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Equipping Australian Manufacturing for the Information Age

iManufacturing – Is Australia ready?

DISCUSSION PAPER • September 2014

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Manufacturing Flagship

Citation

Adams N, Lefort L, King P, Prentice L, Taylor K and Kambouris P (2014) Equipping Australian Manufacturing for the Information Age iManufacturing – Is Australia Ready? CSIRO, Australia.

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1 Executive Summary

Triggered both by current economic circumstances and the global move into the Digital Age, Australian manufacturing is reaching a pivot point. The industry wide adoption and utilisation of modern information technology and the development of associated skills will be significant deciding factors in whether Australia can grow its standing both domestically and internationally in the market for high valued, niche manufactured goods and associated services.

To meet the needs of customers and markets and to be economically viable, it is recognised worldwide that advanced manufacturing is evolving towards smaller batches, customised products, rapid prototyping, and agile manufacturing processes while an emphasis on increased servitisation is also visible. In this context, Australian manufacturers must develop appropriate business models and prepare themselves for increasingly innovative and competitive offerings in terms of price and flexibility in their domestic and international market niches.

We observe, the future megatrend of the Digital Age, the future of manufacturing, will be significantly shaped by the global trend towards *iManufacturing*: 'Internet of Things Manufacturing'. Internet-of-Things (IoT) technologies will operate not only within the factories and across the supply chains, but also as the product and service. This trend has significant implications and opportunities for how Australian SMEs do business, market their products and associated services, shape their factories, train their staff and adapt to the future.

The acceleration in the pace of information technology development creates special challenges for Australian SMEs in many cases: they are smaller than their international competitors and may lag behind in adoption of Internet technologies as well as access to the skills base required to successfully adopt these technologies.

In seeking to understand how Australian manufacturers can benefit and take advantage of these new industrial settings CSIRO has mapped the technology landscape for Manufacturing ICT and reviewed the current pain points for both large and small companies. We have identified four types of technologies, which may be described by the functions they perform in the manufacturing enterprise as having the potential for significant impact.

- ***Materialisation*** technologies support the transition from the design phase to the manufacturing phase.
- ***Lifecycle Management*** technologies cover all phases of a product life and focus on the management of multiple, nested feedback loops to continually improve the production, to redesign parts, components and products, and to optimise the underlying technologies to make a business more sustainable.
- ***Manufacturing Execution System*** technologies support the capture of data from the physical environment and process execution for the management of resources and processes.
- ***Enterprise Resource Planning*** technologies support all type of business transitions and transactions and the management of the underlying data

The relative importance of these technologies as building blocks for integration across different systems varies with the enterprise type. SMEs now and going forward will be faced with the challenge of deciding what data are important, what systems they should use, and whether they should procure or replace existing IT systems by cloud-based services (eManufacturing). All of these systems have the potential to address cost pressures and increasing personalisation of products and inherently improve the competitiveness of the companies themselves; but need to be chosen judiciously.

To proactively engage with emerging digital disruptions, enterprises must face the challenge of the adoption of industrial IoT technologies (iManufacturing): wireless networking and machine-to-machine connection protocols, device and sensor connectivity platforms, and recently developed types of robots, 3D printers and smart building systems. The utilisation of these technologies also requires understanding the costs and benefits of eManufacturing and iManufacturing investments, especially in a context where some services are supplied by a third party. The promised 'Big Data' benefits are often tied to the availability of good quality and continuously captured factory floor data: this is a fresh requirement for suppliers of robots and machine tools and the progress in this area in academia and standards organisations has to-date been patchy.

To compete globally, enterprises need to have the right skills and tools to do business, adapt to the future, link into global networks, market their products, shape their factories, and train their staff – in essence they need to become "digital natives". Specifically,

- Develop workers with not only *eSkills* (general computer/internet abilities) but also *iSkills* (understanding data, connectedness, the Internet of Things)
- Encourage and develop *Materialisation* technologies that more rapidly turn digital, customised data into physical outputs
- Develop collaborations and networks at local and global scales that are not only engaged at the human communications level but are sharers of data, resources, and processes
- Improve supply chain interoperability and material flow efficiencies
- Move manufacturing industries increasingly into the service spaces – the servitisation of Manufacturing
- Develop appropriate business models that maximise the potential that these new technologies provide

Other countries are promoting these themes with initiatives like the Smart America Challenge in the US (http://www.smartamerica.org/) which is "bringing together organisations with Cyber-Physical Systems (CPS) technology, programs, and test beds to demonstrate the potential to improve safety, sustainability, efficiency, mobility, and overall quality of life". These initiatives are timely because the convergence of Web, Internet of Things and Manufacturing technologies is a game-changer for the underlying "stack" of standards which is an important barrier for new entrants in normal times – the current profusion of manufacturing data standards makes it very difficult for SMEs to decide, which standard to commit to.

A first round of industry consultation has helped CSIRO to corroborate the findings of its state of the art review and to identify specific skills acquisition pathways. We have identified that the next step is to develop thematic activities targeting Informatics needs, which are common and critical to each type of enterprise:

- To build "digital enterprises" with superior materialisation skills both in terms of products and factory development;
- To build "virtual enterprises" sustainably, competitive locally and/or as members of global value chains;
- To build "smart enterprises" with the informatics backbone to capture the live data needed to continually tune business performance and reassess tradeoffs;
- To build "informatics-linked" enterprises with superior ability to optimise the use of resources: materials, energy, machines and workforce.

2 Recommendations

This report highlights that for the Australian manufacturing sector to progress in its aspirations to be globally competitive a digitally inspired platform of action incorporating the following recommendations will need to be developed:

Recommendation 1: *Support research into IT solutions enabling the "**digital enterprise**" enterprises with superior materialisation skills both in terms of product and factory planning.*

Recommendation 2: *Support networks for SMEs, that on the one hand assist SMEs in upskilling their workforce and on the other provide decision support and help to analyse a company's IT requirements and make correct purchase decisions. Furthermore, Australia will need to invest in research activities, that work towards developing solutions for the "system of systems" problem and which allow the seamless integration of materials, process, production and business information, including the adoption and development of open data exchange standards.*

*As such, we need to develop "**virtual enterprises**" that are either sustainably competitive locally and/or as members of global value chains.*

Recommendation 3: *Develop business support networks, which will alert SMEs to the possibilities offered by servitisation and work with them to develop the prerequisite eManufacturing and iManufacturing skills. Furthermore, we need to support research into both the economic drivers and barriers towards greater servitisation of the manufacturing industry together with research into information technology that allows the seamless integration of manufactured good and data as outlined above. Many Australian SMEs are currently unaware or not thinking about servitisation as an additional line of business. Business model development e.g. through design-led innovation practices will play an important role in providing business with the wherewithal to develop appropriate business models and thus export opportunities.*

*Through these mechanisms "**smart enterprises**" will be developed*

Recommendation 4: *Develop the "**informatics-linked**" enterprise with superior ability to optimise the use of resources: materials, energy, machines and workforce.*

3 Coming Disruptions

Manufacturing is an important component of the Australian economy and its reach impacts nearly 7% of GDP in 2012-13[1]. The sector is also a significant investor into research and development accounting for 24.4% of Business expenditure in Research and Development in 2011-12[2]. In spite of this, the manufacturing sector's contribution to the gross national product has declined by 2.4% over the over the ten year period from 2002-03 until 2012-2013[3], due to a combination of uniquely Australian factors and developing global disruptions.

