Flinders University
Australian Industrial Transformation Institute

# Robotics and the Digital Shipyard

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## Australian Industrial Transformation Institute

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# Preamble

Large-scale shipbuilding projects like the Hunter Class Future Frigate program can benefit greatly from accelerated application of advanced digital and manufacturing technologies in tandem with lean manufacturing and high performance workplace practices. So too can the supply chains working in support of this national endeavour. The vision to establish a world class ‘digital shipyard’ is a major driver toward achieving sovereign shipbuilding capability. Flinders University is proud to be working in collaboration with BAE Systems Maritime Australia and its supply chain to examine the role that human factors and ergonomics (HFE) play in the uptake and diffusion of advanced manufacturing and digital technologies.

With support from the Innovative Manufacturing Cooperative Research Centre (IMCRC) the partners have embarked on a multi-year program of HFE technology research and trials designed to support the successful and timely uptake of advanced manufacturing and digital technologies in Australian shipbuilding. A unique transdisciplinary research capability has been assembled at the Flinders at Tonsley campus to drive this work. BAE Systems Maritime Australia staff are working alongside Flinders researchers on an ambitious research program based in fit-for-purpose collaborative research labs and the Pilot Factory of the Future – Line Zero trial and test facility.

In line with all other forms of manufacturing, Industry 4.0 offers a vision for transformation of the shipbuilding industry though the establishment of ‘Digital Shipyards’ and adoption of a ‘Shipyard 4.0’ agenda. It is important to acknowledge just how transformative such a vision is and how challenging it will be to realise. The motivations and drivers must be powerful and the benefits very large. The ideal of Digital Shipbuilding and importantly, sustainment, is propelled by the prospect of significant improvements in productivity, efficiency, reliability, quality and safety over the lifecycle of vessels. This is the promise that the Industry 4.0 agenda makes and that HFE can enable.

This report is one of a series of reports arising from our IMCRC project with BAE Systems Maritime Australia. It’s aim is a specific one - to help develop among key stakeholders a deeper understanding of robotics and automation in the context of the digital shipyard ambition.

Our lead industry partners involved in the implementation of this project include Sharon Wilson (Continuous Naval Shipbuilding Strategy Director), Evangelos Lambrinos (Exports and Innovation Manager), Andrew Sysouphat (Principal Technologist - Hunter Class), Ivor Richardson (Project Manager – Strategic), Tom Snowden (Project Manager – Industry 4.0 Trials), and Mark Francis (Project Manager). Collectively we thank the Board of the IMCRC and David Chuter, CEO for their support for this project. We share their vision for growth of advanced manufacturing in Australia.

Professor John Spoehr

Director – AITI

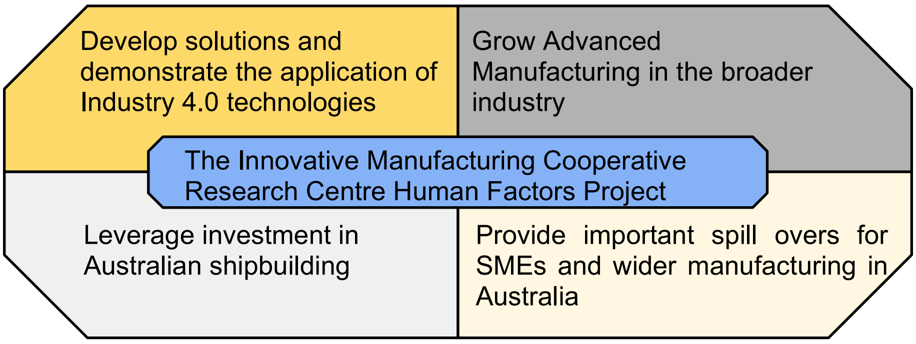
Flinders University

# Executive Summary

For Australia to achieve its goals for long-term productivity growth and global competitiveness in manufacturing, it needs to accelerate pursuit of the Industry 4.0 (i4.0) agenda driving the transformation of manufacturing globally. I4.0 is a strategy that seeks to modernise and transform manufacturing through accelerating uptake and diffusion of advanced manufacturing technologies and processes in tandem with comprehensive enterprise digitalisation. It seeks to drive a new wave of productivity, efficiency, flexibility, environmental, safety and working life improvements that underpin the growth of high value, high skill manufacturing.

The IMCRC based in Australia, is driving research-led innovation for Australian manufacturing business models, products, processes and services. They are investing significant effort into the digital transformation of Australian manufacturers, especially those that fall in the small and medium enterprise (SME) bracket, through the adoption of i4.0 related technologies. This transformation will benefit the Australian manufacturing sector and shipbuilding in particular. The ambition to establish one of the worlds leading digital shipyards in Australia is propelling testing and trialling of a range of technologies and processes for potential application in the Osborne Shipyard in South Australia.

This report is part of a wider project focusing on human factors influencing the uptake and diffusion of advanced manufacturing technologies in maritime shipbuilding. The goals of the project are presented below.




Successful adoption of advanced manufacturing and digital technologies in maritime shipbuilding requires trans-disciplinary research based on an holistic approach to technology assessment, testing and application. The focus of this report is the state of play in relation to robotics including:

- use of collaborative robots for tasks such as welding pipes and spools, and precision cutting
- transformation of workshops with smart benches and their integration in smart manufacturing cells
- use of automated guided vehicles for transportation of equipment and stock
- use of assistive manufacturing technologies to support the efforts of manual labour
- use of big data in operations including:
  - digital transformation
  - track and trace technologies
  - paperless workplace systems
  - advanced software solutions for smart manufacturing.

This report reviews the ‘current state’ of robotics applications in Australian manufacturing to inform considerations about potential applications of the technologies in shipbuilding as part of the digital shipyard ambition. It details a range of use cases and illustrates how the adoption of modern robotics and assistive manufacturing technologies are helping companies to pursue the Industry 4.0 challenge in Australia.

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# 1 Introduction

## 1.1 Robotics and the Digital Shipyard

Advanced manufacturing involves the integration of factory production systems and processes, and the integration of the value chain from suppliers to customers (S. Wang, Wan, Li, & Zhang, 2016). Integration of factory components, also referred to as horizontal integration, relies heavily on Internet of Things (IoT) devices for sensing and actuation. The extent to which a factory can be integrated is dependent on the level of digitisation of production processes. While varying in degrees of autonomy, autonomous agents create value in the performance of repetitive or tenuous tasks. Similarly, robots create value in performance for repetitive or hazardous tasks. Robots can act faster and with better accuracy than humans without challenges like fatigue and injury.

Industrial robots belong to a class of advanced manufacturing technologies that have been developed to supplement or replace human labour. They have tangible and intangible benefits including saving time, quality improvements, higher overall equipment efficiency (OEE) and greater reliability (Ordoobadi & Mulvaney, 2001). Robots and autonomous agents in manufacturing have long assisted in improving competitiveness through simplifying complex processes, shortening manufacturing cycle-time, satisfying customisation demand, cost reduction and improvement of supply chain connections (Brettel, Friederichsen, Keller, & Rosenberg, 2014). Furthermore, they have increased opportunities to engage with customers by facilitating better access to market and communication, which allows for customisable requirements and changes (Koren & Shpitalni, 2010). Increasing these improvements through using newer robotic platforms and autonomous agents could position the Australian manufacturing industry to become more competitive as well as enabling the growth of onshore manufacturing facilities (AMGC, 2018).

A recent trend in i4.0 involves introducing robotics and other advanced manufacturing technologies that have the capability to effectively assist workers in close proximity (Lenz & Knoll, 2014). Examples include Collaborative Robots (Cobots), smart fixtures, Automated Guided Vehicles (AGVs), Radio-frequency Identification (RFID) and smart wearables. In Australia, a wide range of industries including aerospace and mining have already adopted these advanced manufacturing technologies. Various benefits are demonstrated in South Australian case examples (see Chapter 2) and national case examples (see Appendix A: Advanced Technology Case Study). These have contributed to saving time as they automate operations, improve ergonomics, and reduce hazardous tasks.

