kilpatrick, 2020; Papadopoulos et al., 2020).

Industry 4.0 (I4) is a term that has been widely adopted to describe what many consider to be the Fourth Industrial Revolution, the emergence of cyber physical systems to enable automated manufacturing in smart factories (Lasi et al., 2014; Lee et al., 2015), which is expected to have significant implications for future ‘investment, consumption, growth, employment, and trade’ (Piccarozzi et al., 2018, p. 2). The principle driver for I4 is the emergence of key technologies, including 3D Printing, Advanced Robotics, Artificial Intelligence (AI), Autonomous Vehicles (AVs), Big Data Analytics (BDA), Blockchain, Drones, the Internet of Things (IoT), and Aug-

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mented Reality (AR) (Fernández-Caramés and Fraga-Lamas, 2019; Lu, 2017; Rüßmann et al., 2015), and despite its origins in manufacturing, it has wider implications for supply chains, where the combination of these technologies, with increasing customer empowerment, has been described as a 'perfect storm of innovation' (Howells, 2018).

I4 is a topic which is currently attracting a great deal of attention from academic researchers, particularly in the field of manufacturing/engineering, but less has been written about the broader impact of these technologies, and how their data-driven nature contributes to the digitalization of modern supply chains. These technologies could play a valuable role in the future of supply chains, toward a smarter, better-connected, supply chain ecosystem (Schrauf and Berttram, 2016), and potential supply chain application areas for I4 technologies may include, logistics (Hofmann and Rüsch, 2017; Hopkins and Hawking, 2018), procurement (Glas and Kleemann, 2016; Hopkins and Sohal, 2019), warehousing (Lee et al., 2018), supply chain optimization (Tjahjono et al., 2017), customer relationship management (Saucedo-Martínez et al., 2018), and supply chain sustainability (Manavalan and Jayakrishna, 2019).

Australia has been identified as a region having a high level of supply chain maturity (Baldwin and Lopez-Gonzalez, 2015; Fayezi et al., 2015), and is widely recognized as an early adopter of technology (Gill et al., 2016; Power and Sohal, 2002; Ried, 2017), which makes it an appropriate choice for this investigation. To underline this decision, a recent industry survey discovered Australian executives as being 'more likely' to invest in disruptive new technologies than their counterparts in other countries (Deloitte, 2019).

The key aim of this research is to better understand the current adoption rates of emerging I4 technologies amongst Australian supply chain organisations, and analyse the opinions of today's supply chain experts regarding the impact these technologies will have on supply chains in the future, in order to drive new insights that inform supply chain professionals and academic researchers, identify opportunities and challenges, assist business upskilling, and help direct future education and training in this area.

In order to achieve this objective, these first two research questions will be addressed:

RQ1 – What is the current level of I4 technology adoption across Australian supply chain organizations?*?*

RQ2 – How and where will emerging I4 technologies impact Australian supply chains?

Whilst technology adoption is a primary component in any organisation's digital transformation strategy, adequate training, preparation, and the availability of appropriately-skilled staff to harness the full potential of technologies, is another significant factor (Cisco, 2018; Lorenz et al., 2015; Pfeiffer, 2015; Schallock et al., 2018). Therefore, in order to examine that aspect in this investigation, RQ3 seeks to understand– *What preparatory measures are being taken by Australian supply chain firms to ensure they are digitally-ready for the impact of I4 technologies?*

Finally, the size of the organisation is also of interest, as previous research has indicated that organisational size is a critical factor in the adoption of information technologies (Palvia, Means Jr, & Jackson, 1994; Premkumar and Roberts, 1999). In order to test if that theory is valid, for the adoption of I4 technologies by Australian supply chain firms, this final research will be posed:

RQ4 – *To what extent does organizational size impact the adoption of I4 technologies?*

The methods adopted by this research, in order to address these four research questions, will be discussed in the following section.

2. Materials and methods

A descriptive online survey was chosen as the most appropriate method for this research, as descriptive research enables the characteristics of a phenomenon to be studied within their real-life context (Yin, 2003). Focussing on the 'what' rather than the 'why,' surveys are particularly effective for studying specific populations, and collecting data regarding opinions, attitudes, preferences, and common characteristics (McMurray, 2004). Online surveys are also an appropriate method for quickly accessing large populations simultaneously, facilitate data collection in a time-efficient manner, are convenient for participants to complete, have low administration costs, and support a diverse range of different question types (Akbari and Hopkins, 2016; Evans and Mathur, 2005).

The chosen method provides the researcher with a snapshot of the phenomenon under investigation, at a set point in time, from which inferences can then be drawn (Galliers, 1990). The method does not necessarily claim to establish causal relationships, but it is an effective tool for collecting primary data about specific phenomena, from which empirical observations can be made (Chisnall, 1993).

In this instance, the online survey was designed to collect the opinions of Australian supply chain practitioners, and was conducted in collaboration with the Supply Chain & Logistics Association of Australia (SCLAA), who are Australia's largest professional association for supply chain and logistics professionals and practitioners, with a membership of over 3000 active members. The SCLAA were chosen as the most appropriate partner for this research as their membership spans the full supply chain spectrum, from manufacturers and suppliers, to third party logistics (3 PL) firms, wholesalers and retailers, and they were identified as having the best channels available for reaching the target cohort (Australian supply chain professionals). They also had a shared interest and passion for understanding how I4 technologies will impact this profession.

To qualify for membership of the SCLAA, all applicants are assessed on the basis of their experience and qualifications, to ensure they are appropriately-skilled logistics, transport and supply chain management professionals. All new membership applications also require a letter of support from an existing member. This membership screening process ensured that SCLAA members were an appropriate target population for this study.

The SCLAA assisted in piloting early versions of the survey instrument, and distributed the link to the final version of the online questionnaire to their membership base, using targeted email lists and a series of LinkedIn posts. The final survey consisted of 73 questions, including a mixture of multiple choice, Likert scale, drop-down lists, and open-ended text field responses (Appendix 1), and was designed to take no longer than 20 min to complete. An odd number 7-point scale was selected for the Likert questions, as an odd number enables an accurate response to be captured from participants who are genuinely neutral on a subject, rather than an even scale which forces them to answer higher or lower than the mid-point (Malhotra, 2006).

The online survey was accessible for four weeks, and designed to collect the following data:

- Basic demographic information
- Current adoption rates for digital technologies,
- Predict how each digital technology will impact participants' firms,

- Predict how each digital technology will impact participants' sectors,
- Predict the level of investment that will be made in each digital technology over the next 10 years,
- Current preparatory actions being taken for the emergence of each digital technology,
- Concerns regarding each emerging technology,
- Free text feedback to capture any additional information the participants may wish to contribute.

Web-based tool Opinio was selected as the platform for this survey, it has built-in functionality for both authoring and distributing surveys, and response data was exported directly into SPSS for analysis. A combination of descriptive statistics, frequency tables, cross-tabulation and linear regression techniques were employed to analyze the data. The feasibility of the results, and the overarching positive relationship between technology adoption and expected impact, was validated using the Pearson correlation coefficient method. The project was approved by the author's Human Ethics Committee in advance of the survey being distributed.

224 participants commenced the questionnaire, but 21 failed to complete all questions, and were therefore excluded from the sample. Similarly, 15 student members were also excluded from the final sample, as no professional experience or qualifications are required to qualify for that level of membership. This resulted in a final sample of 188 usable responses.

3. Theory

Traditionally, investments in new technology are driven by ambitions to improve productivity and efficiency, increase quality levels, reduce/eliminate problems, expand data and knowledge, improve communication, or enhance prestige (Crespi et al., 2007; Hillmer, 2009). However, simply investing in the technology will not result in the desired outcomes by itself, as there is a need for that technology to be used in an 'appropriate manner' – this appropriate use of new technologies is termed 'technology adoption' (Agarwal and Prasad, 1998).

New technologies represent innovation to potential adopters (Agarwal and Prasad, 1997), and innovation is widely accepted to be a "multi-stage process whereby organisations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace" (Baregheh et al., 2009, p. 1334). It is a vital component of a firm's competitiveness, and causes organizations to increasingly look to their supply networks for innovative new ways to achieve process improvement, increase performance, and innovate their business models, which has made it a topic of interest for many supply chain researchers (Chesbrough and Rosenbloom, 2002; De Martino et al., 2013; Hopkins and Hawking, 2018; Ivan Su et al., 2011; Kavin and Narasimhan, 2017; Rebolledo et al., 2009; Simmons et al., 2013).

In an era where supply chains compete against other supply chains, it is increasingly important to continue the development of innovative, customer-focussed digital solutions that enable supply chain partners to streamline existing processes, not just for products and delivery, but across the entire customer experience. In recent years, supply chain innovation (SCI) has emerged as a field of investigation in its own right, exploring its role as a mechanism for enhancing customer value (Munksgaard et al., 2014), and for driving new business models (Abdelkafi and Pero, 2018). Similarly, investigations into the role supply chains play in "doing something novel to produce value in the form of new products and new services," have also given rise to a new Emerging Technology Supply Chains (ETSC) field of research (Linton, 2017, p. 1).

Von Hippel (2007, p. 1331) believed that, "a supply chain network with superior knowledge management is far more capable of innovation than a network with less effective knowledge sharing," and successful supply chain relationships have widely been identified as key drivers of quality, delivery and cost improvements (Hartley et al., 1997; Kim, 2000; Lau and Lau, 1994; Monczka et al., 1993). However, Arlbjørn et al. (2011) believe that it extends beyond that, and the concept of SCI involves a combination of three key elements – processes, technology, and network structure. *Processes* are defined as activities that "produce a specific output of value to the end consumer.. implemented not only within the focal firm, but also across the members of the supply chain network," *technology* can be "used in isolation or in combination with other technologies to enable increased collaboration, information exchange, as well as visibility within supply chain networks," and the *network structure* refers to the manner in which the network is configured (Arlbjørn and Paulraj, 2013, p. 4). The interrelationships between these three elements are described as *innovations within the supply chain network* (*ISCN*).

As we enter an era where supply chains are looking to leverage I4 technologies to 'transform business processes, develop new delivery models, and create the kinds of experiences that empowered customers expect,' driving innovative changes in the manufacture, transportation, marketing, storage and payment of goods and services, it is important to investigate the implications this will have for firms (Stachová et al., 2019). Supply chains follow a traditional SCOR model, of plan, source, make, deliver, return, and enable activities, and each stage of this model is now being disrupted by technological innovation (Schrauf and Berttram, 2016). Organisations have long recognised how technological innovations, driven not only by themselves but by their network of supply chain partners and customers, have a positive impact on the performance of the overall supply chain, and collaborative innovation activities have been found to increase the overall innovation performance of supply chains (Wang and Hu, 2017). The enhanced virtualization of supply-chain interactions that will be possible, through the implementation of I4 technologies, could enable seamless inter-company connectivity, with real-time access to product and production information, for all participating organisations in a network (Brettel et al., 2014).