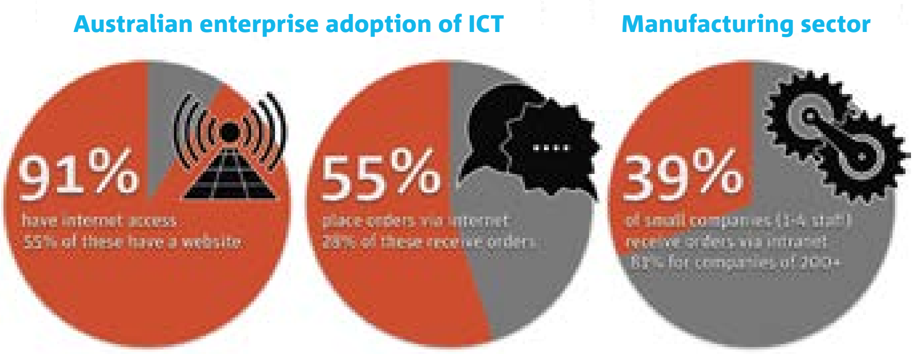
The sector is currently grappling with the fact that it is, on an international scale, small and remote, making it difficult for Australian SMEs to participate in global supply chains as contracted suppliers[4]. Furthermore, there is a relatively narrow economic base through a focus on a small number of industries (foods, beverages, metal products, machinery and equipment), operating on a high cost base and that is has low productivity growth. Nonetheless, Australian companies are still finding opportunities to participate in global supply chains especially around high value, low volume and customised products[5].

CSIRO, through consultation with the industry and the Commonwealth Department of Industry have identified a number of hidden cost factors, which contribute to some of the existing challenges of operating within Australia's so-called high cost economy. Emerging disruptive trends have also been identified, with which Australian companies need to engage early in order to stay both domestically as well as globally competitive. These new observations revolve around how Australian companies access and use information and digital technologies in the manufacturing and broader industrial sector.

Hidden Cost: Underutilisation of Existing Information Technology

The lack of adoption of ICT technologies in manufacturing can be understood on multiple levels, these being: basic use, use of computer-aided manufacturing technologies and technologies required to address future disruptions, which we will discuss below.

When considering the basic use and adoption of ICT technologies in enterprises, while approximately 91% of all Australian businesses have internet access (2011-2012), only half of these have a web presence[6]. Furthermore, while 55% of all businesses place orders over the internet, only 28% are able to receive orders over the internet. Although manufacturing is somewhat ahead of this (39% of very small (1-4 employees) manufacturing companies are able to accept orders rising



Use and adoption of ICT technologies.

[1] ABS, Australian System of National Accounts, Original, Chain Volume Measures (Cat No. 5206.0)

[2] ABS, Research and Experimental Development, Businesses, Australia, Current Prices (Cat No. 8104.0)

[3] ABS, Australian System of National Accounts, Original, Chain Volume Measures (Cat No. 5206.0)

[4] EFIC SME Exporter Index – March 2014 (pages 40-41) http://www.efic.gov.au/export-community/events/exportfinancebriefing2014/Documents/ESI_Brochure.pdf

[5] see, for example, Marand Press release April 2014 http://www.marand.com.au/press/item/91-marand-delivers-first-australian-made-vertical-tails-for-f-35-lightning-ii

[6] Australian Bureau of Statistics 8166.0 – Summary of IT Use and Innovation in Australian Business, 2011-12 (Cat No 8166.0)

to approximately 81 % for companies over 200 employees), this still indicates that many business are significantly under-utilising modern information technologies: adoption of ICT, as measured by internet presence, correlates with company size – the smallest companies being the least connected.

CASE STUDY:

NETWORKS AND DATA-SHARING POTENTIAL IN THE FRESH FRUIT INDUSTRY – RADEVSKI COOLSTORES

The fresh fruit industry in northern Victoria is a significant part of Australia's agricultural landscape and with increasing exports to the Asia-Pacific region their improved use of information systems has the potential to underpin potential opportunities in the sector. Use of modern ICT and sensor technology could significantly impact business both in the management of orchards as well as supply chains. To make optimised business decisions (e.g. when to harvest and how much fruit to bring to market), fruit growers are reliant on environmental data (e.g. weather, rainfall, soil moisture, pH, sunshine hours etc.) in order to not only estimate crop yields, but also harvest times etc.

Another key aspect is supply chain data gathering and communication. Radevski Coolstores has a number of important customer and network links, where improved information transfer could lead to enhanced business outcomes. Data gathered and exchanged by Radevski Coolstores, other fruit growers and various industry bodies includes coolstore stock data. Such an exchange is dependent upon individual coolstores submitting what is often seen as proprietary information. Transmitted data is aggregated by industry bodies and re-distributed to all members mainly via human intervention, resulting in time lag and privacy problems.

Scalable, fit for purpose informatics solutions could not only add validity to orchard and supply chain data, improve timeliness, maintain appropriate levels of security for proprietary information but also value add through analysis and subsequent predictive recommendations. Furthermore, deeper communication between producers/processors and the major industry bodies could lead to productivity gains through increased yields, sales, and profits as well as improved environmental outcomes and resource use being maximised.

The take-up by Australian SMEs has also been identified as an inhibitor to Australian companies being able to take advantage of the digital economy. ACMA in their recent report on Australian SMEs in the digital economy identified that "Sixty per cent of SMEs indicated that their self-perceived lack of knowledge about the digital environment is preventing them from being more efficient. However, only half (51 per cent) have actively tried to improve this, mainly through independent learning tools such as online search (65 per cent of those who have tried to improve) and online tutorials (49 per cent of those who have tried to improve)."[7]

The relatively low take up by business and government of ICTs also contributes to Australia's rather modest rating in the World Economic Forum's Global Information Technology report 2014 – (Australia is ranked 18 in this report)[8]. The development of a web presence and eCommerce capabilities are leading indicators towards using information systems for more complex purposes such as the development of virtual enterprises and supply chain integration.

Information technology infrastructure together with basic ICT tools and – even if not at the level of more sophisticated tools such as Enterprise Resource Planning (ERP) systems to manage business processes – has a significant role to play in improving the operations of even the smallest manufacturing SMEs.

Hidden Cost: Insufficient Manufacturing Data Interoperability in Supply Chains

Our consultations with a number of SMEs across multiple sectors have established that even where enterprises have adopted ICT tools such as enterprise resource planning software, these tools cannot readily exchange information across supply chains, requiring human intervention to "make the data flow". For one SME we consulted, such human intervention represents a cost of up to 14% of profit, which is currently absorbed by the business. Many businesses we have talked to were not aware that this is a "real" cost, but rather just accepted it as an inevitable part of doing business.

Such manufacturing data non-interoperability has significant consequences for Australian SMEs, and has been identified as one of the underlying factors, which

[7] The Australian Communications and Media Authority Communications Report 2012-13 series *Report 1 – Australian SMEs in the Digital Economy* January 2014 http://www.acma.gov.au/~/media/Communications Analysis/Report/pdf/Australian SMEs in the digial economy pdf

[8] Benat Bilbao-Osorio et al, *The Global Information Technology Report 2014*, World Economic Forum in association with the Insead Business School and and Cornell University

prevent them from participating in, and becoming Tier 1 suppliers in global supply chains. The formation of Virtual Enterprises and Virtual Supply Chains, supported by information and computer networks, shared resources and knowledge, would enable Australian SMEs to economically and scalably take part in the global supply chains but also to address the externality of tapping into distributed innovation, contributing to it and benefiting from it.[9]

While manufacturing companies are relatively ahead of the game in accepting orders for products over the Web, 80% of manufacturers do not have any automated link to transfer an order received via email or a web site to the company's internal business systems, and this weakness is well above Australian industry average[10]. While it may relate to the relative complexity of orders in the manufacturing industry, it must contribute significantly to both costs and supply chain inertia in the industry.