The journey towards fully automated factories is yet to be realised. According to Lai et al. (2020) many industrial automation projects have introduced disturbances into production and as such key challenges involve understanding how much automation is feasible and determining a workable collaboration scheme between human and machine. Similarly, Evjemo, Gjerstad, Grøtli, and Sziebig (2020) claim that the attainment of the vision of Industry 4.0 is challenged in all contexts by the requirement to find the balance between the involvement of humans and automation.

I4.0 represents a new manufacturing paradigm globally and is regarded as critical to maintaining Australia's industrial competitive advantage (IMCRC, 2019). By design, i4.0 was conceived in part to maintain manufacturing productivity despite labour shortages, as it would require fewer operators to control factory operations. I4.0 is envisioned as an advanced manufacturing methodology that uses networked automation/human-machine collaboration technologies to deliver better human wellbeing, improved production quality, reduced occupational hazards, cost efficiency and environmental objectives. Australian i4.0 initiatives originated from the Prime Minister's taskforce launched in 2016 to support the transition to a new economy and to enable the nation's i4.0 capabilities (AMGC, 2018).

I4.0 involves the optimisation of manufacturing processes through the application of advanced technologies, including automation, robotics, Cyber Physical Systems (CPS), IoT and cloud computing (Hermann, Pentek, & Otto, 2016; Lu, 2017). Due to the benefit of its application in regions with labour shortages, and its cost-effective nature, i4.0 is well suited for implementation in countries such as Australia. It is hoped that i4.0 might help to 're-shore' some manufacturing production lost to other countries. According to a World Economic Forum report (2018), Australia has high potential for future production by adopting i4.0 manufacturing. In fact, the Australian manufacturing industry is already adopting i4.0 (IMCRC, 2019). The industry is benefitting from a significant investment into digital and advanced manufacturing technologies as well as the integration of a wide range of manufacturing processes and supply chains (AI Group, 2019)

## 1.2 The Robotics Dividend

The global market value of manufacturing using advanced robotics is gradually increasing and the future adoption rate is expected to almost double in various industries including manufacturing. This is attributed to the adoption of advanced robotics and assistive manufacturing tools which offer various advantages including productivity and quality improvements and reduction of cycle-time and downtime (Küpper et al., 2019).

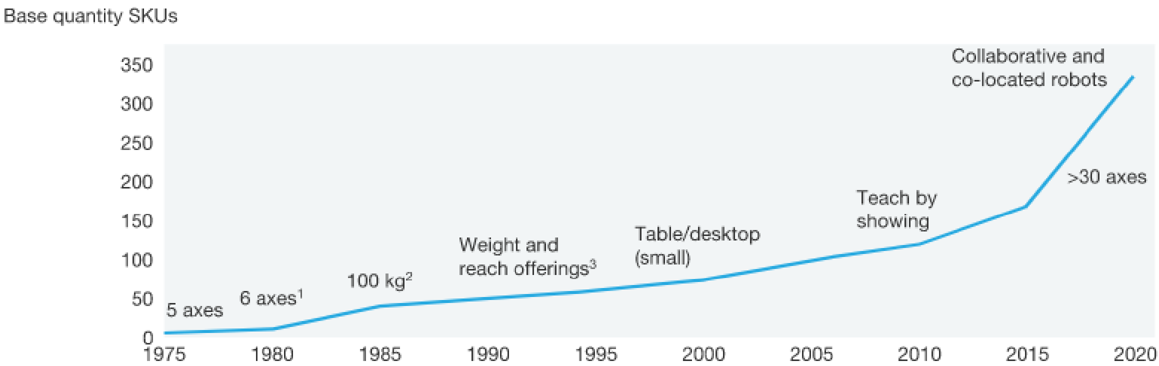
Australia currently has a lower advanced technology adoption rate than other developed countries. South Korea has a relatively high robot density of 631 per 10,000 employees in manufacturing industry, while it is around 83 per 10,000 employees for Australia (Smith, 2018). The Robotics Roadmap for Australia indicated that Australia recorded just 1 percent growth in industrial robotics adoption over 2011 to 2016 (Australian Centre for Robotic Vision, 2018).

## 1.3 Value of Integrating Robotics and Automation in Manufacturing

The primary value proposition of robotics and automation in manufacturing is through efficiency improvements and improved workplace wellbeing. The cost per unit reduction in costs from 1994 to 2018 has fallen by a factor of four, making robotics a financially tractable solution to be deployed in companies of all sizes (Deloitte, 2019). Coupled with lowered costs, there has been a concomitant increase in the capability and sophistication of the robotics allowing for more complex tasks to be accomplished. Along with significant improvements in robotics programming, will allow for a more agile deployment of robotics allowing for adaptability to new tasks.

For context, the International Organization for Standardization defines a robot as an “actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks” (ISO, 2012). Figure 1 shows the the progression of manufacturing robotics over the last 50 years along with the approximate number of robots been taken into the economy (Tilley, 2017). This figure marks points in time where advances in robotics payload capacity and number of operational axes approximately occurred. Cobots represent one of the most recent advances in manufacturing robotics.

**Figure 1: Advances in Robotics Capability**




| | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of axes | 5 | 6 to 8 | 12 | | 21 | 27 | | | 32 | |
| Capacity, kg | 6 | 60 | 90 | >120 | | | | 1,000 | | |
| Maximum reach, meters | 1 | | 2 | | | | | 3 | | |

[1]Allows arc welding, adhesives dispensing, machine loading.
[2]Spot welding, materials handling.
[3]All application areas; right size for the task.

*Source: (Tilley, 2017)*

There is a common fear that robots replace humans at work, however according to a World Economic Forum report, robots are projected to create more jobs than they destroy. The study finds that globally, 75 million jobs will be displaced by robots between 2018 to 2022, but that this will be offset by 133 million new roles emerging (Forum, 2018). Increased investment in Artificial Intelligence (AI) technologies such as natural language processing, and speech and visual recognition will begin to automate non-routine tasks and judgement-based processes to solutions in almost every industry sector (Deloitte, 2019). Cobots provide a viable platform to incorporate all of the above advances in robotics and software.

The value proposition by Cobots is similar to that of robotics in general, which is, to allow people and property to be more efficient, which supports higher productivity and lower prices (CEBR, 2017). This in turn may allow more time to for a worker to potentially dedicate time to higher value tasks which can increase the productivity of labour and raise worker incomes. However, this may also lead to increased inequality if the benefits are not pushed down to the workers (Deloitte, 2019). Cobots also help improve the productivity of capital by using existing space allowing humans and robots to share spaces and machinery more efficient, reducing the need for new capital investment (Deloitte, 2019).To identify inefficient tasks and processes that are amendable to automation, techniques such as process and value stream mapping are well suited . These tools ‘quantize’ the work flow into discreet tasks to better identify the seven types of inefficiencies as defined by standard Lean practices. Often in literature there is also an 8$^{th}$ inefficiency which begins to shed light more on the cognitive and Human Factors and Ergonomics (HFE) aspects which is unused skills and talent (Way, 2017). These indirect costs are often ignored because they are more difficult to quantify. The economic benefit of improving tasks with this approach would be the reducing the aggegated and on-going costs of reduced work satisfaction, safety, engagement (O’Keeffe, Moretti, Hordacre, S., & Spoehr, 2020).

# 2 Use Cases in Manufacturing

## 2.1 Industrial Robots and Cobots and Industry 4.0

Industrial robots and cobots are among a range of so called key-enabling technologies that are regarded as foundational to the Industry 4.0 agenda. Others key technologies include additive manufacturing; photonics; advanced materials; nano-technology; artificial intelligence and bio-technology. Industrial robots are automated systems used primarily in manufacturing. They are programmable and have movement capability in three or more axes. Globally, industrial robots are used in a variety of processes including welding, assembly and disassembly, pick and place among others (Lee, 2014; Pellicciari, Berselli, Leali, & Vergnano, 2013; Wegener, Chen, Dietrich, Dröder, & Kara, 2015).