The characteristics of I4 technologies and concepts are viewed as having 'high importance,' for driving product or process innovations, to enable a technological view of procurement, production and distribution activities throughout the supply chain (Pfohl et al., 2015). Key benefits from this could include increased flexibility, optimised decision making, higher quality standards, and improved efficiency and productivity, enabling mass customization to better meet customers' demands (Tjahjono et al., 2017).

Improvements in functions such as delivery and network design, reducing touch points, removing bottlenecks and decreasing the time taken for products to be delivered to customers, creates greater overall customer value and increases the likelihood of repeat business, to the benefit of all actors in that network.

As Australia demonstrates a high level of supply chain maturity (Baldwin and Lopez-Gonzalez, 2015; Fayezi et al., 2015), and is regarded as an early adopter of new technologies (Gill et al., 2016; Power and Sohal, 2002; Ried, 2017), it presents an appropriate region in which to base this investigation.

When selecting which technologies should form the basis of this investigation, it quickly became apparent that the I4 field is highly heterogeneous, and that no unique and concise definition or formal classification framework for I4 technologies existed in the current body of academic literature (Chiarello et al., 2018; Hofmann and Rüsch, 2017; Oesterreich and Teuteberg, 2016).

For example, Dalmarco and Barros (2018) identify I4 as being represented by eight key technology areas: 3D printing; BDA;

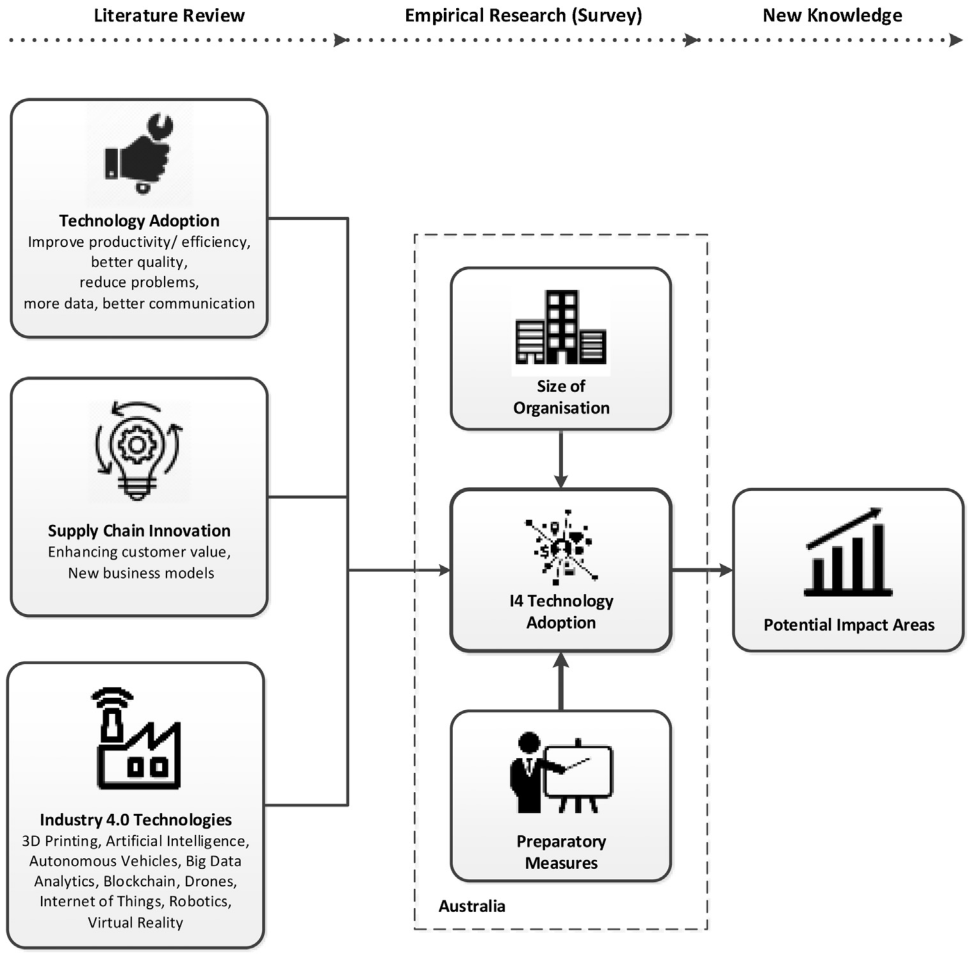

Fig. 1. Research Framework.

cloud computing; cyber-physical systems; cyber security; internet of things; robotics; and visual computing. However, Tjahjono et al. (2017) think slightly differently, and identify VR/AR, 3D printing, simulation, BDA, cloud, cybersecurity, IoT, miniaturization of electronics, Auto-ID, robotics, drones, machine-to-machine communication, business intelligence and AI, as being the key I4 technologies. Fernández-Caramés and Fraga-Lamas (2019) classify Blockchain as an I4 technology, and the importance of autonomous vehicles in I4 has also been widely discussed (Gilchrist, 2016; Lom et al., 2016).

The term Industry 4.0 was found to be commonly used to describe a wide range of different technologies, the classification for which can differ significantly, from article to article. In the absence of a consistent definition for I4, the list of technologies chosen for this research were those considered to represent the most significant I4 Megatrends and NextGen supply chain innovation themes at the time of commencing this investigation, those regularly discussed in academic and non-academic literature, white papers, industry forums and corporate blogs etc. (Almada-Lobo, 2015; Barreto et al., 2017; Chiarello et al., 2018; Deloitte, 2018; Eckert et al., 2016; GSCI, 2017; Ivanov et al., 2019; Manavalan and Jayakrishna, 2019; Pacchini et al., 2019; Tjahjono et al., 2017). These technologies will now be defined and briefly discussed.

3.1. 3D printing

Additive manufacturing, or *3D printing*, describes a process for creating 3D physical haptic objects from digital data, building up layers from feed material (Rengier et al., 2010). Mainly used for new product prototyping in its earlier days, 3D printing now promises to challenge traditional volume/variety trade-offs in manufacturing (Bozarth and Handfield, 2008), as a viable option in instances where production volumes are small, end-user customization is desirable (Weller et al., 2015), and features need to be manufactured which can't be created using traditional means (Petrick and Simpson, 2013). It promises to also disrupt the existing spare parts supply chain and create a 'substitution scenario' which may replace traditional manufacturing (Khajavi et al., 2014; Rehnberg and Ponte, 2018). This 'dematerialisation' of physical products enables customers to purchase data, and print the physical version of the product themselves, unites digitization and servitization (Lerch and Gotsch, 2015; Vendrell-Herrero et al., 2017). This supports reduced transportation and storage costs, improvements in last mile delivery (McKinnon, 2016), a shortening of product development cycles (Rehnberg and Ponte, 2018), an outsourcing of manufacturing costs to the end consumer (Rayna and Striukova, 2014), lower energy usage and a reduction CO_2 emissions (Gebler et al., 2014).

3.2. Artificial intelligence

Artificial Intelligence (AI) is defined as 'agents that receive percepts from the environment, which enable those agents to map percept sequences in order to perform specific actions' (Russell and Norvig, 2016, p. 9), underlining an ability of machines to demonstrate intelligence, as opposed to humans or animals. Advances in AI enable real-time fraud and risk management to be per-

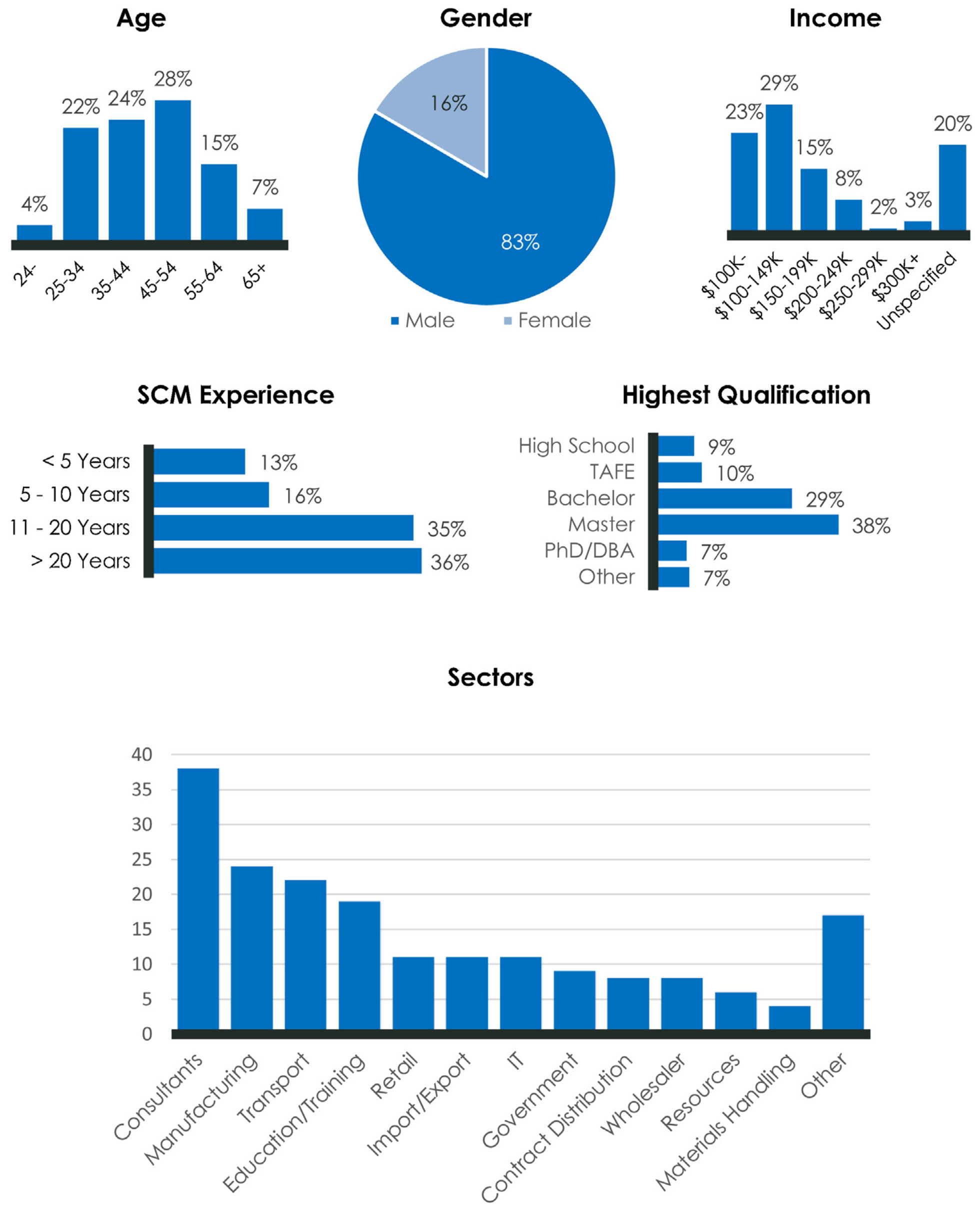

Fig. 2. Demographic Information of Survey Participants.

formed (Lotakov, 2016); have led to improved inventory placement (Frommberger et al., 2012), and could remove many current human tasks from the workplace. The McKinsey Global Institute (2017) predicted that AI will enable the automation of at least 30 % of current tasks associated with the majority of US occupations.