The adoption and use of modern ICT technologies and open data standards can be expected to have a significant role to play in removing both these costs and inertia.

Coming Disruption: Significant Global Expansion of Manufacturing Capacity

Global industrial production continues to grow by around 3% per year, despite the dip caused by the Global Financial Crisis of 2008. Manufacturing capacity continues to grow particularly strongly in developing countries, whereas high income countries have experienced little growth over the last 5-10 years. Within this context, Australian manufacturing has become a smaller player in the global industry. Because of this expansion, Tier 1 manufacturers are seeking to de-risk and diversify their supply chains. Again, sufficient scale and de-risking could be achieved through the formation of virtual enterprises and supply chains.

The extensive use of information technology and an effort to develop manufacturing data interoperability will be prerequisites for navigating this disruption.

Coming Disruption: Fragmenting demand, shortening product life-cycles and the increasing requirement for "bespoke" and personalised products

Emerging economies in Asia are rapidly adding wealth. According to the McKinsey Global Institute, the per capita income in China has doubled in the last twelve years.[11, 12] McKinsey estimates, that by 2025, an additional 1.8 billion people in developing countries will be part of the consuming class bringing this up to a total of 4.2 billion. For manufacturers this means that, while consumers in developed economies demand new products at increasing speed, "new" consumers in emerging economies often require different products from those sold in established economies, thus adding significantly to manufacturing complexity. Further complexity is added through the increasingly routine availability of additive manufacturing tools, which allow the development of highly personalised products – in extreme cases, products of one for markets of one.

Information technologies will be critical in managing manufacturing complexity and personalisation and mitigating risk arising from this. For SMEs, this means having to decide which information tools to use to manage this complexity and to have the skills base and absorptive capacity within an organisation that allows such decisions to be made.

Coming Disruption: Transition from Pure Manufacturing to Manufacturing and Services – Servitisation, "Industry 4.0"

The convergence of manufacturing and services is another global trend. Manufacturers are moving away from purely making "widgets" to developing services around a product which are tightly integrated with the product, allow the product to be used more optimally and which can be used by the manufacturer to develop new lines of business. Servitisation can considerably shift a manufacturer's activities and profit base towards the provision of ongoing services for the products that the company supplies.

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9 P. Marlow et al., Joined Up Innovation: Making the right connections across Australia's innovation ecosystem to support our future growth and international competitiveness. Microsoft Australia 2014

10 Australian Bureau of Statistics – Summary of IT Use and Innovation in Australian Business, 2011-12 Internet commerce – Business systems supporting the receipt of orders (Cat No 8129.0)

11 J. Manyka et al., Manufacturing the future: the next era of global growth and innovation, McKinsey Global Institute (2012), http://www.mckinsey.com/insights/manufacturing/the_future_of_manufacturing

12 J. Manyka et al, Global flows in a digital age: How trade, finance, people and data connect the world economy, McKinsey Global Institute (2014), http://www.mckinsey.com/~/media/mckinsey/dotcom/insights/globalization/global flows in a digital age/mgi_global_flows_executive_summary_april2014.ashx

Such services are often based on data or have a data and information component. An example in the consumer space are manufacturers of external hard drives and storage devices, for example, which have developed services around the hard drive that allow a consumer to turn the device into a private cloud, which can be managed and accessed with, for example, a corresponding smartphone app.

"Industry 4.0"

Many developed Western countries have already realised that they need to move away from manufacturing without services and services without manufacturing if they want to stay competitive on their own soil and be active members of global value chains. In these countries, this has led to a reassessment of how ICT technologies should be used in manufacturing with a strong pressure on formerly endemic markets to adopt disruptive approaches like Cloud Computing and the Internet of Things at the same rate as they are adopted in the rest of the economy.

This movement, known as "Industry 4.0", is driven by governments, public/private partnerships and industry alliances in all major countries. The leading initiative is Germany's "Industrie 4.0" flagship program[13], which federates 32 research projects (20 on Cyber-Physical Systems, and 12 on Autonomics research themes)[14]. France's research efforts are driven by the National Research Agency (ARC) via the FutureProd roadmap[15] and the Industry 4.0 themes are endorsed by GIMELEC[16], the French Industry Association for Electrical Engineering and Control. The United Kingdom has also recently completed a major "Future of Manufacturing" foresight program[17] and its Technology and Strategy Board introduced several catapult centres[18] to grow the innovation networks and increase the technology transfer from academia to industry. A similar objective motivates the creation of several Innovation institutes grouped together into the National Network for Manufacturing Innovation[19] in the United States. There are also other initiatives directed at innovation in cyber-physical systems, including interoperability test bed challenges like Smart America.[20]

Responding to this servitisation trend will again require SMEs to become information and data savvy.

Coming Disruption: The Physical and Virtual World will Seamlessly Intermix

Recent trends reduce the distinction between the purely physical and the purely digital.

Manufactured products may be specified or designed in a virtual world, visualised in their final form and place, and manufactured by real equipment to produce the final physical product. In the final phase of this transition, the physical and virtual worlds are blurred: reality is augmented with information on products, services, and specifications – not only in the consumer/outside world but also within the factory. Manufacturing machines and processes 'speak' with operators, managers, and the Informatics-linked enterprise that oversee the process. Such a blurring of the virtual and physical worlds is also often the prerequisite for the development of services described above.

Taking advantage of and participating in this trend will again require SMEs to become knowledgeable about information technology and data.

[13] Industrie 4.0 Working Group, Securing the future of German manufacturing industry Recommendations for implementing the strategic initiative INDUSTRIE 4.0 Final report of the April 2013 (2013) http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf

[14] Rauschecker, U. (ed.) Road4FAME Deliverable D1.1 Report on Results and Concepts from Relevant Initiatives (Annex I: Identified research initiatives and projects) http://road4fame.eu/wp-content/uploads/2014/04/Road4FAME_609167_D1-1_ReportOnResultsAndConceptsFromRelevantInitiatives.pdf

[15] Brissaud, et al., What Tracks for Sustainable Production Systems in Europe?. Procedia CIRP, 7, 9-16. (2013) http://dx.doi.org/10.1016/j.procir.2013.05.003

[16] GIMELEC, Industrie 4.0 L'usine connectée, GIMELEC (2013) http://www.gimelec.fr/content/download/1186/11411/version/3/file/Industrie+4.0_L%27usine+connect%C3%A9e+Version+finale.pdf

[17] UK Foresight, Future of Manufacturing http://www.bis.gov.uk/foresight/our-work/projects/current-projects/future-of-manufacturing/reports-and-publications

[18] http://catapult.org.uk/

[19] http://www.manufacturing.gov/nnmi.html

[20] http://www.nist.gov/el/smartamerica.cfm and http://www.smartamerica.org

4 Information Technology Needs of Manufacturing in the 21st Century

Background

The information technology needs of manufacturing companies vary by business type and size, and this diversity is a key challenge for the Australian industrial and manufacturing sector global future competitiveness.