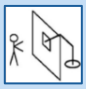
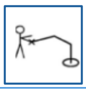
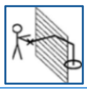
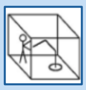
The concept of an industrial robotic platform capable of operating in an unguarded space beside a human was conceived in the late 20th century (Colgate & Peshkin, 1999). Through years of research and development, this platform evolved and came to be known as the Cobot or collaborative robot (Bloss, 2016). The main difference between a Cobot and a traditional industrial robot are the reduced requirements for typical forms of barrier protection (e.g. cages surrounding the robot) due to integrated safety systems contained in Cobots (ISO, 2014).

Early versions of Cobots included models such as the LBR3 of Kuka Robotics in 2004, the UR5 robot arm of Universal Robots (UR) in 2008 and the dual-armed Baxter Cobot of ReThink Robotics in 2011 (Institute of Robotics and Mechanics, 2018; ReThink Robotics, 2014; Universal Robots, 2018).

Today, Cobots are widely used to partially automate manufacturing processes that are difficult to fully automate. The ideal use case of Cobots is to supplement manual human labour whilst improving output, product quality and consistency in tasks (Vysocky & Novak, 2016; Zanchettin, Croft, Ding, & Li, 2018). Some companies such as Xiemen Runner in China are using Cobots to near-fully automate all processes, from injection moulding to product assembly (Universal Robots, 2017).

Most modern Cobots run the Robotics Operating System (ROS). Additionally, some Original Equipment Manufacturers (OEMs) offer software for users to easily develop their own ROS applications or drivers for Cobots (Cobotics World, 2019). The publisher/subscriber methodology of ROS enables Cobots to display their runtime data in real-time for factory operators to read through their Human-Machine Interface (HMI). One of the many benefits of this functionality is that easy access to data can assist in track and trace operations within i4.0 (Universal Robots, 2016). Cobots can collaboratively support workers within a common workspace without safety barriers in the manufacturing line. This unique feature offers different types of collaborative operations between humans and machines (Bauer, Bender, Braun, Rally, & Scholtz, 2016) (Figure 2).

**Figure 2: Basic Cobot operation types**

| No | Collaborative features | Risk reduction methods | Images (ISO 10281-2) |
|---|---|---|---|
| 1 | Safety monitoring | Motion control of robot (No movement) when operator is working within a workspace |  |
| 2 | Hand guiding | Robot motion can only be controlled by an operator |   |
| 3 | Speed and separation monitoring | Enough distance & having minimum separation distance |   |
| 4 | Force and power control | Constrained forces are allowed | |

*Source: (Matthias, 2015)*

Universal Robots, one of the leading brands of Cobots, have sold more than 42,000 units globally and are used across thousands of production environments (Universal Robots, 2020). The underlying reason for the demand is their collaborative features, easy integration and broad ecosystem of third-party support.

Close interaction and cooperation may be required between workers and Cobots, where each performs separate sub-tasks that are best suited to their skills (Fryman & Matthias, 2012). Human interaction between workers and Cobots can improve complex manufacturing processes where workers and Cobots support each other (Simões, Soares, & Barros, 2019). Thus, Cobot applications should take into consideration human factors that facilitate successful integration between workers and the technology.

The Cobotic platform is still a novel feature in complex manufacturing industries such as shipbuilding. This slow adoption can be attributed to the nature of the shipbuilding process, which involves constructing complex structures in challenging and potentially dangerous working environments including confined spaces. The lack of research into the many technical and human challenges associated with the adoption of advanced manufacturing technologies in shipbuilding irepresents a barrier in itself (Micheler, Goh, & Lohse, 2019). There is a need to systematically test and evaluate potential applications of robotics technologies in support of maritime shipbuilding and sustainment. A much more substantial body of knowledge and experience is needed to inform the uptake and diffusion of advanced manufacturing technologies in the shipyard.

## 2.2 Australian Manufacturing use cases of Industrial Robots and Cobots

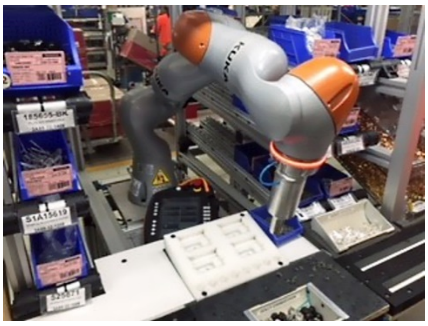
The uptake and diffusion of industrial robots and Cobots is observable in many Australian industries such as manufacturing, in particular, the electrical/electronic equipment and food and beverage industries. Some examples are highlighted below.

### 2.2.1 Clipsal by Schneider Electric

Clipsal Schneider Electric, located at the Gepps Cross site in South Australia, is a household name across Australia for providing homes with energy delivery solutions. The company has recently upgraded their long-standing production line of KUKA industrial robots with supplemental KUKA Cobots (Manufacturing Automation, 2016) (Figure 3).

Clipsal Schneider Electric have deployed a Cobot to assist with the assembly process, of inserting switches in the switchboard assembly. The Cobot works unguarded alongside factory workers to supplement their manual labour effort. A number of plastic injection moulding and assembly cells were also seen to have integrated industrial robots, for the purposes of component assembly, trimming and palletisation operations, with some components coming straight off the moulding machines (Vanderwielen, 2018).

**Figure 3: KUKA Cobots at Clipsal Schneider Electric**



*Source: image taken on-site, provided by Vanderwielen (2018)*

### 2.2.2 Electrolux

Electrolux is a global manufacturer of home appliances. The Dudley Park factory in Adelaide, which produces 1600 ovens daily, uses ABB Industrial robots and UR Cobots. The ABB robots are used for heavier and more complex technical processes. In total, Electrolux has over 45 industrial robots integrated into their appliance manufacturing processes. These robots were observed in use on site tours conducted between 2018 and 2020.

The cooling fan assembly cell features two industrial robots working in parallel using a vision system, and an oven cavity coating line uses one industrial robot (Martin, 2020). The oven door gluing and assembly cell designed and integrated by Andrew Donald Design Engineering was a $1.5 million investment which required a 3-year payback period (Figure 4). There are 4 ABB robots in the cell which look after trimming, handling, plasma treating and gluing of glass doors, as well as outfeed onto a conveyor belt. Each robot performs 5-6 functions and all doors are completed in single shift, where previously this was accomplished over two shifts which also required some travel between multiple work cells. The introduction of this robot cell has increased the quality of the product and reduced the service call rate by 75% (C. Thomas, 2020).

The final packing line (Figure 5) was designed and integrated by Hot Melt Packaging Systems and features 6 ABB robots that apply the final packaging components for the oven assemblies, in preparation for transport. Packaging components consist of pieces of wood, expanded polystyrene and cardboard. In a standard 8-hour shift, the line packages 1600 units with an average cycle time of less than 4 minutes per part, achieving an OEE of 90% (Hot Melt Packaging Systems, 2018).

**Figure 4: Oven door assembly at Electrolux**

*Source: image taken on-site (Manning, 2018a)*

**Figure 5: Final packaging line at Electrolux**

*Source: image taken on-site (Manning, 2018a)*

There is also an $8 million tandem press line built in the early 2000s that presses various sheet metals into parts of the oven (Figure 6). The tandem press features seven ABB robots and five Manzoni presses and at the time of installation replaced the jobs of twenty human workers. It offers an OEE of 90% and can produce eleven parts per minute, which is double the amount produced by human workers using manual methods. The line has a team of three human operators per shift who handle the die changes, the stacking of parts at the end of the line and the cleaning. Previously, three shifts were needed to run the line but with the introduction of robots, a full cycle can be completed in two shifts leaving the third shift for the operators to perform any maintenance (ABB Robotics, 2000).