3.3. Autonomous vehicles

Autonomous vehicles are vehicles which are capable of "intelligent motion and action without requiring either a guide or teleoperator control" (Lozano-Perez, 2012, p. xix), they can perceive their own environment, and respond appropriately when faced with unexpected situations (Hagen et al., 2007). The integration of these vehicles, across a range of supply chain functions, is seen as an important step in the evolution towards digital supply chain networks (Bechtsis et al., 2018). The potential impact of long-haul autonomous trucks is seen as extremely significant (Abbott et al., 2017), whilst the technologies required for autonomous shipping also already exist (Jokioinen et al., 2016), and autonomous vehicles are widely promised to lower overall shipping costs, reduce accidents, eliminate driver wages, reduce liability, reduce fuel costs and reduce greenhouse gas emissions (Bonnefon et al., 2016; Greenblatt and Saxena, 2015; Heard et al., 2018; Litman, 2017; Van Meldert and De Boeck, 2016).

3.4. Big data analytics

Big data analytics (BDA), first identified as a performance challenge for computer systems that struggled to process large data sets which over-burdened the "capacities of main memory, local disk, and even remote disk" (Cox and Ellsworth, 1997, p. 4), is now established as a critical mechanism for driving supply chain improvement (Hazen et al., 2014, 2016a,b; LaValle et al., 2011; Novoa and Storer, 2009; Tan et al., 2015; Waller and Fawcett, 2013). Supply chains generate vast amounts of data, as networks of organizations communicate, monitor and transact, in an effort to quickly move their products from the point of manufacture to the point of consumption (Russom, 2011; Wang et al., 2016).

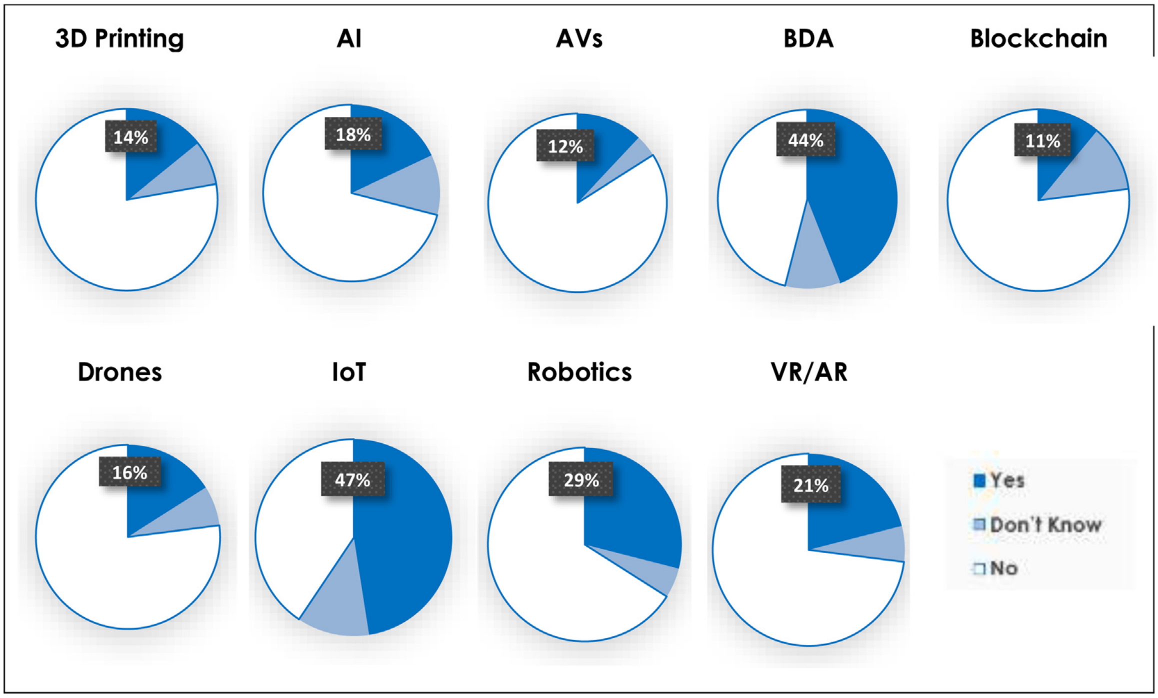

Fig. 3. Current Adoption Rates for each Emerging Digital Technology.

These digital networks of multi-directional, real-time, information flows enable the identification of new opportunities and support digitally-enabled supply chain strategies (Schoenherr and Speier-Pero, 2015). BDA enables better targeted marketing, predictive analytics, more accurate forecasting, improved agility, clearer business insights, client-based segmentation, and improved recognition of sales and marketing opportunities (Barbosa et al., 2018; Belhadi et al., 2019; Fan et al., 2015; Hazen et al., 2014, 2016a,b; Monahan and Hu, 2015; Sagiroglu and Sinanc, 2013; Turner et al., 2014; Wang et al., 2016, 2018).

3.5. Blockchain

Blockchain first emerged as a public ledger for cryptocurrency transactions, where new blocks of information are added in chronological order, to create a history of transactions (Swan, 2015). It has since grown to become a decentralized system, where transactions of any kind can be stored securely and permanently which, together with its time stamping functionality, offers significant potential for improving collaboration, accuracy, transparency and security across supply chains (Braga et al., 2018; Francisco and Swanson, 2018; Korpela et al., 2017; Tian, 2016). The digital nature of these transactions, as opposed to physical assets like cash, also has clear links to improvements in environmental sustainability (Giungato et al., 2017).

3.6. Drones

'Drone' is a term that has come to describe unmanned aerial vehicles and micro aerial vehicles. A technology which was originally designed for military purposes, with assault drones being used as early as World War II, drones have now emerged as a potential solution to many supply chain challenges – such as last-mile/urban parcel delivery, stock taking, surveillance, the inspection of vehicles (ships) and infrastructure (roads/bridges/tunnels/oil rigs etc.), traffic congestion and CO2 reduction (Appelbaum and Nehmer, 2017; Floreano and Wood, 2015; Gregory, 2011; Irizarry et al., 2012; McGuire et al., 2016; McKinnon, 2016; Nentwich and Horváth, 2018; Schröder et al., 2018; Sun and Zhang, 2018; Troudi et al., 2018).

3.7. Internet of things

Emerging from research at MIT's Auto-ID Centre in the late 1990s, the Internet of Things (IoT) has more recently come to describe a worldwide network of devices, or *things*, wireless transmissions, and computational capability (Atzori et al., 2010; Boos et al., 2013; Sarma et al., 2000), that supports communication between "people and things, and things and other things" (Vongsingthong and Smanchat, 2014, p. 1). These *things* can range from sensors, actuators, pumps, and washing machines, to weighbridges, water meters, lights, or RFID tags (Atzori et al., 2010; Gubbi et al., 2013; Kopetz, 2011; Kortuem et al., 2010; Wortmann and Flüchter, 2015; Xia et al., 2012), and connect physical items with the digital world. IoT is predicted to have a significant impact on future supply chains, as an increasing number of sensors are fitted to vehicles, containers and products, which enable them to be monitored and measured more accurately (Da Xu et al., 2014; Hopkins and Hawking, 2018; Zhou et al., 2012). IoT has been linked with a range of benefits, including an improvement in the identification of counterfeit products, real-time tracking, predictive maintenance, more accurate sales data, a reduction in overproduction/underproduction, personalized marketing, biometric payments, more accurate carbon monitoring, improved competitiveness and the achievement of sustainability goals (Abdel-Basset et al., 2018; Adhya et al., 2016; Bandyopadhyay and Sen, 2011; Bibri, 2018; Khoo, 2010; Lade et al., 2017; Liu et al., 2016; Nagy et al., 2018; Peppet, 2014; Shrouf and Miragliotta, 2015; Wortmann and Flüchter, 2015; Yan et al., 2016; Zhang et al., 2015).

3.8. Robotics

Robots are electro-mechanical machines, designed to automate or assist human tasks, either autonomously or via a set of commands (Eckert et al., 2016; Gunasekaran et al., 2008). They are commonplace throughout most industries, particularly in man-

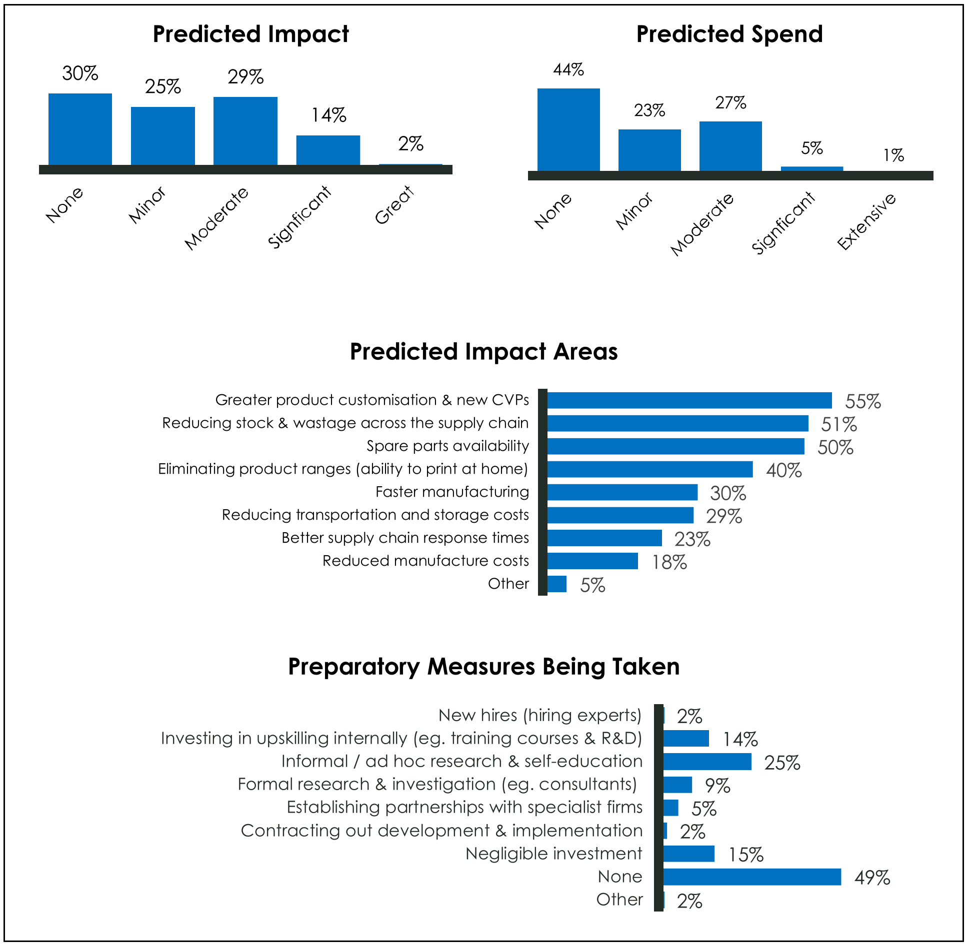

Fig. 4. Predicted Impact and Spend Forecast for 3D Printing.