For the past thirty years, manufacturing ICT has been characterised by tools which broadly fall under the heading of "computer-aided manufacturing", denoting software that can be used to control manufacturing tools, workplaces and the operations of factories. Typically, such tools are targeted for an individual machine or enterprise and are static, data-siloed and relatively heavy weight.

The last ten to fifteen years of manufacturing ICT and associated data standards development has seen ongoing incremental improvements in these tools, enabled by very significant increases in computing power at smaller size and cost. For example, advances in the power, connectivity, and programmability of controllers (hardware) have now been combined with industrial wireless networks and more secure communication protocols. This adoption of mainstream ICT is continuing with a switch to cloud-based services run in remote data centers and the replacement of PC-like hardware by smaller and cheaper Internet of Things devices (see below).

With the advent of new internet technologies, collectively known as the "Internet of Services" and the "Internet of Things", we are beginning to have three generations of ICT products, which are relevant for manufacturing, and the transition of manufacturing into the next century can be framed in terms of the adoption and use of these technologies:

- ***"Classical" Computer Aided (20th Century)Manufacturing ICT – cManufacturing ICT*** – corresponds to the first 30 years of use of ICT for Manufacturing characterised by a fragmented market and limited connectivity between proprietary tools. Many Australian SMEs currently have not even adopted these tools.
- ***eManufacturing ICT*** corresponds to the evolution to web-based products or cloud-based software products and to what is generally known as the servitisation of Manufacturing.
- ***iManufacturing ICT*** corresponds to the evolution towards products developed with the web or the internet of things in mind. These products can be differentiated into two categories: (a) products manufactured through use of these technologies in the factories or supply chains and (b) products, which incorporate these technologies directly.

cManufacturing ICT

20th century Manufacturing ICT principally addresses the needs of two functions within a company:

(a) the design of internal processes and products and

(b) the management of relationships with customers and supply chain partners.

Software providers have therefore focused on the development of product data management tools for the design function, and enterprise data management for the business operations function. Typically, proprietary interfaces are used to translate 3D designs into milling machine instructions and to retrieve information from the factory floor or from the external supply chain to feed into business transactions.

Many Australian SMEs have not fully adopted even these tools, and where such tools have been adopted, the acceleration of the pace of technological change in these automation and control systems, increases the complexity of the system migration problem[21] with a marked growth in technical obsolescence issues and workforce upskilling challenges. These issues are partially mitigated by the incremental but constant consolidation of the industry (via mergers and acquisitions) and the development of industry standards and consortia.

Figure 1 shows that a number of technologies are extended over more than one manufacturing market segment. The four arrows on the figure emphasise the different motivations behind these bridging technologies:

- ***Materialisation*** technologies support the transition from the design phase to the manufacturing phase. The key motivations here are to speed up the configuration of new factories and to use the product design data to better program the machines and robots for tasks such as the inspection of a finished product or part.

[21] O'Brien, L. and Woll, D. (2010) The Control System Migration Survival Manual ARC Strategies http://www.schneider-electric.co.uk/documents/solutions/process-automation/life-cycle-services-and-modernisation/The%20Control%20System%20Migration%20Survival%20Manual.PDF

- ***Lifecycle Management*** technologies cover all phases of a product life and focuses on the management of multiple, nested feedback loops to continually improve the production, to redesign parts, components and products, and to optimise the underlying technologies to make a business more sustainable.
- ***Manufacturing Execution System*** technologies support the capture of data from the real world required for the management of resources and processes.
- ***Enterprise Resource Planning*** technologies support all types of business transitions and transactions and the management of the underlying data.

Where we are now – cManufacturing ICT

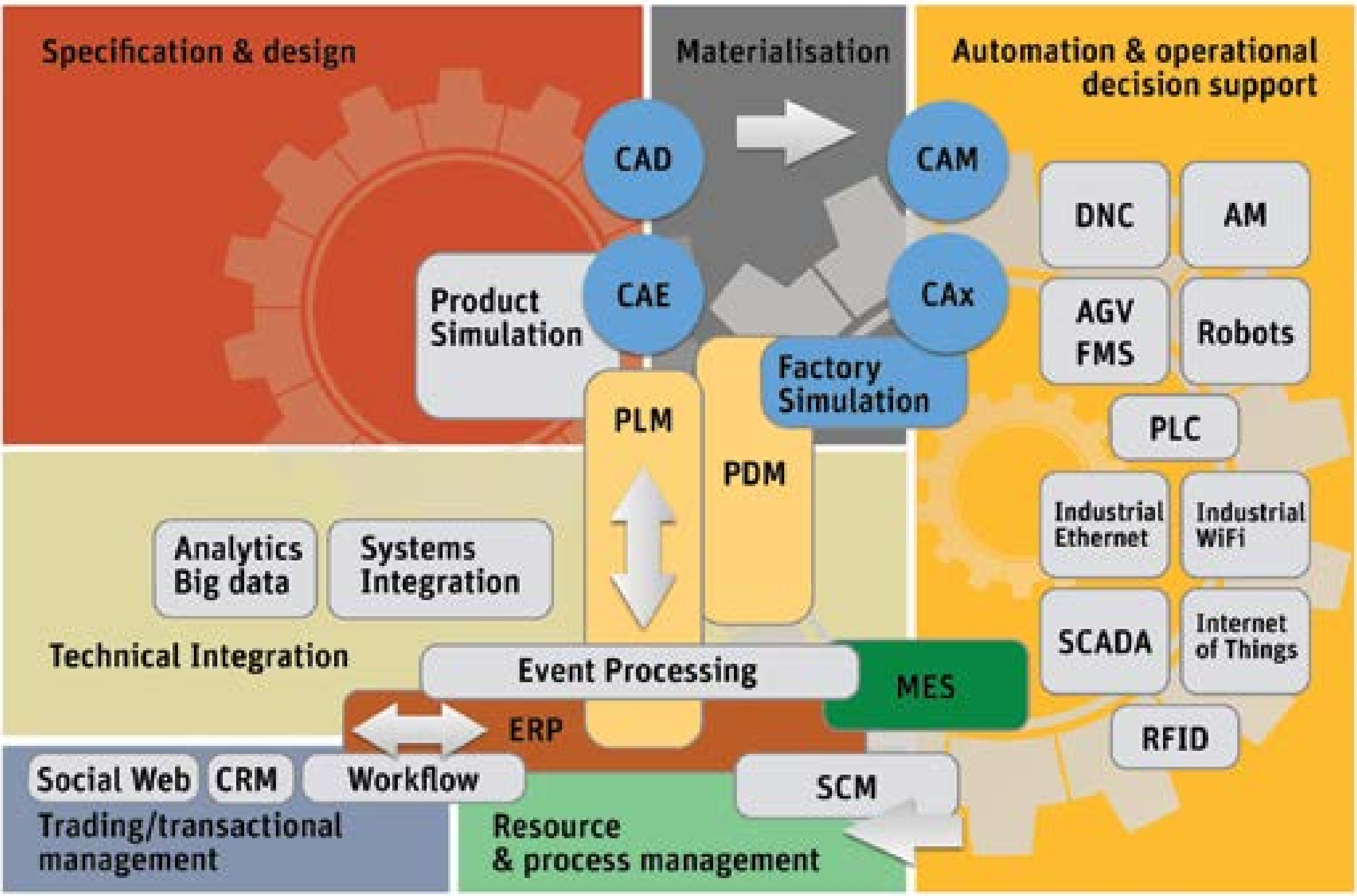


FIGURE 1: **Manufacturing ICT market segments.**

eManufacturing ICT

eManufacturing ICT corresponds to the evolution of localised manufacturing ICT products to the cloud. More precisely, two major evolutionary steps can be observed: (a) the transition to web-based technologies and (b) the transition to new business models where key IT infrastructure services are outsourced to third party companies. This has been a progressive evolution, first from a web of documents to a web of services, and then from a more interactive or social web of apps to cloud-based infrastructures supporting a range of professional services exploiting large-scale data resources.