**Figure 6: Tandem press at Electrolux with ABB robots and Manzoni Presses**

*Source: image taken on-site (Manning, 2018a)*

UR Cobot models are used in pick and place applications such as performing label placement on a range of oven types and for loading carrier pallets onto conveyor belts (Figure 7).

**Figure 7: UR Cobots integrated into various cells at Electrolux**

*Source: image taken on-site (Manning, 2018a)*

The Cobot is told the oven type and picks a freshly printed label from the printer using a pneumatic vacuum gripper. It then places the label in the appropriate position, as determined by the oven type. Next it reads the barcode on the label to ensure it has been placed correctly and is readable, using a computer vision system. If the barcode is unreadable, the Cobot will signal the printer to create a replacement label and the Cobot will repeat the process, sticking the new label on top of the unreadable one.

The very rigorous use of the Cobots at Electrolux over the past 3 years has allowed for identification of some limitations. The reach distance of the UR10 has provided a flexible solution for picking and placing operations, particularly in label placement and pallet loading operations. It is acknowledged by users that "*the load limit of 10kg can be problematic*" (Martin, 2020). The 10kg limit includes any end-effectors mounted onto the flange of the robot, as well as the weight of the workpiece being held. Hence, for applications such as loading pallets onto conveyor belts, with the typical end-effector weighing a couple of kilos, it *"only leaves less than 8kgs of load capacity to work with. Resultingly, the Cobots often e-stop due to them almost being near their load limits".*

### 2.2.3 REDARC Electronics

In 2018, REDARC Electronics designed (in-house) and commissioned a smart manufacturing cell which is now used in the assembly of one of their most popular products. The cell features three UR Cobots with a mounted PICKIT 3D Vision System that are all coordinated by a central Mitsubishi programmable logic controller (PLC)(Figure 8).

**Figure 8: A multi-UR Cobotic cell at REDARC Electronics**

*Source: REDARC Electronics (2019)*

Previously, REDARC conducted experiments with a Rethink Robotics - Sawyer Collaborative robot, in collaboration with Flinders University. Through their experiments, they found that the robot worked best when conducting difficult or repetitive work in tight confines and for tasks that were ergonomically challenging (REDARC Electronics, 2016).

REDARCs recently installed UR Cobot cell has provided a space for collaborative work between factory workers and the machines. The UR Cobots are responsible for part feeding hoppers and pallet handling for the PCB carriers. Following the adoption of new advanced manufacturing technologies, such as the Cobots, REDARC have been able to increase their production capacity by 250% and have given themselves *"more flexibility leading into the future as we enter new export markets and defence industries, making us more agile to deal with our customers' ever-changing needs" (Kittel, 2019)*.

### 2.2.4 Multislide Industries

Multi Slide Industries, located in Edwardstown SA, operate the largest range of wire-forming machines in Australia and handle the entire spectrum of low, medium, and high-volume projects. Multi Slide's machinery consists of 2D and 3D CNC machines, wire straining, straightening and cutting machines, as well as pedestal and robotic welders which were observed on a site visit (Figure 9) (Todd, 2018). The use of automation and robotics equipment allows Multi Slide industries to provide low-cost tooling, high production rates with low energy consumption, and high consistency and performance. Two welding stations feature Kawasaki industrial robots that perform spot welding jobs to weld various wires together to produce fences (Figure 10). Their large reach radius allows for large welding jobs to be undertaken.

**Figure 9: Multi Slide automotive seat frames, brick ties and shop fittings**

*Source: image taken on-site (Manning, 2018b)*

**Figure 10: Kawasaki industrial robots spot welding at Multislide**


*Source: image taken on-site (Manning, 2018b)*

### 2.2.5 Seeley International

Seeley International is the largest air conditioning manufacturer in Australia. Their products are manufactured from the injection moulding stage all the way up to final product assembly. Half of the manufacturing sites are located in Australia, and in Australia alone, more than 1.5 million components are manufactured and 80,000 products are assembled yearly (Seeley International, 2017). A site tour was held at their Lonsdale SA site in late 2016, where industrial robots were observed in use for machine tending purposes where one is mounted with its base axis of rotation parallel to the factory floor (McBratney, Schwarz , & Coupe, 2016). This removed the need for additional fencing as it was several meters out of human reach and allowed it greater reach mobility for performing tasks such as removing of pallets from a machine and placing them into a slide. It is also noteworthy that across Seeley's manufacturing sites, AGVs, automation machinery and shared human/Cobot workstations are also used in their manufacturing processes.

### 2.2.6 Treasury Wines Penfolds Barossa Valley

At Treasury Wines Penfolds, Barossa Valley, some product lines are seasonal and therefore Penfolds rely heavily on hiring casual working staff. However, there are periods when it can be difficult to recruit sufficient workers to assist in production for the gift packaging of seasonal wine (Drogemuller, 2019). Factory workers also find the work repetitive and ergonomically challenging.

Penfolds are investigating the use of Cobots to assist in partially automating some gift-packaging processes for their premium seasonal wines. They have purchased a Techman TM12 Cobot for its reach capacity, load limit and integrated vision system (Figure 11). Experimental trials are underway and if successful, the TM12 will be the first Cobot in South Australia integrated for such a purpose, paving the way for greater uptake in the future.

**Figure 11: A TM12 Cobot at Penfolds Barossa Valley used in experimental trials**


*Source: image taken on-site, provided by Drogemuller (2019)*

### 2.2.7 SMR Automotive Australia

SMR Automotive Australia produces car components ranging from various plastics to lights. The company's production processes begin at the injection moulding stage and extends through to the final product assembly stage. A site tour was held at the Lonsdale site in South Australia at the start of 2019 where plans for the addition of new smart manufacturing cells with Cobots were being drafted. The Cobots are now completely integrated into daily operation (R. Thomas, 2020).

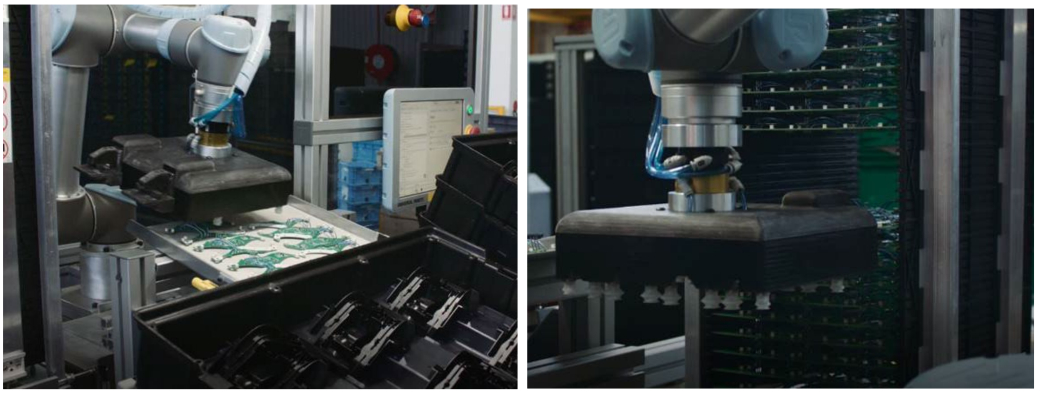
One UR Cobot cell is for loading and unloading of terminal insertion (Figure 12), another is used for PCB de-panelling, where a pneumatically actuated vacuum gripper is used (Figure 13), while a third is used for loading and unloading parts from an ultrasonic welding station (Figure 14).

Plans were being devised for 2 Techman Cobot cells. It was stated that these cells would be up and running in the coming months, to partially automate additional manufacturing processes (R. Thomas, 2020).