ufacturing and warehousing (Krueger et al., 2016; Shneier and Bostelman, 2015), and are widely accepted for their effectiveness in conducting tasks like material handling, picking, intensive and repetitive labour, welding and inspection, which can lead to increased capacity, cost reduction and safer, more sustainable, workplaces (Brossog et al., 2015; Bugmann et al., 2011; Ganesan et al., 2017; Pellegrinelli et al., 2017; Rui et al., 2014; Winfield, 2015).

3.9. Virtual reality/augmented reality

Virtual Reality (VR) enables users to interact with realistic electronic simulations, of three-dimensional situations, using head-mounted goggles and clothing fitted with sensors (Steuer, 1992). This helps users to better understand situations and make decisions, through the provision of a realistic visual experience, without interacting with the real phenomenon (Choi et al., 2015). Augmented Reality (AR) describes the ability to integrate virtual 3D objects into a real environment, in real time (Azuma, 1997), and the potential of AR is starting to be realized as the technology reaches a stage where is can create increasingly compelling experiences (Billinghurst et al., 2015). Both technologies have been recognized for their potential in training/education, product visualization (Lu et al., 1999), improved picking / inventory management (Cirulis and Ginters, 2013; Ginters and Martin-Gutierrez, 2013), and are increasingly been investigated for their ability to create virtual work environments, that enable meaningful interactions between colleagues, partners and customers, regardless of their physical location (Grajewski et al., 2015; Song and Fiore, 2017).

Fig. 1 illustrates the fact that the research gap is positioned where three key areas of academic literature intersect, and that an empirical study was adopted to collect new primary data regarding current I4 technology adoption levels, preparatory measures and organisation size, to better understand how/where these emerging technologies might impact Australian supply chains.

4. Results

A total of 188 usable responses were collected, from participants working in 13 different sectors, with 83 % being male and 17 % female. Participants spanned all age groups, and were found to be highly experienced and qualified, with 71 % having worked in SCM for at least 11 years and 70 % having attained a Bachelor degree or higher (see Fig. 2). From the technologies studied, IoT was found to be the most widely adopted (47 %), followed by BDA (44 %), and Robotics (29 %). The technologies currently experiencing the lowest adoption rates were Blockchain (12 %) and autonomous vehicles (11 %) (Fig. 3).

4.1. 3D printing

Only 14 % of participating firms were found to have already adopted 3D printing, only 16 % think it will have a significant/great impact on their organisation, and only 6% expect to make any significant kind of investment over the next 10 years.

The areas where it was expected to have the greatest impact were in *greater product customization and customer value propositions* (55 %), *reduced stock and wastage* (51 %) and *greater product*

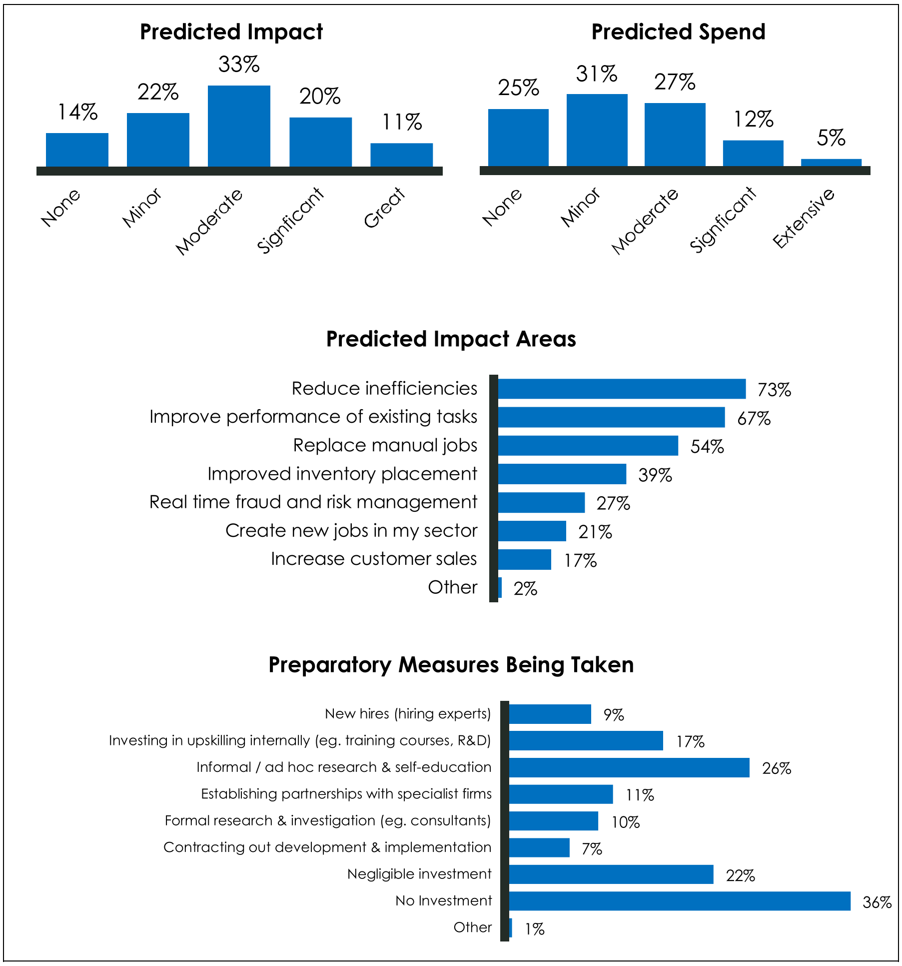

Fig. 5. Predicted Impact and Spend Forecast for AI.

customization improved spare parts availability (50 %). Whilst almost half of the participants (49 %) weren't currently taking any steps to prepare for the arrival of 3D printing, the highest figure recorded for any of the technologies (25 %), admitted they were taking some form of ad hoc/informal research or self-education (Fig. 4).

4.2. Artificial intelligence

Whilst only 18 % of participants are already using AI, 64 % predict it will have at least a moderate impact on their organisation over the coming decade, with *reduced inefficiencies* (73 %) and *improved performance of existing tasks* (67 %) the areas of greatest expectation. 25 % of participating firms are already making negligible investments, to prepare for the emergence of AI, and 9% have already hired staff with these specific skills (Fig. 5).

4.3. Autonomous vehicles

12 % of participants indicated that they are already using autonomous vehicles, 84 % indicated that they were not, and 4% were unsure. 18 % of participating firms were found to be conducting formal research into autonomous vehicles (via consultants etc.), in preparation for the arrival of autonomous vehicles on the roads, and 19 % anticipate that their organisation will spend significantly in this area over the next 10 years (Fig. 6).

The greatest impact of autonomous vehicles is expected to be their ability to *remove the need for driver wages* (60 %) and *improved driver safety/reduced liability* (58 %).

4.4. Big data analytics

Findings from this research revealed that 44 % of organisations are already using BDA, 89 % of the participants expect this technology to impact their organisation, particularly in the areas of *predictive analytics* (76 %) and *process optimization/cost reduction* (64 %), and 20 % expect it to attract significant or great financial investment in their organization (Fig. 7).

BDA is also the technology that was found to be attracting the most significant level of preparation, with 64 % of firms already taking some kind of action, with *internal training & development* (41 %) found to be the most common first step.

4.5. Blockchain

Only 11 % or organizations are currently using Blockchain, but 69 % expect it to have some sort of impact on their organisation, and 51 % forecast some level of spend on the technology. The areas where Blockchain is expected to have the most significant impact, over the next 10 years, is in *improving supply chain collaboration* (63 %) and *supply chain transparency* (62 %).

Whilst 30 % of participants expect the eventual impact of Blockchain to be significant or great, that figure that rises sharply amongst the under 35 s, where 41 % predict a significant impact.

Similarly, whilst 51 % of overall participants expect moderate/extensive financial investment in Blockchain, that figure is far more prominent in the *Education and Training* sector (77 %) (Fig. 8).

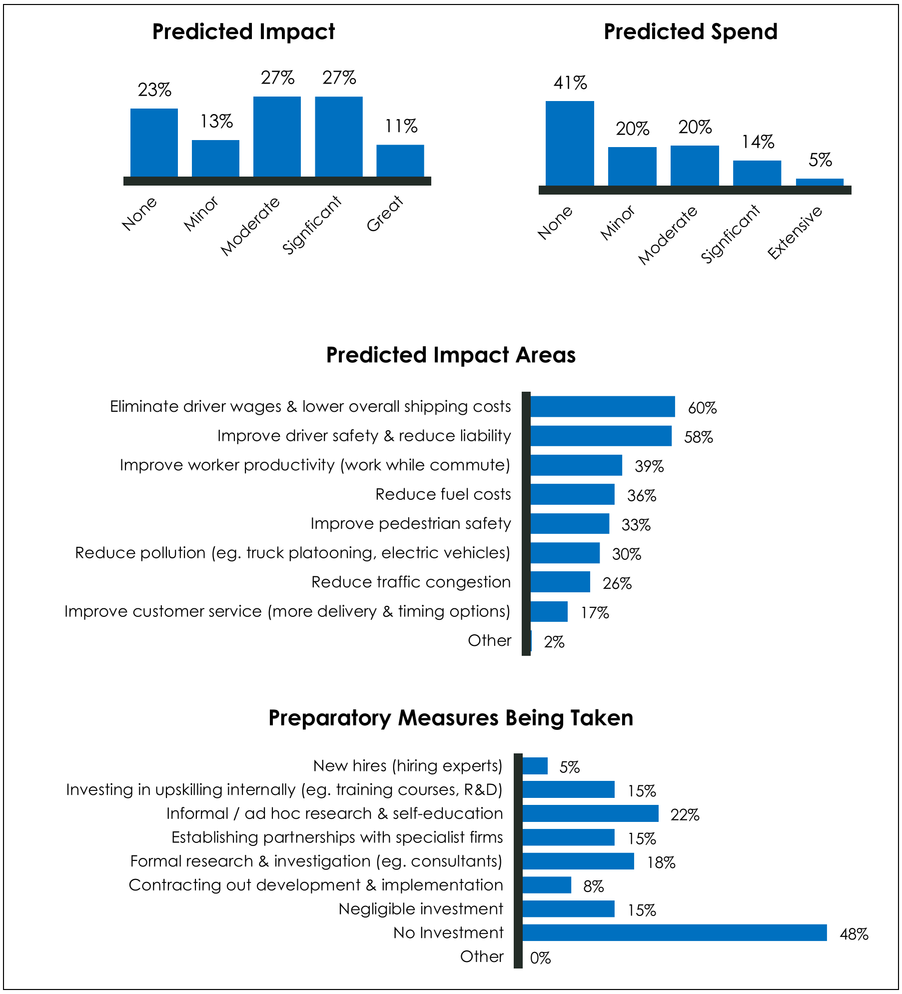

Fig. 6. Predicted Impact and Spend Forecast for AVs.