The transition from *cManufacturing ICT* to *eManufacturing ICT* was started mainly through the adoption of Software-as-a-Service (SaaS) business models by leading software vendors. These new *eManufacturing ICTs* are defined as a group of technologies that serve the needs of a broader community of users via the virtualisation of IT services to the cloud like Enterprise Resources Planning software.

This evolution has enabled the emergence of global supply chains, of better coupling of products, manufacturing processes and their associated services,[22,23] and of new forms of collaboration. The emphasis on value co-creation, especially in non-hierarchical supply chain networks, requires significantly better external data exchange capabilities for all the types of IT systems used in Manufacturing. External access to formerly closed systems must now be offered to a range of new users, including partnering company staff and end customers for co-design, co-planning, and sometimes co-engagement with third-party stakeholders. Better internal integration of manufacturing systems is also required because of the increasingly tight coupling of services and products, which is now recognised as a key factor for the competitiveness of enterprises, especially for High Value Manufacturing countries.

CASE STUDY:

CLOSE THE LOOP

Close the Loop® (CtL) is Australia's leading collector and recycler of inks and toner systems. Based in Melbourne, Victoria, the company has grown rapidly, and now operates across Australia and in the United States. The primary customers of CtL are the OEMs (Original Equipment Manufacturers) of the ink and toner products. CtL's value proposition is the combination of the physical process and the overall service: the collection, testing, sorting, return for OEM reuse, recycling, and data capture (including embedded 'chip' data) on the cartridges.

Close the Loop operates over 50,000 collection sites, down to the level of specific floors or rooms within office buildings, which are individually identified in their data system. CtL supplies collection boxes/bags to their end users (sites), who can submit an online request for collection. Physical collection is achieved through Australia Post's reverse-logistics system.

Data flow and tracking systems allow detailed communication and transmission of information about each collected package. Close the Loop identifies the weight of each package, the type and manufacturer of each cartridge, residual ink/toner weight, specific 'on chip' information (where available), and proportion and type of counterfeit cartridges collected. The collection of these data is assisted by highly-trained employees who are familiar with each ink/toner system and its specific details of construction and information embedded.

The informatics system currently in operation by Close the Loop is an example of the management of good data collection systems and the potential to be gained from the information. Furthermore, the 'service' offered to the OEMs has very significant potential: the scope of Close the Loop's value proposition has gone far beyond the physical collection and recycling of ink and toner cartridges, and has extended to the service value of the data for environmental reporting, installed printer/copier base auditing, counterfeit detection/tracking, 'chip' data integration, and so on.

[22] Nielsen, et al. The Services Dilemma: Productivity Sinkhole or Commoditisation? Services Transformation and Professionalisation: The Algorithmic Revolution and Empowered Human Value Creation (2013) http://www.serviceplatform.dk/videnbase/documents/services_dilemma_book-4.pdf

[23] Brax, S.A. The process based nature of services – Studies in management of industrial and business-to-business services Aalto University publication series Doctoral Dissertations 60/2013 (2013) http://lib.tkk.fi/Diss/2013/isbn9789526051109/isbn9789526051109.pdf

Next transition – eManufacturing ICT

Additionally enterprises will benefit from tools, which enable mass information sharing, mass collaboration and mass data processing. For the manufacturing space, such tools are currently largely missing, but technologies developed for software development applications (e.g. DropBox for mass sharing, GitHub for mass collaboration etc.) may provide some indication of the functionality requirements of similar tools for manufacturing[24].

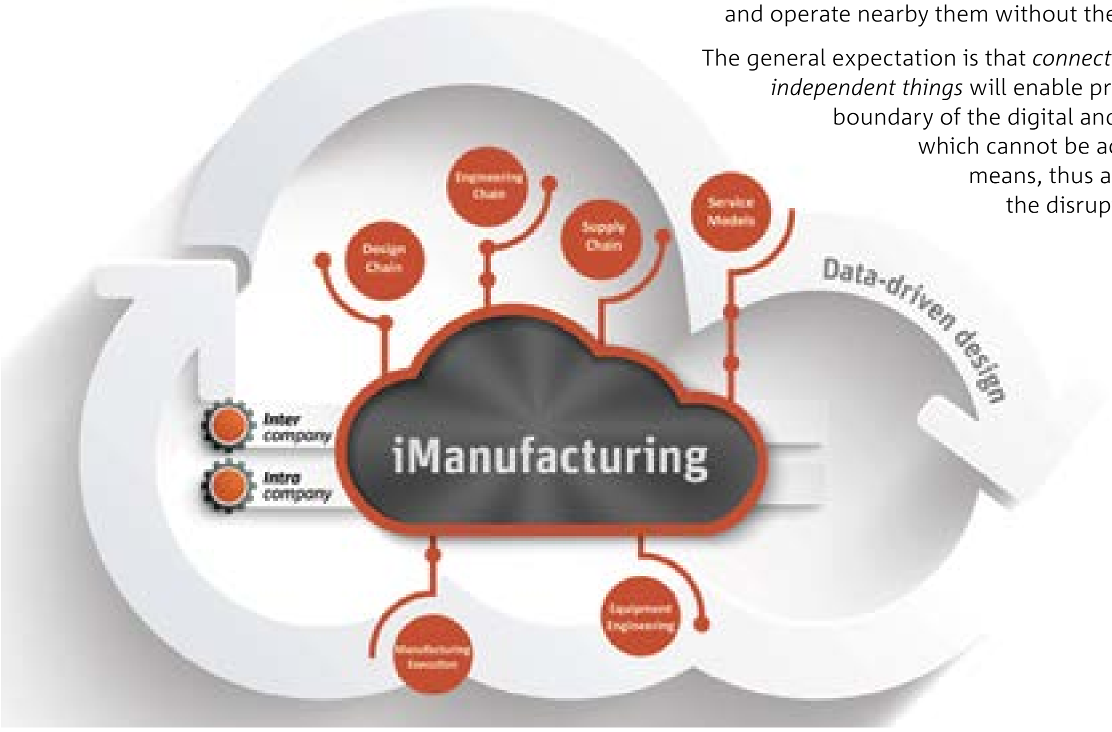
[24] Maranzana, et al. Collaborative Design Tools: A Comparison between Free Software and PLM Solutions in Engineering Education. In *Product Lifecycle Management. Towards Knowledge-Rich Enterprises* pp. 547-558, Springer (2012) http://link.springer.com/chapter/10.1007/978-3-642-35758-9_49

iManufacturing ICT

The next evolution in manufacturing ICT, *iManufacturing*, is being enabled by the introduction of smaller and cheaper wireless-connected devices in manufactured products, developed for consumer markets like home automation, fitness or health and into the manufacturing process itself.