**Figure 12: UR Cobot Terminal insertion cell at SMR Automotive**

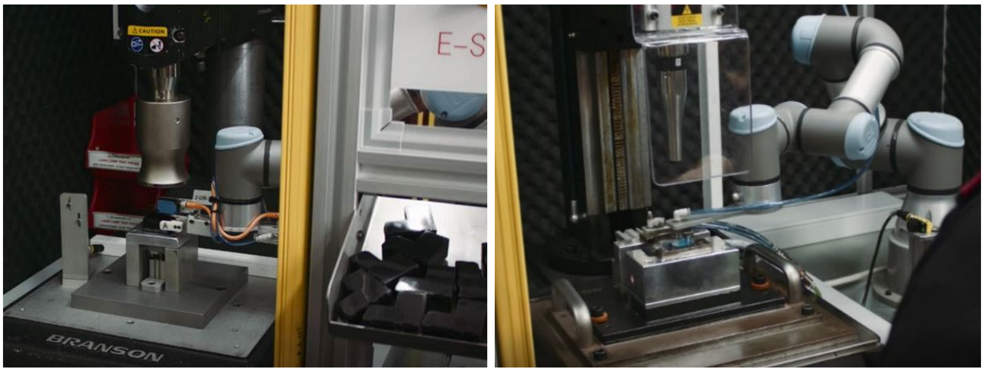
*Source: image taken on-site, provided by R. Thomas (2020)*

**Figure 13: UR Cobot PCB de-panelling cell at SMR Automotive**



*Source: image taken on-site, provided by R. Thomas (2020)*

**Figure 14: UR Cobot ultrasonic welding station at SMR Automotive**

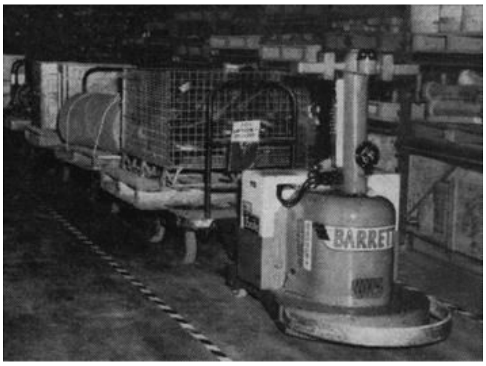



*Source: image taken on-site, provided by R. Thomas (2020)*

## 2.3 Use of AGVs in Industry 4.0

When first conceptualised, Automated Guided Vehicles (AGVs) were envisioned to be a new autonomous delivery solution which could automate logistical processes in a wide range of industries, such as the farming industry (Ullrich, 2015). Early versions of the AGV were used in industrial settings for towing carriages with large payloads, in operations that would otherwise typically be performed by human-operated tractors. One of the first companies to successfully implement an AGV system was Barrett-Cravens of Northbrook, Illinois (Savant Automation, 2020). Their AGV was installed at Mercury Motor Freight Company, South Carolina (Figure 15). These early versions of AGVs did not have navigation capabilities and were guided using rails. While the usage of rails was a robust solution, it was not modular. Hence, the technical evolution of the AGV platform developed solutions that were more modular, for example following lines of magnetic tape on the floor which was easier to apply to and remove from factory floors, compared with rails.

**Figure 15: Early AGV in developed in 1954, used for towing carriages**



*Source: Ullrich (2015)*

Modern AGVs include powerful on-board computing solutions that allow for real-time path planning to perform efficient and dynamic obstacle avoidance. The computations from one AGV can be relayed to a central computing server via infrared signals, radio waves or Wi-Fi which would allow for a fleet of AGVs to communicate over the network and be coordinated (Bandyopadhyay, 2017). AGVs come in various types, provide an abundance of functionality and are commonly seen in sites that have adopted i4.0 (Clark, 2019). Types of modern AGVs include:

- Automated Guided Carts (AGC): these are typically lower in cost and a good starting point for mobile automation. AGCs typically use more traditional methods of navigation such as following lines of magnetic tape.
- Autonomous Mobile Robots (AMR), also known as Autonomous Intelligent Vehicles (AIV): these are typically more expensive compared to AGCs and have advanced autonomous navigation systems such as Simultaneous Localization and Mapping (SLAM). They also include more onboard processing power to handle the large amounts of data required by a SLAM system.

SLAM is a discretised map creation method that has emerged from many years of development in robotic mapping systems (Self, Cheeseman, & Smith, 1988). Modern SLAM functions utilise Bayesian Filtering with re-sampling through an importance weighting of data. It has become an essential function for modern AMRs and allows them to map an area in real time, using live sensory feedback (Montemerlo, Thrun, Koller, & Wegbreit, 2002). Once the map has been created, the human operator can instruct the AMR through its HMI where locations of interest are. The AMR is then able to autonomously navigate to and from those locations of interest, while observing higher-level instructions or rules (Jungheinrich YouTube, 2017; SICK Sensor Intelligence YouTube, 2016).

## 2.4 Australian use cases of AGVs

The uptake of AGVs within the Australian manufacturing industry has been observed at several local sites, which are detailed below.

### 2.4.1 SMR Automotive Australia

In addition to integrating Cobots into its manufacturing processes as described above (see page 9), SMR Automotive has several lesser-intelligent AGVs, which follow lines of magnetic tape. These AGVs were observed at a site visit conducted in 2019, before the Cobot cells were operational. The travel lines are outlined with hazard tape to remind workers to cross with caution.

There are several fenced sections along the various paths which serve as loading bays for AGVs to park, and for human operators to manually hook trolleys onto the AGV (Murray, 2019). The trolleys, which may be full of new parts or need refilling, are then towed away to their next destination(s).

SMR Automotive's needs and budget dictated that they could only purchase the lesser-intelligent AGCs over the more intelligent AMRs. Whilst they have been able to make considerable use of them, over the long term the solution chosen has left them with little room for variation. If their production processes change, reconfiguring their AGVs would be more difficult as the existing tape and guard-rails would need to be shifted.

### 2.4.2 Clipsal by Schneider Electric

Alongside the previously detailed integration of Cobots (see page 5), Clipsal by Schneider Electric have also integrated AMRs into their processes at the Gepps Cross facility in South Australia. The AMRs were observed in operation at the facility on a site-tour, where two AMRs were navigating autonomously for delivery and retrieval of parts from the storage area to assembly areas (Vanderwielen, 2018).

The benefit of an integrated SLAM system, and inclusion of modern sensory technology such as the LIDARs, offers improved prospective performance. The AMR can navigate dynamically to avoid obstructions on its path and still arrive at its destination with insignificant delay or intervention required from a factory worker. Factory workers re-program it's points of interest when needed with ease through just a few mouse clicks applied at a workstation. This easy programming method allows for an improvement in time management for factory workers.

### 2.4.3 Navya Autonomous Shuttles

In shipyards, workers can traverse kilometres during shifts which presents significant fatigue and efficiency challenges (Salzer, 1986). A method of transportation through the shipyard could greatly reduce the burden of travel on shipyard workers, in larger shipyards.

In mid-2018, a program aiming to test the capabilities of autonomous shuttles was introduced at the Tonsley Precinct (Chadwick, 2018). The Navya Autonomous Shuttle has the capacity to transport up to 15 passengers (Figure 16). It has an operator available to take manual control and ensure that systems are running as intended.

**Figure 16: Navya Autonomous Shuttle at the Tonsley precinct used by Premier Steven Marshall**

*Source: image taken on-site (Manning, 2019)*

The trial aims to test other capabilities and inner intricacies of using autonomous vehicles commercially (Zito, 2019). Real-world data acquired via the daily trials of the Navya Autonomous Shuttle allow for testing and improvement of the autonomous algorithms. The early stage of the trial has focused on improving the shuttle's algorithms' reliability and repeatability.

Initially the shuttle followed a pre-planned route with movement essentially restricted to 'on-rails'. The shuttle follow a predetermined path and used live sensory feedback to determine safety and availability to perform manoeuvres, subject to environmental obstacles. Later trials of the shuttle will involve connecting multiple units to bus stops on South Road, the Clovelly Park train station, the Bedford Park campus and other local public transport hubs. A digital system for passenger booking is also planned.

### 2.4.4 Royal Adelaide Hospital

The recently built New Royal Adelaide Hospital (NRAH) opened in 2017 (Crouch, 2017). The NRAH has AGVs operating daily to assist staff in providing better patient care through assisting with delivery of medications and meals (Figure 17).