4.6. Drones

16 % of participating organisations have already adopted Drone technology, and the most significant impact is forecast to be in *B2C last mile delivery* (55 %) and *management activities* (e.g. stock taking and crop surveillance – 43 %), but only 9% or participants expect their firm to make significant investment in drones in the future (Fig. 9).

4.7. Internet of things

48 % of participants were found to be already using IoT technologies, which was the highest overall adoption rate observed for any of the technologies in this study, and more informal preparatory research was found as being conducted into IoT (32 %) than any other technology (Fig. 10).

Current usage of IoT technologies was found to be particularly prevalent in the *Transport* (64 %) and *Manufacturing* (56 %) sectors, and IoT is expected to drive the most significant improvements in *supply chain efficiency* (70 %), *real-time tracking* (55 %) and *predictive maintenance* (46 %).

4.8. Robotics

29 % of participants were found to be using some sort of robotic technology today, 44 % forecast further investment, whilst 62 % predict at least a moderate impact on their organisations over the next 10 years (Fig. 11).

The greatest impact for robotics was predicted in the manufacturing sector, where 90 % of participating firms are currently undertaking some sort of preparatory action.

4.9. Virtual reality/augmented reality

In readiness for the emergence of VR/AR, 27 % of participating firms are investing in informal research, and the most significant impact of this technology is expected in *Education & Training (59 %), Product Visualization/Design* (57 %) and in *Creating Virtual Work Environments (48 %)*. 48 % predict that VR/AR will have a direct impact on their firm, whilst even more expect it to have an impact on their partners/sector more widely (59 %). 36 % of participants expect further investment in VR/AR over the decade, but only 10 % expect this investment to be significant or great, and 40 % indicate that no preparation activities are currently being undertaken for the emergence of this technology today (Fig. 12).

4.10. Concerns

In addition to identifying the benefits of these emerging digital technologies, the participants also expressed a number of concerns, with the chief causes of unease being that of security/hacking (62 %), and the loss of employment due to the technology (44 %) (Fig. 13).

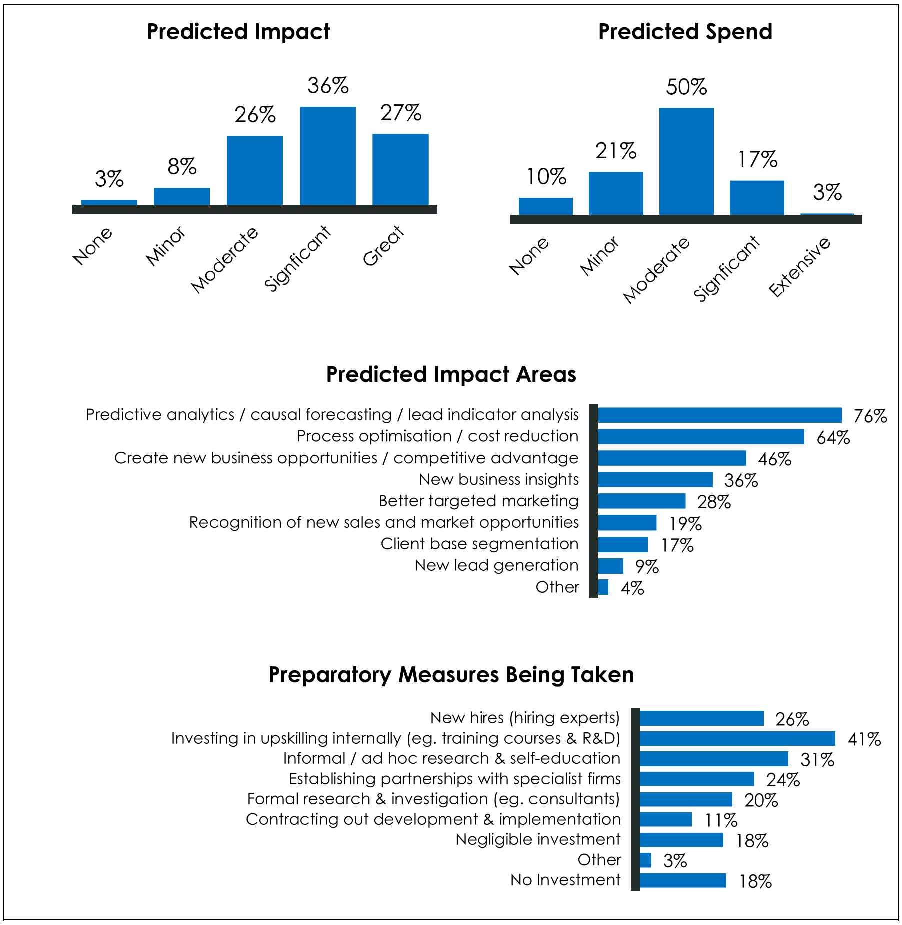

Fig. 7. Predicted Impact and Spend Forecast for BDA.

With data security being such a serious issue facing many organizations today, with instances cybercrime and data leaks receiving increasingly widespread media attention, the concerns of the participants seem justifiable.

4.11. Most significant overall impact

At the end of the survey, participants were invited to rank all nine technologies, in terms of where they see the most significant impact on supply chains occurring in the future (awarding '9' to the technology they think will have the greatest overall impact, '8' to the technology they think will have the second most significant impact etc.. and '1' to the technology they think will have the least impact). From the heat map developed from these results, it can be clearly seen that the technologies expected to impact Australian supply chains most significantly, are big data analytics, Autonomous vehicles, artificial intelligence, and Internet of things. Whilst the technologies expected to impact Australian supply chains the least are 3D Printing and virtual/augmented reality (Fig. 14). The responses to this final question align well, and therefore validate, the attitudes that emerged towards each individual technology earlier in the survey.

4.12. Text commentary

The availability of free text fields throughout the survey enabled the capture of interesting qualitative feedback from the participants. BDA was the technology that attracted the most commentary, with popular themes being : *"Big Data Analytics is essential for market leaders to maintain their position"* . . . *"our first step is getting more consistent and modernised system to capture the data"* and *"the BI tools are there but they are still not in front of key decisions"*. Blockchain attracted the second most comments, mainly regarding its infancy and the confusion it can cause, including: *"once the hype around crypt-currencies settles, then the true benefits of Blockchain will be recognised"* . . . *"[it is a] very exciting development with potential that is not yet understood"* and it is *"still very much misunderstood in the workplace"*.

5. Discussion

5.1. Current adoption and forecast impact

IoT was found to be the most widely adopted I4 technology amongst Australian supply chain organisations, with 48 % of participants claiming to be already using it, whilst BDA was predicted to have the most significant impact in the future. Key impact areas for BDA were expected to include *predictive analytics* and *process optimization/cost reduction*, in line with recent literature (Barbosa et al., 2018; Belhadi et al., 2019), as was IoT's capacity for improving *supply chain efficiencies*, *real-time tracking* and *predictive maintenance* (Abdel-Basset et al., 2018; Adhya et al., 2016; Khoo, 2010).

Significant correlation was found to be evident, in the relationship between the predicted impact and current adoption rate for most of the technologies, which suggests organisations are prioritising the adoption of technologies that will have the greatest impact on their current business needs (Fig. 15).

However, when plotting the relationship between the expected impact and future predicted investment, the results were quite dif-

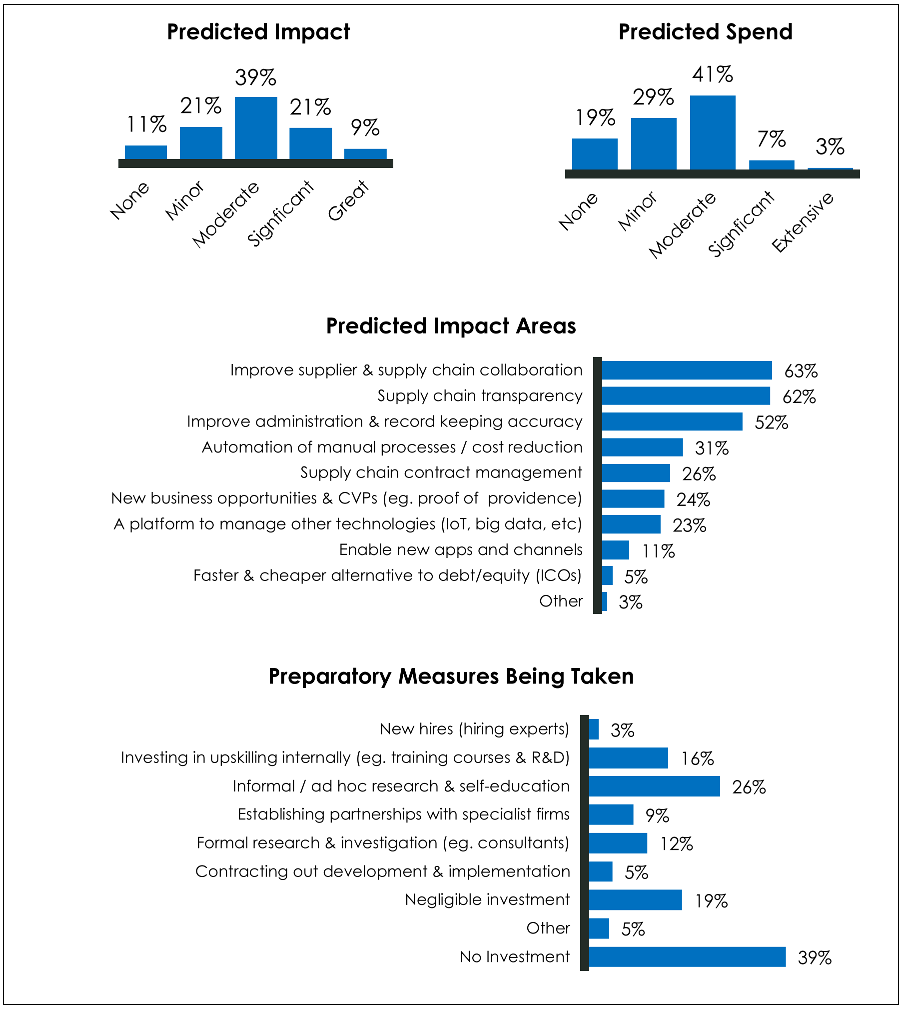

Fig. 8. Predicted Impact and Spend Forecast for Blockchain.

ferent. For example, whilst 63 % of participants predicted that BDA to have a Significant-Great impact on their organisation over the next 10 years, only 17 % expected their firms to make a Significant-Great investment in the technology. A similar pattern to this was evident for most of the technologies investigated, with results skewed higher for impact than expected investment, with the largest investment/impact gaps possibly offering the most significant opportunities for future competitive advantage (Fig. 16).