Products incorporating such connectivity are often called 'smart products', relying on Internet of Things (IoT) technologies that may also be used in an industrial context.[25] For example, IoT technology may be embedded in resources used to manufacture end products including machines, robots or the factory floor environment, or it may be employed in the supply chains via smart RFID tags attached to pallets or unit items.

Where we need to be – iManufacturing ICT



IoT devices fall into three categories of *cyber-physical systems* or *things*: "connected things", "controlled things" and "independent things".[26]

- ***Connected things*** combine mission-specific sensors plus enough electronics to capture and transfer the data to other IT systems consuming this data. A simple example of this is a cloud-based app running on a mobile phone or tablet.
- ***Controlled things*** combine mission-specific sensors and actuators to support a simple or complex control loop. An example is to remotely control an air conditioning device to take account of the energy consumption in the neighborhood.
- ***Independent things*** have a greater degree of autonomy and self-learning capability - making them able to operate in complex environments. The Baxter robot developed by Rethink Robotics, for example, is an instance of such an independent thing, which can learn from human operators and operate nearby them without the need for a safety cage.

The general expectation is that *connected*, *controlled* and *independent things* will enable productivity gains at the boundary of the digital and the physical worlds which cannot be achieved by other means, thus addressing several of the disruptions outlined above.

[25] Xu, L.; He, W.; Li, S., "Internet of Things in Industries: A Survey," *Industrial Informatics, IEEE Transactions on Industrial Informatics*, vol.PP, no.99, pp.1,1 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6714496&isnumber=4389054

[26] Mejtoft, T., Internet of Things and Co-creation of Value. In *Internet of Things (iThings/CPSCom), 2011 IEEE International Conferences on Internet of Things, and Cyber, Physical and Social Computing*, pp. 672-677, IEEE (2011) http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6142177

5 Equipping Australian Manufacturing for the Information Age: Three Challenges

Challenge 1 – Enabling Competent ICT Decision-Making

The first challenge for all stakeholders in the manufacturing ecosystem is the development of decision-making competency regarding information collection and management tools.

SMEs need the capability to decide what data are important for their bottom line, what systems they should use, and whether they should procure or replace existing IT systems with cloud-based services. For example, many manufacturing SMEs use multiple CAD products to develop and apply their 3D models, with separate products needed to design for specific processes or machine tools. Information on data integration, translation, or other simplification options could bring immediate savings.

In another example, 'engineering-to-order' businesses (e.g. in the aerospace sector) are not well served by classic Enterprise Resource Planning (ERP) systems because of the burden of the requirement to manually enter detailed and highly technical product descriptions. Product Lifecycle Management (PLM) products are far more flexible than basic ERP systems for this purpose.

To take maximise the advantage of the increasing customisation trend towards 'products of one for markets of one' requires a truly agile and interoperable manufacturing and management information system. Traditional workflow-based approaches for Manufacturing IT systems tend to be broken by non-hierarchical supply networks and by agile businesses where there is a stronger need to handle unforeseen events as efficiently as possible.

The major limitation of currently available cloud-based offerings of software suites, previously procured as commercial off-the-shelf products directly from the vendors or via Independent Software Vendor services, is the lack of seamless interoperability between *Software-as-a-Service* (SaaS) and the cyber-physical assets of sensors, machines and robots owned by an enterprise. These integration requirements are particularly poorly met for companies belonging to non-hierarchical supply chains.

Challenge 2 – Enabling Competent IoT Decision-Making

The second challenge is to push towards the adoption of IoT technologies.

IoT sub-segments which are relevant in a manufacturing context mainly utilise technologies such as wireless networking, machine-to-machine connection protocols, device and sensor connectivity platforms, and recently developed types of robots, 3D printers and smart building systems.

The value proposition for most of these technologies is attached to their ability to better use information available in a digital form and/or to capture data, which can be useful to make a business leaner, more agile and more competitive as well as enabling new service business models to be built around products incorporating these technologies. Reducing, for example, the time a workpiece/work-order spends idle would have immediate cost and agility benefits.

The pace at which manufacturing technologies are upgraded to become iManufacturing technologies is variable and dependent on multiple factors. These factors, are often either external (customer requirements, a changing industry) or security-related. For example, the security risks associated with previous-generation control technologies have triggered their upgrade from proprietary solutions to Internet-proven approaches that have secure protocols, firewalls, and Virtual Private Network capabilities.

In general, the trajectory into *iManufacturing* technologies has followed a common pattern where ICT systems are becoming more interoperable and more complex. Products like Programmable Logic Controllers (PLCs) or Programmable Automation Controllers (PAC) now offer a larger number of programming language options. Products such as industrial networking routers are now implementing all the protocol variants, which multiple industry consortia and standards development organisations have published. Numerical Control machines and robots are now capable of performing a much larger range of functions than previous. Added complexity, however, also requires a more highly skilled workforce to competently take advantage of these improvements.

However, the introduction of the new generation of cheaper, more ubiquitous devices is relatively rare in factories. More diverse and physically distributed sensing capabilities can be implemented by Wireless Sensor Networks with low risk because these systems generally don't require major changes in the way machines or robots are used. Smaller and cheaper single-board actuators and control systems are available and appreciated because their simplicity of configuration and ease of use.

Finally, while it is comparatively straightforward to leverage IoT-derived data from systems such as current generation smart products, when this data is generated in the context of a system or network (e.g. energy consumption data generated by a fridge connected to a city grid, where the ensemble of data generated by all devices on the grid together with data about a power plant's output, for example, is used to set prices), using this data to make decisions about the network is much harder and more work needs to be done by academia and industry.

Many trade-offs exist in making *eManufacturing* and *iManufacturing* investments especially in a context where some of the services are supplied by a third party. The promised "Big Data" benefits are often tied to the availability of good quality and continuously captured data. This is a new requirement for robots and machine tools suppliers and the work in this area by academia or by standards development organisations is patchy.

Challenge 3 – Enabling Workers and Enterprises in the New Information Age – More iSkills for the 21st Century Enterprise and Worker

Australia has very significant personnel, skills, and materials resources to address the challenges of the 21st century and the transition to *iManufacturing*.[27, 28]

The opportunity that presents itself this century is to re-think how manufacturing is undertaken – in particular to re-think manufacturing within a much broader context of information, global connectedness, and the Digital Economy.

Enabling Workers

A key part of future manufacturing is the high performance worker. While a fuller discussion of the role of education and training in Australia's industrial development is beyond the scope of this white paper, the need for greater *eSkills*[29] required for a manufacturing work environment (data management, information literacy, cyber security) are not significantly different from those skills required in other sectors of the economy.

The very recent Manufacturing Workforce Study[30] highlights the increasing necessity for further training: at present 45.2% of the manufacturing workforce has no post-school qualifications. Furthermore, many of the post-school qualifications are technical with very little focus on the technologies required for future informatics adoption in manufacturing. To equip its enterprises with the right skills and tools to do business, adapt to the future, market their products, shape their factories, and train their staff, Australia must bring together many interested parties.