**Figure 17: AGVs at the NRAH (left) and towable meal trolleys (right)**

*Source: SA Health (2017)*

The NRAH has a fleet of 25 AGVs, which collectively transport over 1600 trolleys daily over the entirety of the hospital. They have dedicated lifts and lobbies to reduce congestion in elevators for doctors, nurses and patients which allows for most AGVs to not be seen during travel. The AGVs move at walking pace, with a maximum speed of up to two meters per second, and their deliveries and collections are all coordinated by a single control centre. The AGVs can read the contents, weight and required destination of the trolleys they are transporting, through embedded RFID tags (SA Health, 2017).

## 2.5 Data Tagging, Object Tracking and Digital Stocktaking

### 2.5.1 QR Codes

A Quick Response (QR) code is a two-dimensional barcode, differing from traditional one-dimensional barcodes that are typically used in supermarkets. Traditional 1D and the newer 2D QR barcodes both come in different formats and store varying levels of information, with QR Codes able to store more information due to their increased resolution. Traditional barcodes must be read with a scanner positioned perpendicularly to the barcode, whereas QR Codes can be read from any orientation (Figure 18).

**Figure 18: Examples of QR Codes (left) and barcodes (right)**


*Source: (ScienceABC, 2019)*

With the extra storage capacity, QR Codes can store data that can be assembled into varying sets of information such as phone numbers, emails and webpages which can be used as an effective method of communication (Dou & Li, 2008). QR Codes can be read by most smartphone cameras and robots and are easy to create.

A valuable feature of QR Codes is the potential for error correction. There are multiple levels of QR code error correction meaning that up to a third of the QR code can be covered, but the data can still be read from it (Barland, 2017). The advantage of error correction is that in dusty and dirty environments such as manufacturing sites, the QR codes can still be successfully read. At Electrolux, Dudley Park Adelaide, grids of QR Codes mounted to the floor are used to convey instructions to the AGVs that transport goods around the factory floor (Figure 19).

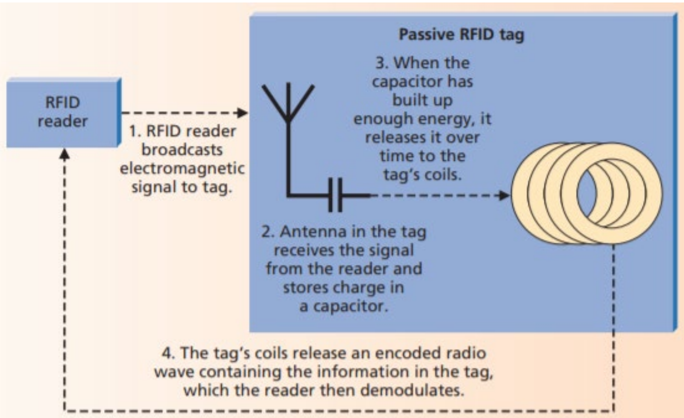
**Figure 19: QR Codes on the Electrolux factory floor are read by the AGVs**

*Source: image taken on-site (Manning, 2020)*

### 2.5.2 RFID

RFID is a method of communication used to identify objects through radio waves. Typically, an RFID reader interacts with a transponder, which holds digitised data in a microchip. The nature of the technology enables items to be identified from a distance without requiring line of sight (Want, 2006). Unlike barcodes (both 2D and 3D), where a direct line of sight is required for the product to be identified by scanning, RFID technologies simply requires the product's RFID transponder tag to be within physical range of the RFID reader (Figure 20).

**Figure 20: Simplified diagram of data transfer in low-frequency passive RFID tags**




*Source: Weinstein (2005)*

### 2.5.3 Track and Trace

In a factory setting, objects are often tagged with barcodes or RFID transponders which contain various bits of information. This allows advanced manufacturing technologies, such as Cobots, to read the data to identify what the product is and its various specifications, and to apply necessary operations in the manufacturing process (Ivantysynova & Ziekow, 2008). This process is track and trace in its simplest form as it allows for the parts to be recognised by machinery and tracked by a connected factory computer. Track and trace, in a broader form, is a methodology that uses an array of technologies to provide a system of tracking an item's current location and tracing its location history. Historically, in the shipbuilding industry, locations of items and equipment were documented on paper and required a person to deliver and receive catalogues of data (such as stocktake reports) to and from factory workers (Jang, 2020).

**Figure 21: Mailperson delivering engineering drawings to workers in a shipyard**

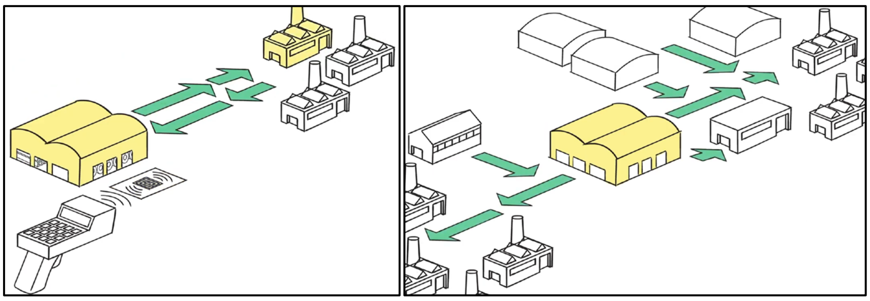
*Source: 3R solutions YouTube Channel (2017)*

This manual process is still used in some shipbuilding industries across the world, and within Australia's own shipbuilding industry. Digital transformation requires paper to be removed from a workplace and replaced with a digital tool to view the documentation. As there has not been a significant push for digital transformation within the Australian Defence industry until recently, a digital ecosystem has not yet developed to develop and test solutions.

Track and trace can be adapted for use in Australian defence shipbuilding yards, as it aligns with digital transformation methodologies and is also a key part of i4.0. A combination of QR and RFID can be used in conjunction with GPS and when integrated successfully, has the potential to provide a robust solution for track and trace (He, Tan, Lee, & Li, 2009). As technologies such as RFID and GPS do not require constant line of sight, these are ideal for integration into scenarios where line of sight would be impeded, such as dark and confined spaces.

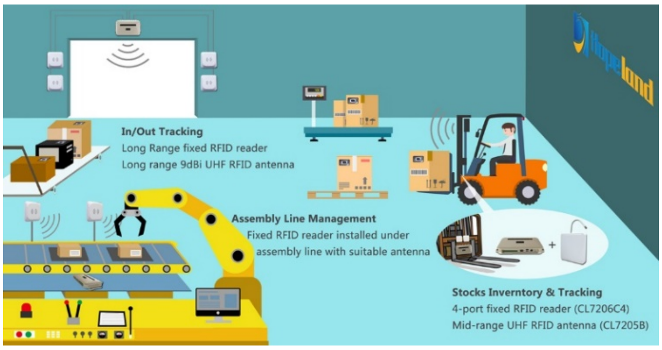
Modern Cobots, AGVs, mobile phones and tablets offer the ability to read barcodes and QR codes. With an integrated RFID reader, they can also be used to read RFID tags. Ideally, a true i4.0 implementation of track and trace would encompass a connected system that reports real-time locations of items and an autonomous agent would handle the data and provide updates on stock levels accordingly (Figure 22 & Figure 23) (Sharma & Siddiqui, 2010; Techman Robot, 2019).