The technology driving the highest demand for new talent was also BDA, with 26 % of participating organizations indicating they had already hired BDA talent, underlining a need for these skills in the supply chain profession. This also aligns with previous research, that identified BDA as one of the fastest growing employment segments, presenting clear opportunities for universities, students/graduates and other training providers (Columbus, 2015; Radovilsky et al., 2018).

5.2. Adoption, impact and spend by sector

Table 1 illustrates which I4 technologies have experienced the highest levels of adoption to date, are predicted to have the greatest impact in the future (ranked as either *significant* or *great*) and attract the greatest levels of future spending, for each of the 13 sectors appearing in this research.

BDA was found to be the most commonly adopted technology in the Education, IT and Materials Handling sectors, whilst IoT was the most commonly adopted in Import/Export, Transport and Wholesaling. Unsurprisingly, robotics was found to be the technology most widely adopted in the Manufacturing sector, and drones were found to be the most commonly adopted I4 technology in the Government sector.

BDA is expected to have the greatest future impact of all the I4 technologies by the Consulting, Education & Training, Government, Import/Export, IT, Manufacturing, Resources, and Retail sectors. The Transport and Contract Distribution sectors expect autonomous vehicles to have the most significant future impact, whilst Wholesalers expect it will come from IoT.

Consultants expect their greatest spend over the next decade to be on BDA, as do those in those from the Education & Training, IT and Transport sectors, whilst participants working in Contract Distribution expect their highest level of investment to be in either BDA or Blockchain. The Import/Export, Wholesale, Retail, Materials Handling and Government sectors all expect to spend most significantly in IoT technology, whilst the greatest expected spend in Manufacturing is expected to be on Robotics.

5.3. Large firms vs small firms

In answering RQ4, the technology adoption rates of large firms (250+) versus smaller firms (<250) were compared, and the findings indicate that larger firms are significantly more likely to have adopted emerging I4 technologies. This validates the findings from

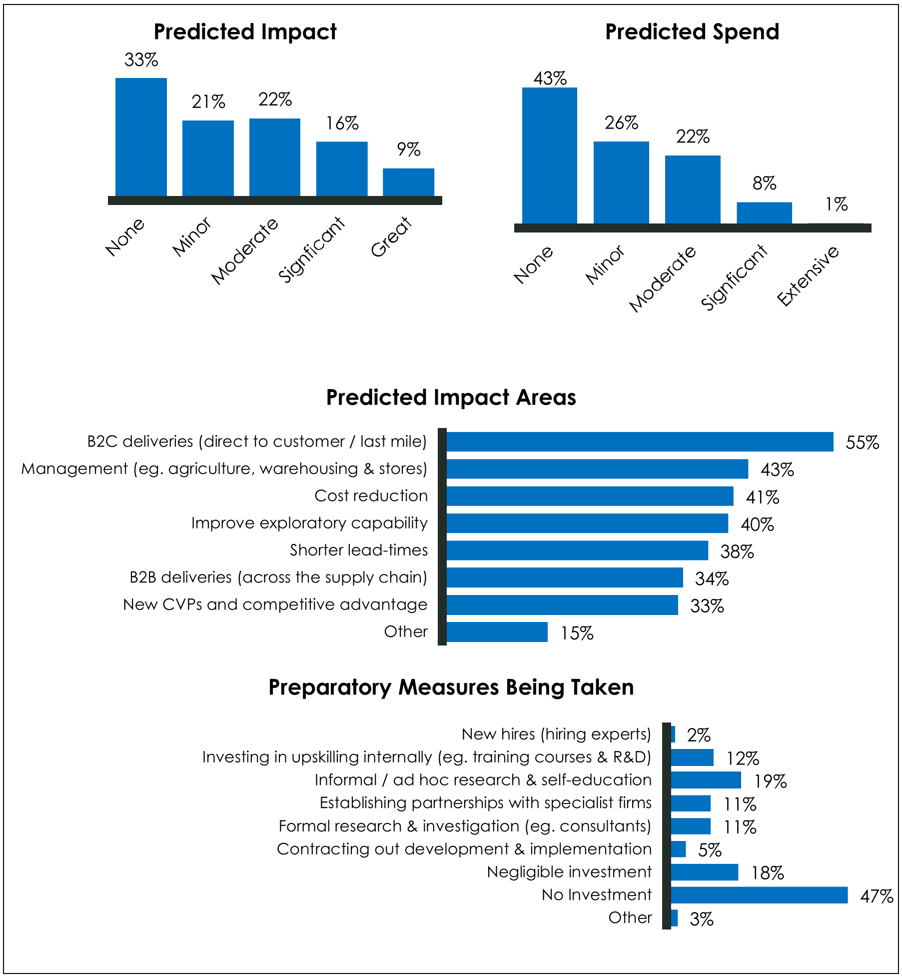

Fig. 9. Predicted Impact and Spend Forecast for Drones.

Table 1
Highest adoption rates, predicted impact and spend areas, by sector.

Sector	Highest Current Adoption	Greatest Expected Impact	Greatest Expected Spend
Consulting	BDA/IoT (42 %)	BDA (55 %)	BDA (64 %)
Contract Distribution	BDA/IoT (60 %)	AVs (71 %)	BDA/Blockchain (80 %)
Education/Training	BDA (38 %)	BDA (70 %)	BDA (85 %)
Government	Drones (60 %)	BDA (44 %)	IoT (60 %)
Import/Export	IoT (67 %)	BDA (50 %)	IoT (83 %)
IT	BDA (100 %)	BDA (80 %)	BDA (80 %)
Manufacturing	Robotics (69 %)	BDA (53 %)	Robotics (73 %)
Materials Handling	BDA (100 %)	Robotics/IoT (50 %)	IoT (100 %)
Others	BDA (53 %)	BDA (65 %)	BDA (65 %)
Resources	Drones/IoT (67 %)	BDA (83 %)	BDA/Drones (83 %)
Retail	Robots (55 %)	BDA (92 %)	IoT (73 %)
Transport	IoT (60 %)	AVs (69 %)	BDA (76 %)
Wholesaler	IoT (60 %)	IoT (33 %)	IoT (80 %)

previous literature (Palvia et al., 1994; Premkumar and Roberts, 1999), and indicates that organisational size is still a critical factor in the adoption of technologies in the I4 era.

The relationship between firm size and technology adoption was found to be particularly strong for Robotics, VR/AR and Drones (Fig. 17).

This relationship was found to follow an increasing linear trend for most technologies, meaning the larger the organisation is, the more likely they are to have adopted new technologies, across the four size categories studied. However, the one exception to this trend was found to be Blockchain, where a higher proportion of smaller firms (12 %) have adopted compared to large firms (6%), exhibiting a clear downward linear relationship (Fig. 18).

When comparing the preparatory measures being taken by large firms, with those of smaller firms, there was another clear distinction. As a percentage, large firms were seen to be taking greater preparatory action than their counterparts, in all areas other than 'ad hoc research.' To illustrate this, Fig. 19 clearly shows how larger firms are far more likely to be appointing new hires, investing internally, conducting external research, and contracting out BDA and IoT development, than small firms.

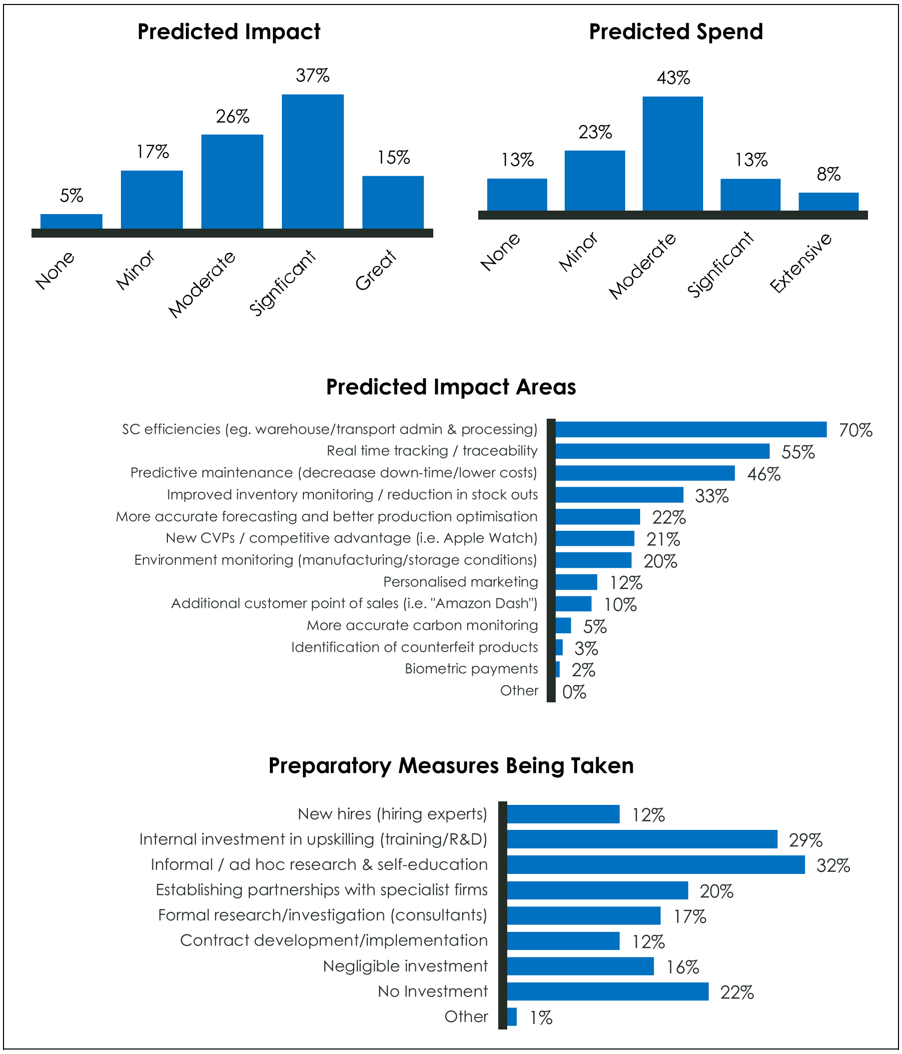

Fig. 10. Predicted Impact and Spend Forecast for IoT.