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[27] Manufacturing workforce study, Australian Workforce and Productivity Agency, April 2014 http://www.awpa.gov.au/publications/Documents/Manufacturing%20workforce%20study.pdf

[28] Allison, J., Broun, D. and Lacey, J. (2013) The Rise of New Manufacturing Implications of Game Changing Approaches for Productivity, Skills http://www.utas.edu.au/__data/assets/pdf_file/0005/416588/FINAL-Progress-Report-The-Rise-of-New-Manufacturing.pdf University of Tasmania

[29] Cloud Computing, Cyber Security and Green IT: The impact on e-Skills requirements Final Report for the EU Commission Cloud Computing Cyber Security and Green IT, Danish Technology Institute and Fraunhofer (2012) http://ec.europa.eu/enterprise/sectors/ict/files/eskills/e-skills_and_cloud_computing_final_report_en.pdf

[30] AWPA Manufacturing workforce study, Australian Workforce and Productivity Agency, April 2014 (2014) http://www.awpa.gov.au/publications/Documents/Manufacturing%20workforce%20study.pdf

Furthermore, enabling the Australian workforce to respond to the three challenges outlined in the previous section is a requirement for upskilling Australia's workforce from *cManufacturing* to *eManufacturing* and *iManufacturing*. Any such upskilling efforts can benefit from the general trend of these technologies to converge with technologies used in other sectors of the economy (services) and also in the consumer sphere. Furthermore, all stakeholders in the Australian manufacturing ecosystem should recognise, that "knowledge worker"- or "innovator"- skills are as much applicable to manufacturing – particularly when seen in the context of servitisation, as they are to purely digital services.

We need to rethink how technical trades, mechanical engineering, and computer science curricula can be connected through the contact points defined by the arrows in Figure 1.

Several countries have compiled detailed skills lists for ICT for manufacturing skills to adapt their vocational training and higher education programs to the transition from low-cost manufacturing to high-value manufacturing.

Enabling SMEs

The skills discussion highlights the overall framework for future productivity. There is an increasing need for "system of systems" solutions that not only leverage materials, processing, and information sciences but also seamlessly integrate into the production and business flows of an enterprise.

For resource-poor SMEs, the quality of the support networks and the accessibility of external skills are critical to help them to develop their IT capabilities[31] with a higher risk of outsourcing failure in the procurement of Information Systems.[32]

There is limited access to good quality resources and support networks for the three Informatics challenges highlighted above.

The selection criteria for cloud-based analytics systems of SMEs are comparable to those of larger enterprises[33]: level of software functionalities, capacity to handle large amount of data, and implementation cost. Frequently the role or training of the workers is secondary, but SMEs also need more responsive systems for the handling of customer support requests and rich *human-data interactions* between manufacturing processes and the individual people who work in or with these processes. For example, a common method of order communication to SMEs is through an email, which is monitored by a person (frequently a production manager or sales engineer). The information contained in such an email must be accessed, interpreted (frequently combining the information with 'know-how' of the SME's business process) and input into the ERP system. Often an order must be split into a detailed task list before the corresponding jobs can be planned internally or externally. These information exchange requirements are made more complex by developments in customisation, bespoke manufacturing, or customer-specific manufacturing processes. In relation to customer focused activities, Accenture and Red Hat (in a report for HBR Analytic Services) have identified that high performing companies were looking to invest in systems that provided customer focused solutions as amongst their top priorities when it comes to investing in IT.[34, 35] These investments will only increase as companies strive to improve their market performance, making it an imperative that these systems are interoperable and also deliver on productivity improvements.

Going forward, it will be critical to reduce the amount of human intervention and to enable SMEs to develop more automation inside their businesses and across their supply chains.

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[31] Bilan, T. J., & McCord, S. A.. A Process Improvement Framework for Information Technology Management in Small to Medium Enterprises (PI4IT). In *Proceedings of the Conference for Information Systems Applied Research* Vol. 2167, p. 1508 (2013) http://proc.conisar.org/2013/pdf/2815.pdf

[32] Devos, J., et al., The theory of the lemon markets in IS research. In *Information Systems Theory*, Integrated Series in Information Systems Vol. 28, pp. 213-229, Springer (2012) http://link.springer.com/chapter/10.1007/978-1-4419-6108-2_11

[33] Agostino, A., et al., Cloud solution in Business Intelligence for SMEs– vendor and customer perspectives. Journal of Intelligence Studies in Business, 3(3). (2013) https://ojs.hh.se/index.php/JISIB/article/view/72/76

[34] Doherty,P., Accenture, *Masters of the digital universe*, Outlook Issue No 1 – 2014 http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Outlook-Masters-of-the-digital-universe-IT.pdf

[35] Red Hat for HBR, *Business Transformation and the CIO role*, A report by Harvard Business Review Analytic Services 2014, hbr.org/hbr-analytic-services

6 Equipping Australian Manufacturing for the Information Age

Development of Data Sharing, Virtual Enterprises and Virtual Supply Chains

Just like physical infrastructure such as road and ports, investment in the creation of virtual enterprises and supply chains will make Australian SMEs competitive in global value chains.

The current fragmentation of the Australian SME landscape, combined with significant variation in the information systems in use by companies, inhibits effective data sharing and collaboration and therefore ultimately the formation of virtual enterprises. Furthermore, when SMEs are seeking inputs to their processes, whether they be raw materials, consumables or components, current methods are far from optimised.

CSIRO's industry consultations have shown that the primary methods of identifying potential suppliers are personal relationships and broader industry reputation rather than more data-driven and ICT-based approaches such as automated information transfer or business process integration. While we acknowledge the importance of such relationships, a more data and information driven approach adds benefits: while some of the larger suppliers, for example, have real-time stock information and order tracking online, this is very rarely true of SMEs. Even more specifically, there are very few suppliers whose information management systems can be queried by, or interact with, the companies to whom they supply. Informatics has the potential to integrate this process by assisting in the identification, selection, and optimisation of the supply process for Australian SMEs.

One prime prerequisite of this is the development and adoption of open standards allowing the exchange of this information or – if this cannot be achieved – of translation systems that can be used to translate data from the "vernacular" of one information system into that of the next, without the need for human intervention. When coupled with cloud-based services, this may enable data sharing for mutual competitive advantage while maintaining security and confidentiality. The development of Virtual Enterprises in Australia has the potential to move second- and third-tier SMEs into the top level of interaction with major global companies and markets, moving up the value chain with enhanced information flow, tracking, timeliness, and efficiency.

Recommendation 1: *We need to develop support networks for SMEs that on the one hand assist SMEs in upskilling their workforce, provide decision support, help to analyse a company's IT requirements and make correct purchasing decisions. Furthermore, Australia needs to invest in research activities, that work towards developing solutions for the "system of systems" problem and which allow the seamless integration of materials, process, production and business information, including the adoption and development of open data exchange standards. We need to develop "**virtual enterprises**" sustainably competitive locally and/or as members of global value chains.*

More Servitisation

In the first section of this paper, we have already alluded to the fact that IoT enabled products may allow the development of new lines of business for manufacturers, based on data generated by such products. Services also fundamentally change the nature between vendor and customer from a single or a series of ongoing single-point transactions to – in an ideal scenario– an ongoing relationship. Service models can vary from single pay-per-use service to long term ongoing relationships. Drivers for the provision or adoption of services on client and service provider side are either motivated defensively (e.g. increasing business efficiency, realising cost savings etc.) or offensively (improving competitiveness, platform building etc.).[36] However, data derived from service related offerings can also be used to design and develop the next generation of products and can be part of an integrated business model – bridging the manufacturer and the customer.