**Figure 22: Track and trace using RFID**



*Source: Kloeckner Metals Corporation YouTube (2019)*

**Figure 23: Track and trace: a factory example on interconnected technologies**

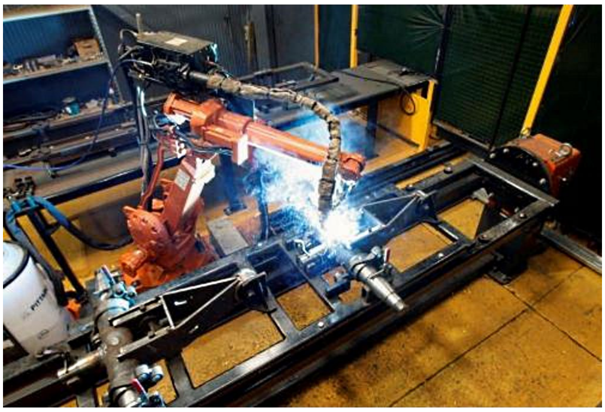



*Source: Hopeland RFID (2018)*

## 2.6 Smart Fixtures & Benches

Fixtures are devices that are used to position and secure workpieces in a fixed state to allow a human worker or machine such as a robot to perform operations on the workpiece, with minimal error and an overall reduction in the need for inspection (Bakker, Papastathis, Ratchev, & Popov, 2013). Fixtures are often used in manufacturing processes that utilise robots and automation tools as they assist in reducing variability, leading to greater consistency in quality of manufactured products. A jig is a collection of fixtures on a surface. Jigs, and their respective fixtures, are often made of rigid, lightweight materials to facilitate easy handling. Jigs are often used in robot assembly processes such as pick & place activities and welding (Figure 24) (Okpala & Okechukwu, 2015).

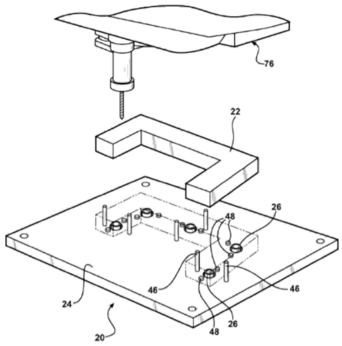
**Figure 24: Robotic welding on a workpiece secured on a fixture**



*Source: Scott Automation (2020)*

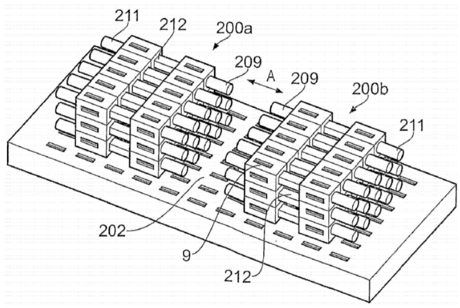
Fixtures can be classified into several categories, some common fixtures are chuck-based, pin-type array and reconfigurable fixtures (Figure 25, Figure 26 & Figure 27).

**Figure 25: Chuck-based fixture**



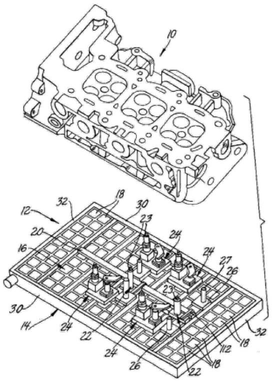

*Source: DeMeter and Powell (2009)*

**Figure 26: Pin-type array fixture**




*Source: Gindy, Fahmi, Wang, Kancharla, and Walker (2011)*

**Figure 27: Reconfigurable Fixtures**



*Source: Shen et al. (2003)*

Smart fixtures are a relatively unexplored technology in the manufacturing industry, as the technology is still in its infancy and is yet to be researched on a broader scale. It can be described as a reconfigurable fixture or bench mounted with sensors and is IoT enabled, facilitating connections to a network of systems and technologies. The smart fixture could relay information through a screen to an operator, providing real-time feedback on assembly processes and relevant production metrics (Figure 28) (Hydrotech, 2020). Such a digitally rich system not only supports zero-fault production but also high levels of production process visability, generating data that is the feedstock for artificial intelligence applications that support continuous improvement, energy efficiency and predictive maintenance.

**Figure 28: A Smart Bench concept prototyped**

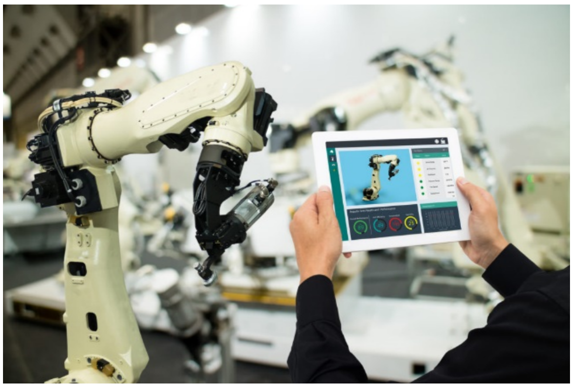
*Source: Hydrotech (2020) with Cobot model by Li (2014) [right image edited to add Cobot]*

Smart benches are intended to be paperless, completely digital workstations that promote the use of new technologies and tools for work. As the adoption rate of Cobots continues to increase, one ideal method for use of a smart bench is for integration in human-machine collaborative cells (Figure 29). An ideal use of the feedback data from the smart bench is for a HMI display on fixed and mobile devices to further the paperless workplace methodology that is part of digital transformation and i4.0 (Figure 30) (Djuric, Urbanic, & Rickli, 2016; L. Wang & Wang, 2018).

**Figure 29: SMC Workstation with various sensors, mounted with a Cobot**

*Source: image taken on-site (Manning, 2018c)*

**Figure 30: Tablet HMI displaying data about the smart bench and robot**



*Source: IEEE Innovation at Work (2020)*

## 2.7 Software Solutions for Simulation of Robots

Robots are not often equipped with high levels of autonomy and are typically programmed directly and tested live. Hence, various solutions have been developed over the past decade addressing the need for simulation packages of robots. These are often used for writing and testing preliminary robotic software in simulated virtual environments. This approach has the potential to reduce risks associated with running early prototype code on powerful and potentially dangerous machines such as industrial robots.

Most OEMs offer various simulation packages that the end user can use for testing and evaluation purposes of their robotic product. In response to the COVID-19 pandemic, ABB Robotics made several programming and simulation tools freely available for commercial use. The company stated that *"ABB's Robotics and Discrete Automation business will make key software services available free of charge to our customers until the end of 2020"* which will help to minimise downtime on production lines during the social isolation period of people working from home. ABB Robotics also signalled its intention to allow students and other robotic enthusiasts to install and evaluate the software (ABB Robotics, 2020a).

Similarly, as detailed in section 2.1, many modern Cobots are either running ROS or their OEMs offer ROS drivers. This operating system can provide the end user with tools for more advanced robotic simulation through packages such as Gazebo (Open Source Robotics Foundation, 2014) and data collection using the publisher/subscriber methodology underpinning ROS. Using tools such as ROS requires a sound understanding of the underlying software platform, APIs and requirements for implementation on various robotic hardware. There are various useful textbooks that enable beginners to learn how to use ROS to control robots using C and Python programming languages (O'Kane, 2014), as well as using other scripting packages such as MATLAB for programming of robotic control systems and machine vision (Corke, 2017).

A multitude of online courses and resources exist to enhance users' understanding of programming Cobots and other similar robots. Some courses include options provided by Robot Ignite Academy which offers courses on learning ROS (Robot Ignite Academy, 2020) as well as Universal Robots' online short course on how to program their UR Cobots (Universal Robots, 2020). Lastly, Coursera has an abundance of courses on robotics such as ones for ROS (Lynch & Park, 2017).

A list of software resources has been provided in Appendix B: 'Software packages for programming and simulation of Cobots' has been evaluated that may be relevant and useful for the purposes of simulation and testing of robotic software.

# 3 Summary

Significant benefits are likely to be realised from successful integration of robotic and automation technologies into the shipyard as part of a wider Digital Shipyard strategy. Improvements in safety and wellbeing, productivity, quality and cost efficiency can be expected where holistic approaches to system development and equipment integration are adopted.

Industrial Robots have been in operation for many years in Australia, particularly in the automotive industry. Cobots are an emerging robotic platform that offer significant safety and installation cost benefits. A growing number of manufacturing companies are integrating various Cobotic platforms into production lines, mostly for use in repetitive and ergonomically challenging assembly processes that would typically be done by factory workers. Some limitations have been highlighted for the platform, for example, load limits. Industrial robots are deployed for a wider range of processes but safety concerns require they operate in confinement.