However, overall, preparatory measures were found to be relatively low across firms of all sizes. This suggests most firms still aren't currently engaging their staff, or external providers, with regard to formal research and training. As preparation for the inevitable changes, to the type of skills that will be demanded as a result of I4 digital transformation, Rajnai and Kocsis (2017) proposed that education systems should focus on:

- Strengthening science, technology, engineering, mathematics (STEM),
- Regularly updating curricula in higher education, and
- Offering a wider set of knowledge and skills, suited to the dynamically changing, complex nature of modern work roles.

5.4. Significance of the findings

As Australia has been identified as having a high level of supply chain maturity, and is regarded as an early adopter of technology, these results act as a barometer for the current state of I4 technology adoption more broadly. The level of detail that these findings offer, in terms of technology adoption, impact, preparedness and spending predictions, was previously lacking, and contributes new and original knowledge to the existing body of academic literature in this field.

The findings emphasize the broader influence of I4 technologies, the impact they are making outside the traditional realms of manufacturing, and their contribution to the long-term digitalization of supply chains. They will play a valuable role in the creation of smarter, better-connected supply chain networks, which offer greater supply chain transparency, real-time tracking, better forecasting, improved product customization, a reduction of inefficiencies, and an increased automation of repetitive tasks.

Finally, the importance of providing adequate training, and hiring appropriately-skilled staff who can leverage the full potential of these technologies, has been strongly emphasised.

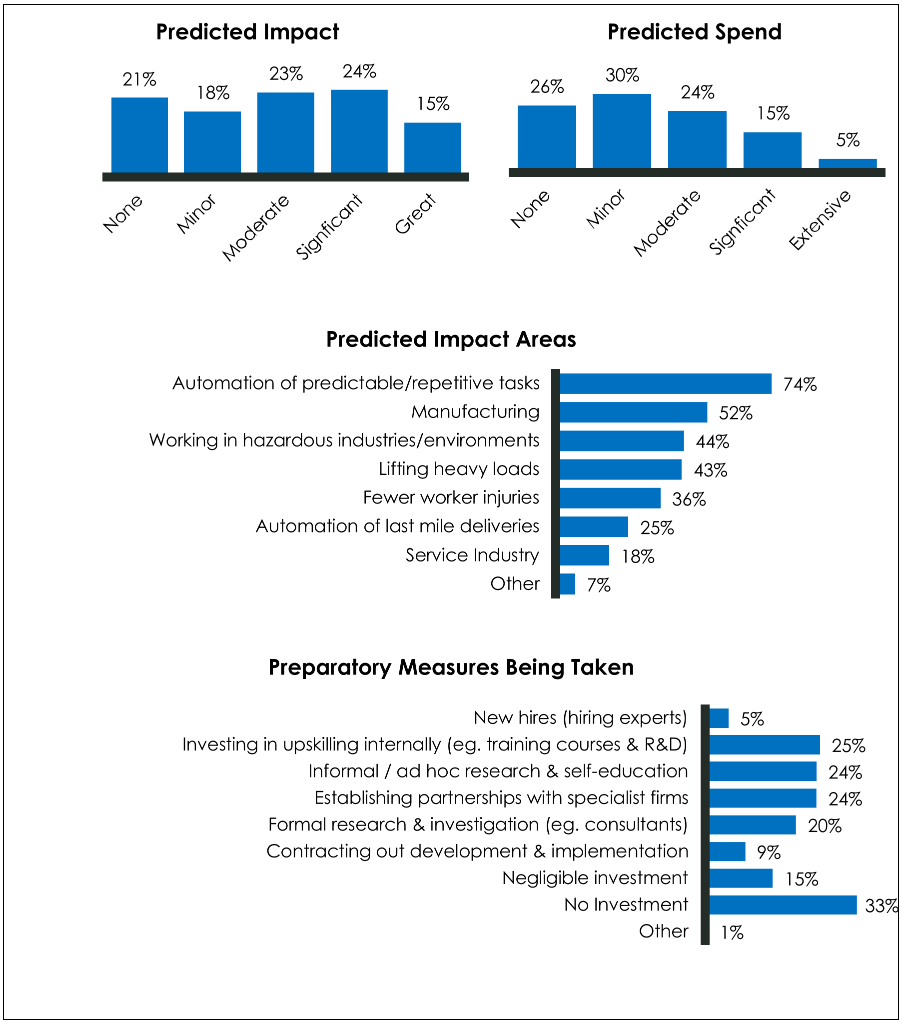

Fig. 11. Predicted Impact and Spend Forecast for Robotics.

6. Conclusions

This empirical study has generated a number of interesting new insights, which extend the existing knowledge of supply chain digitalization, and proposes areas of opportunity where I4 technologies might advance current digital supply chains and service future customers more effectively. Whilst much contemporary research is being conducted into the subject of I4, and the influence of digital technologies in the world of manufacturing, this research gives an alternative insight into the current landscape from a supply chain perspective.

The primary data collected during this study clearly indicates that most I4 technologies investigated are still very much in the early stages of adoption, within Australian supply chain organizations, and that impact predications and investment forecasts vary significantly across different technologies and sectors.

Overall, in addressing RQ4, it was found that larger firms were better prepared for I4 technology adoption than smaller firms, which confirms previous theories regarding organisational size being a factor for technology adoption rates, are still valid (Palvia et al., 1994; Premkumar and Roberts, 1999). Larger firms appear to be more likely to adopt emerging technologies, and take more preparatory measures, which is most likely a result of having access to greater resources, R&D budgets, in-house support, and operational capacity to experiment with new technologies. However, Blockchain is the exception to this rule, where smaller firms have been the quickest to adopt.

A key contribution of this research is the identification of a number of significant gaps, between the expected impact of I4 technologies, and investment forecasts in those areas. In a number of cases, whilst certain technologies were expected to have a significant impact on particular organisations and sectors, the investment predications for those technologies were surprisingly low by comparison. Similarly, the extent of current preparatory measures were also found to be low, despite significant digital disruption being predicted. These observations have significant practical implications for supply chain managers, could influence investment planning and recruitment strategies, and may provide potential sources of future competitive advantage.

This research also extends the current body of knowledge in the emerging field of supply chain innovation, as a mechanism for enhancing customer value, and underlines the impact that I4 technologies may have in maintaining competitive advantage. It identifies a number of potential sources of innovation throughout the supply chain, sectors where particular technologies are predicted to have the greatest impact, and the nature of improvements those technologies are anticipated to generate. A reduced demand for human labor in some areas can be expected, along with the requirement for new skills in others, which can help inform future education and training needs. Similarly, these findings contribute

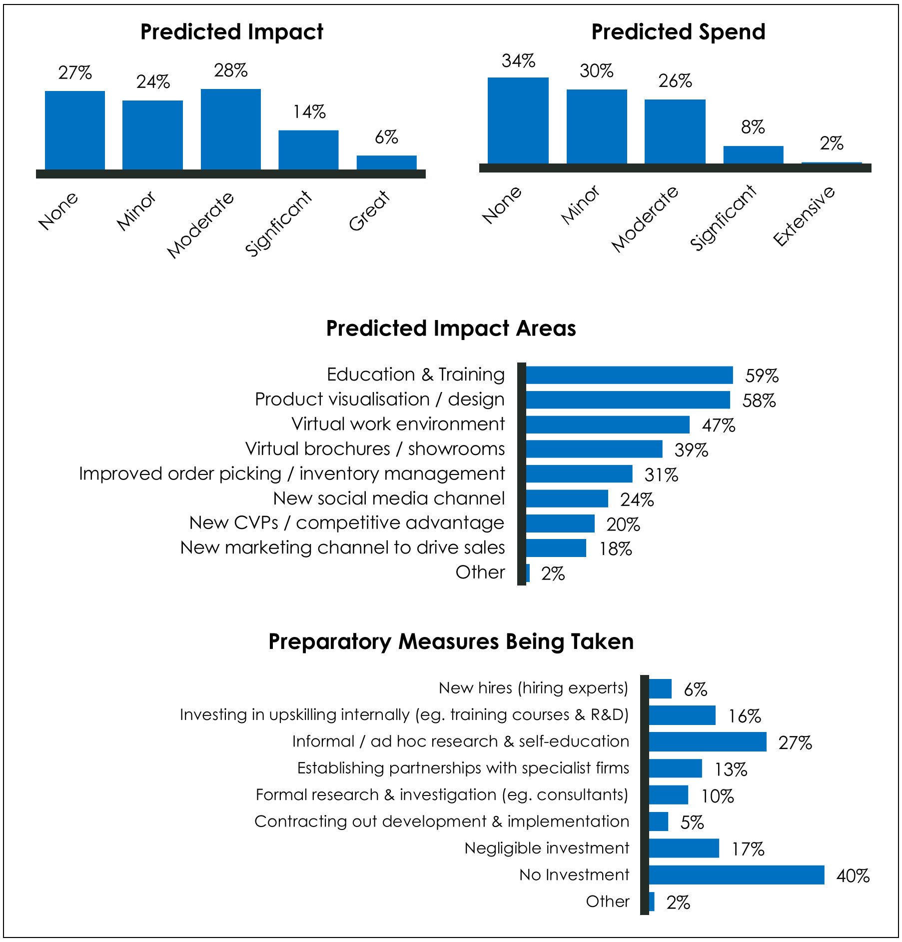

Fig. 12. Predicted Impact and Spend Forecast for VR/AR.

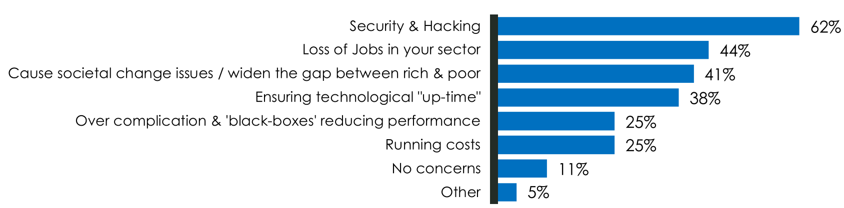

Fig. 13. Concerns regarding the Emerging Digital Technologies.