Web connected products and devices, open data standards, expertise in building appropriate data platforms and leveraging data generated by connected products are often the pre-requisites for building such services. Supporting servitisation will be a natural progression from developing more iSkills for Australia's manufacturing

[36] Servitisation Impact Study: How UK based manufacturing organisations are transforming themselves to compete through advanced services, Aston Business School, Birmingham, UK (2013) https://connect.innovateuk.org/documents/416351/3926914/Servitisation+impact+study.pdf/5b31740a-56ff-41c2-bdc8-e4289353fa66

CASE STUDY:

FLYING MACHINE

Flying Machine is a small designer and manufacturer of bicycles based in Perth, Western Australia. Started in 2008, the company now sells bicycles across Australia and globally, and specialises in custom bicycles built to individual geometries, particularly high-quality titanium bicycles.

A customised titanium bicycle is now on the market using parts produced with Additive Manufacturing technology: the 3DP-F1 ('3DP' after 3D Printing). The information flow necessary for the customisation begins with the measurements of the individual for whom the bicycle is tailored: the measurements form a type of 'digital representation' of the individual. Base CAD models of the parts to be 3D printed have been developed by rapid prototyping and incorporation of advanced tools such as Finite Element Analysis and Topological Optimisation. These base models are customised using the digital representation of the individual to produce customer-specific designs of the titanium parts to be manufactured.

Electron-beam Additive Manufacturing is completed at CSIRO's facilities in Victoria, and has enabled very rapid production: the timeline from receiving a customer's measurements to finished parts is ten days; to a finished bicycle, three weeks.

This project is an outstanding example of combining an information advantage obtained through rapid digitisation and the resulting adaptation of designs with materialisation technologies, and their direct impact on an Australian SME. Matt, the founder and owner of Flying Machine, has said "The F1 is just the beginning of our adventures in titanium and 3D printing, work has already commenced on taking the 3DP concept through our entire range plus several exciting all new models..."

workers and more eSkills for its SMEs. Highly developed infrastructure, such as the National Broadband Network, will also be an essential component in the mix.

Recommendation 2: *Many Australian SMEs are currently unaware or not thinking about servitisation as an additional line of business. Business model development e.g. through design-led innovation practices will play an important role in providing business with the wherewithal to develop appropriate business models and thus export opportunities. We need to develop business support networks, which will alert SMEs to the possibilities offered by servitisation and work with them to develop the prerequisite eManufacturing and iManufacturing skills. Furthermore, we need to support research into both the economic drivers and barriers towards greater servitisation of the manufacturing industry together with research into information technology that allows the seamless integration of manufactured goods and data as outlined above.*

More iManufacturing for Australia – Industry 4.0

A number of initiatives are necessary to equip Australian industry for the future. These may be usefully grouped by the type of enterprise most relevant to the initiatives, though there are also areas of overlap, convergence, and adaptation from one group to another.

Materialisation

For enterprises focused primarily on the *Digital Factories* part of the economy – that is, where the transfer of virtual designs into physical reality is key – there is a necessary focus on *Materialisation* technologies. These technologies may take many forms, but are most clearly represented by additive manufacturing technologies and the convergence of computer-aided design with machine control and feedback. Additive manufacturing technologies, based on plastics and metals, are increasingly entering the mainstream, though the application and customisation to specific industries remains niche and specialised. The future will require much more direct connections between digital concept/ design and the final finished product, and will include the detail of the process used to arrive at the digital product.

At a level above, 3D and simulation modeling can be used to prototype and refine the overall design, layout, and operation of a factory and minimise its prototyping, ramp up or reconfiguration time. This will also represent a significant step towards agile manufacturing and the ability to customise highly bespoke products.

Augmentation of digital and real-world data (for Smart Enterprises)

Inefficiencies in business processes are not routinely quantified in SMEs, and significant potential exists for tracking materials and orders to improve efficiency and quality. For example, the 'idle time' for some materials in some factories – the proportion of time an item waits for equipment orpersonnel, or is stored in an intermediate or unfinished state – may be very significant. This reduces efficiency, increases the risk of errors, accidents and losses and increases reliance on human scheduling and optimisation. Implementation of informatics solutions may highlight these inefficiencies, which in many cases are simply solved.

Quality improvement and timeliness are also improved by materials and order tracking through a factory. Combined with digitised information about the materials and the processes, the quality control system becomes a more efficient validation of both the materials and the processes, in addition to the end result achieved. Some SMEs are implementing such systems – e.g. combining CAD drawings with 3D scanning of finished products – but real-time tracking of individual parts and processes is only beginning.

The augmentation of digital data with real world data is a new requirement for robots and machine tools suppliers and the work in this area by academia or by standards development organisations is patchy largely because the metrology and data reporting tasks were performed by specialised machines.

With the addition of IDs and readable and writable memory to the products, the joint collection of good quality data by all the contributing suppliers in complex supply chain becomes easier. To adjust to the increase in the volume of the data collected and shared, new investments in enterprise computing infrastructure are required.

Equipping Australian companies for iManufacturing ICT

Big Data (analytics) for Factories and Supply chains

Some of the Customer Relationship Management and Business Intelligence big data capabilities developed for e-commerce[37] can also be critical for Manufacturing enterprises especially those ones managing multiple product variants and the associated services allowing them to be more responsive to their customer demands at all levels.

The "use of CAD and machine data in their Big Data Solutions"[38] is more specific to Manufacturing: *predictive manufacturing*[39] targets the savings associated to the optimisation of manufacturing capability and of its readiness.

Recommendation 3: *We need to support research into IT solutions enabling the "digital enterprise" with superior materialisation skills both in terms of product- and factory planning.*

More Industry 4.0 Thinking – Informatics Linked Enterprises

When taking all of the above together, the transformation of Australian manufacturing must go towards the "informatics linked enterprise": digital companies, making optimal use of data and manufacturing ICT tools, which can participate in global virtual supply chains through the seamless integration of data and which – where appropriate – have superior materialisation capabilities in terms of product, business process and factory planning. This will require the development not only of appropriate technology, commercialised in ways which make these technologies accessible to all Australian manufacturers, but also the development of business support networks and educational offerings for both present and future manufacturing workers.

Recommendation 4: *We need to develop the "**informatics-linked**" enterprise with superior ability to optimise the use of resources: materials, energy, machines and workforce.*

[37] Baars, H., et al. . Shaping the Next Incarnation of Business Intelligence. Business & Information Systems Engineering, 6(1) pp 11-16 (2014) http://link.springer.com/article/10.1007/s12599-013-0307-z

[38] Barry Devlin, S. R. (2012). Big Data Comes of Age. An Enterprise management associates® (EMA™) and 9sight Consulting http://www.9sight.com/Big_Data_Comes_of_Age.pdf

[39] Lee, J., et al., Recent advances and trends in predictive manufacturing systems in big data environment Manufacturing Letters, 1(1), 38-41. (2013) http://dx.doi.org/10.1016/j.mfglet.2013.09.005

7 Conclusion

Australian manufacturing must grab the iManufacturing future. We are capable of doing so and we must do so to sustain and grow the industry. We must invest in the creation and growth of:

- "***digital enterprises***" with superior materialisation skills both in terms of products and factory development;
- "***virtual enterprises***" sustainably competitive locally and/or as members of global value chains;
- "***smart enterprises"*** with the informatics backbone to capture the live data needed to continually tune business performance and reassess tradeoffs; and
- "***informatics-linked***" enterprises with superior ability to optimise the use of resources: materials, energy, machines and workforce.

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