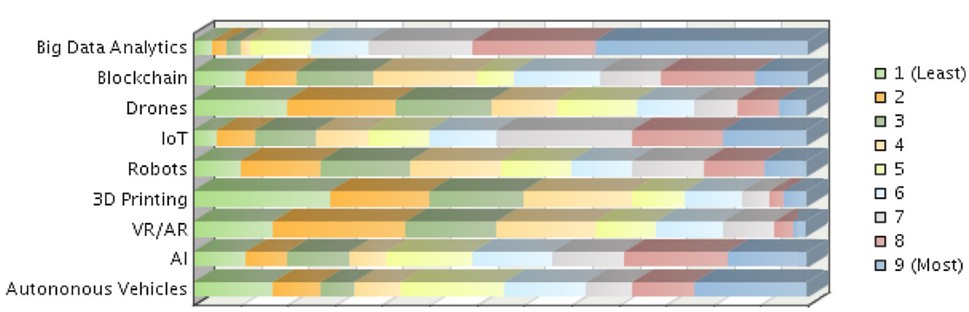

Fig. 14. Most Significant Overall Impact of Emerging I4 Technologies.

valuable new real-world data on opportunities and potential limitations for I4 technologies, which support future academic theory building.

The interrelationships between these advances in technology, with improvements in process and network structure, support Arlbjørn et al. (2011)'s concept of *innovations within the supply chain network* (*ISCN*). Similarly, if technologies enable supply chains to function in new ways that generate value, this aligns with Linton (2017)'s Emerging Technology Supply Chains (ETSC) field of research.

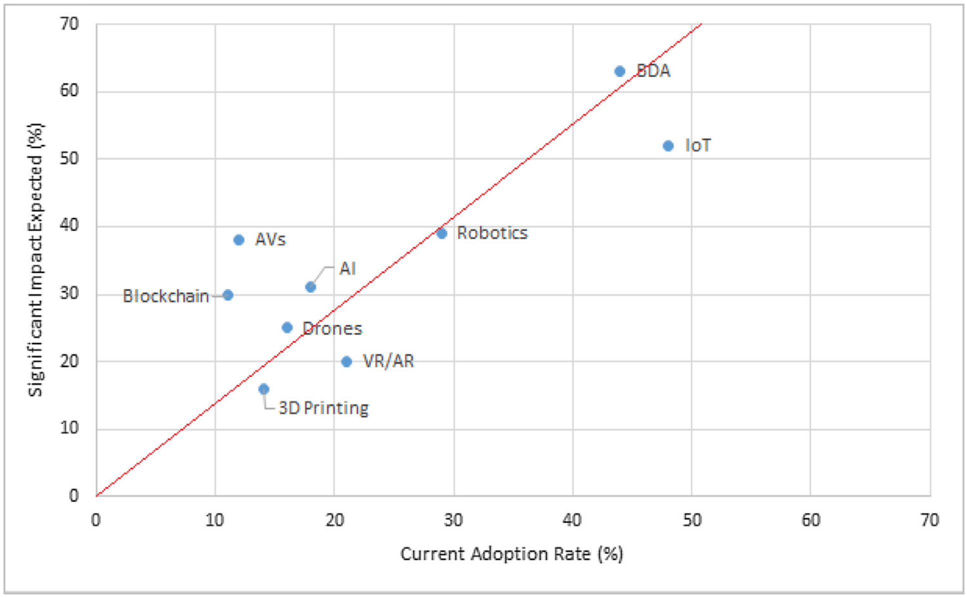

Fig. 15. Level of Current Adoption Rate vs Impact Expected.

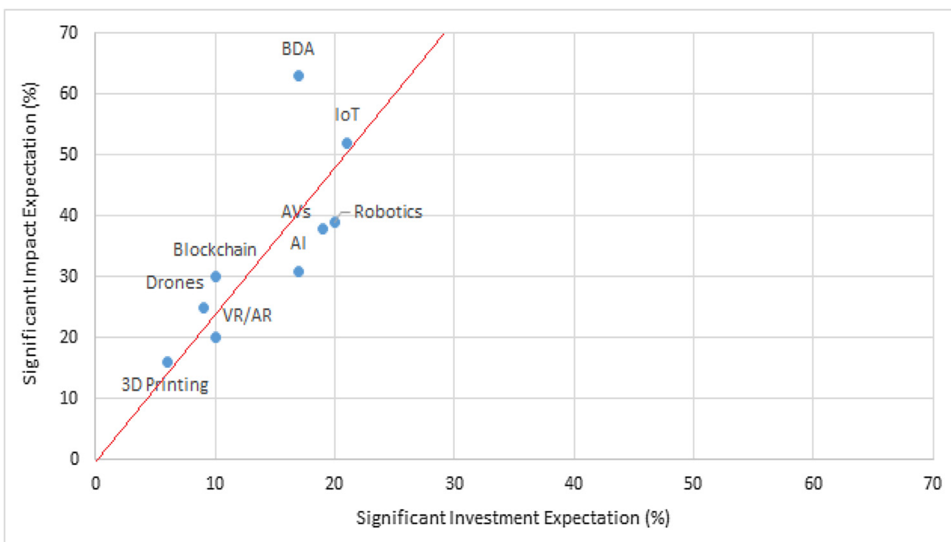

Fig. 16. Significant Impact Expected vs Significant Spend Expected.

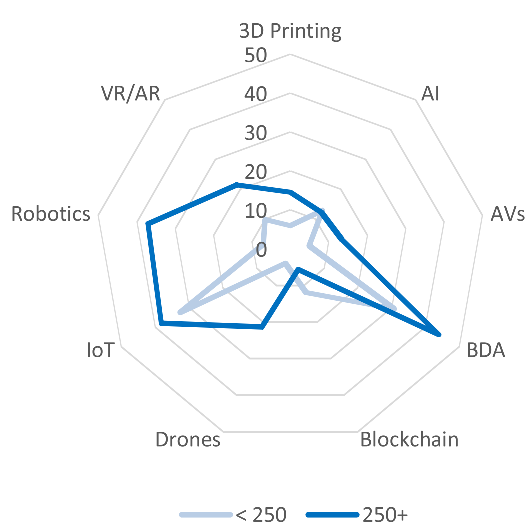

Fig. 17. Technology adoption rates of large firms vs small firms (%).

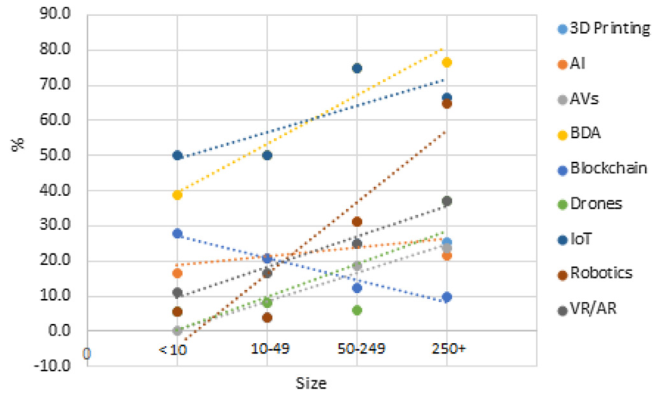

Fig. 18. Linear relationship for technology adoption rates of large firms vs small firms.

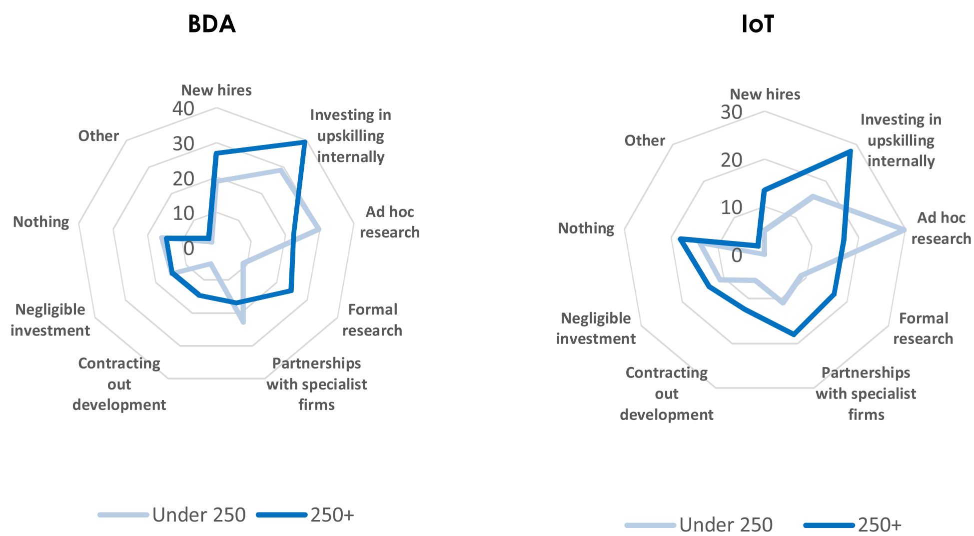

Fig. 19. Comparing typical preparatory measures of large firms vs small firms.

The author believes that the objectives of this research, to create new knowledge and gain an accurate depiction of current adoption rates, preparatory measures and impact predications for I4 technologies amongst Australian supply chain organisations, and the role that organisational size plays in this, have been achieved. It is hoped that the findings make a noteworthy contribution to a significant field, have practical implications for both academic researchers and industry practitioners, and encourage further debate and investigations into this fascinating topic.

One key limitation of this study is its focus on a small geographical region. To address this issue, the researcher is partnering with a number of other academic institutions to extend this investigation outside of Australia, to Europe, Asia and North America, where the they hope to conduct a 'compare and contrast' analysis of I4 technology adoption and usage, across different parts of the world.

The emergence of COVID-19 in 2020 has significantly impacted global supply chains, restricting the movement of goods and forcing many to staff to work from home, in an attempt to slow the spread of the pandemic. As a reaction to this, supply chain firms have had to adapt and find alternative ways of operating, including the digitalization of existing processes.

An acceleration of interest in digitalization and automation is extremely likely, as companies seek ways to increase their resilience to the catastrophic threats they have seen pandemics can have on supply chains, by automating more tasks and processes traditionally conducted by humans.

The technologies investigated in this paper will play critical roles in the post-COVID recovery, and it is hoped that these timely findings can inform both government policy makers and industry practitioners, as they prepare their new digital roadmaps for the challenging years ahead.

CRediT authorship contribution statement

John L. Hopkins: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration.

Declaration of Competing Interest

There are no conflicts of interest to report.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.compind.2020.103323.

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