In recent years AGVs have been transformed by increases in demand and availability of powerful on-board computing solutions. There are many Australian manufacturing sites and hospitals that have adopted the platform to provide automated delivery services. Modern AGVs fall into two categories - a 'smarter' type of AGV with more advanced on-board navigation solutions and a more traditional AGV that uses less sophisticated navigation methods. Project budget was identified as a contributing factor on deciding which platform was chosen for service.

Track and trace is a methodology that combines a suite of 'off the shelf' technologies to enable location and status tracking of items and people as well as enabling traceability. The contribution of track and trace to digital transformation includes real time assurance, security, safety, system flexibility and optimisation. Technologies that are relevant to track and trace include Wi-Fi, RFID, AGVs, smart cameras and others, all of which provide integrated functionalities to capture and transmit identification and operational information through the instrumentalities of sensors in real time. Recently emerging 5G technologies promise to widen the scope of track and trace applications, particularly for security and safety functions. These were not investigated in this review.

Smart fixtures and smart benches are new technologies that have not been widely adopted in Australian manufacturing, possibly due to a lack of applied research. Case trials and more research is required to support the adoption of such technology within the manufacturing and/or shipbuilding industries.

The recent boom in the use of cobots has introduced a need for software solutions that provide programming and testing capabilities of the platform in simulated environments. There are many solutions available, with some OEMs offering their own proprietary software. Some packages cover many brands of both cobots and industrial robots, offering a 'one stop shop' for all robot arm programming and simulation needs. These programs are often licensed, but there are a few that are free and offer an excellent starting solution for programming and simulated testing needs.

More in-depth research and case studies are needed to demonstrate the day to day applications and benefits of integrating advanced manufacturing technologies into Australian manufacturing sites and most notably, Australian shipyards. With increased awareness and confidence in the processes and outcomes linked with integrating these technologies into manufacturing processes, Australian companies stand to make significant competitive gains, nationally and internationally.

# References

3R solutions YouTube Channel. (2017). An introduction of 3R solutions compared to conventional spool fabrication. Retrieved from https://www.youtube.com/watch?v=KoItK5hZErg

ABB Robotics. (2000). Electrolux Case study: Metal Fabrication. Retrieved from https://search.abb.com/library/Download.aspx?DocumentID=MF2008020&LanguageCode=en&DocumentPartId=&Action=Launch

ABB Robotics. (2020a). ABB to make digital service available free of charge to help customers maintain production. Retrieved from https://new.abb.com/news/detail/59343/abb-to-make-digital-service-available-free-of-charge-to-help-customers-maintain-production

ABB Robotics. (2020b). The world's most used offline programming tool for robotics. Retrieved from https://new.abb.com/products/robotics/robotstudio

AI Group. (2019). *Australian Manufacturing in 2019 Local and Global Opportunities*. Retrieved from https://cdn.aigroup.com.au/Economic_Indicators/Economic_Outlook/Australian_Manufacturing_in_2019.pdf

AMGC. (2018). *Advanced Manufacturing. A new definition for a new era*. Retrieved from Sydney, NSW: https://www.amgc.org.au/wp-content/uploads/2018/11/Advanced-Manufacturing-a-new-definition-for-a-new-era.pdf

Australian Centre for Robotic Vision. (2018). *A Robotics Roadmap for Australia 2018*. Retrieved from Australia: https://www.roboticvision.org/wp-content/uploads/Robotics-Roadmap_FULL-DOCUMENT.pdf

Bakker, O., J, Papastathis, T., N, Ratchev, S., M, & Popov, A., A. (2013). Recent research on flexible fixtures for manufacturing processes. *Recent Patents on Mechanical Engineering, 6*(2), 107-121.

Bandyopadhyay, S. (2017). *Intelligent Vehicles and Materials Transportation in the Manufacturing Sector: Emerging Research and Opportunities: Emerging Research and Opportunities*: IGI Global.

Barland, G. (2017). Error Correction And Qr Codes. *Saint Paul*.

Bauer, W., Bender, M., Braun, M., Rally, P., & Scholtz, O. (2016). Lightweight robots in manual assembly—best to start simply. *Frauenhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart*.

Bloss, R. (2016). Collaborative robots are rapidly providing major improvements in productivity, safety, programing ease, portability and cost while addressing many new applications. *Industrial Robot: An International Journal*, 463-468.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: International Journal of Information and Communication Engineering,. *International journal of mechanical, industrial science and engineering, 8*(1), 37–44.

CEBR. (2017). *The impact of automation*. Retrieved from

Chadwick, J. (2018). South Australia begins trials of Flinders Express autonomous shuttle bus. Retrieved from https://www.zdnet.com/article/south-australia-begins-trials-of-flinders-express-autonomous-shuttle-bus/

Clark, J. (2019). Evolution of AGVs - What's Available and What's to Come? Retrieved from https://www.mapyourshow.com/mys_shared/packexpo17/handouts/Dematic1.pdf

Cobotics World. (2019). A complete list of all the ROS-enabled cobots. Retrieved from http://www.coboticsworld.com/2019/05/27/what-a-terrific-duo-a-complete-list-of-all-the-ros-enabled-cobots/

Colgate, J. E., & Peshkin, M. A. (1999). USA Patent No. US5952796A.

Convergent Information Technologies. (2020). Faster Robot Programming with AUTOMAPPPS Software. Retrieved from http://convergent-it.com/robot-programming-software/

Corke, P. (2017). *Robotics, vision and control: fundamental algorithms in MATLAB® second, completely revised* (Vol. 118): Springer.

Crouch, B. (2017). New Royal Adelaide Hospital is open for business. Retrieved from https://www.adelaidenow.com.au/news/south-australia/new-royal-adelaide-hospital-is-open-for-business-from-7am-on-tuesday/news-story/f8be5863c881ec689e93892e3c28923a

Cyberbotics. (2020). Webots OPEN SOURCE ROBOT SIMULATOR. Retrieved from https://cyberbotics.com/

Deloitte. (2019). *Automated growth: the economic impacts of industrial robots in Australia*. Retrieved from Adeliade, SA:

DeMeter, E. C., & Powell, R. M. (2009). USA Patent No. US7524390B2

Djuric, A. M., Urbanic, R., & Rickli, J. (2016). A framework for collaborative robot (CoBot) integration in advanced manufacturing systems. *SAE International Journal of Materials and Manufacturing, 9*(2), 457-464.

Dou, X., & Li, H. (2008). CREATIVE USE OF QR CODES IN CONSUMER COMMUNICATION. *International Journal of Mobile Marketing, 3*(2).

Drogemuller, M. (2019, February) *Site Visit to Penfolds Barossa Valley Treasury Wines Nuriootpa, South Australia/Interviewer: K. Manning*.

Energid Technologies. (2020). Industrial-Grade Software for Advanced Robotic Solutions. Retrieved from https://www.energid.com/actin

Evjemo, L. D., Gjerstad, T., Grøtli, E. I., & Sziebig, G. (2020). Trends in Smart Manufacturing: Role of Humans and Industrial Robots in Smart Factories. *Current Robotics Reports, 1*(2), 35-41.

Forum, W. E. (2018). *The Future of Jobs Report 2018*. Retrieved from <http://

www3.weforum.org/docs/WEF_Future_of_ Jobs_2018.pdf

Fryman, J., & Matthias, B. (2012). *Safety of industrial robots: From conventional to collaborative applications.* Paper presented at the ROBOTIK 2012; 7th German Conference on Robotics.

Gindy, N., Fahmi, A., Wang, Y., Kancharla, V., S, & Walker, K. (2011). GB Patent No. US20110272537.

He, W., Tan, E. L., Lee, E. W., & Li, T. (2009). *A solution for integrated track and trace in supply chain based on RFID & GPS.* Paper presented at the 2009 IEEE Conference on Emerging Technologies & Factory Automation.

Hermann, M., Pentek, T., & Otto, B. (2016). *Design principles for industrie 4.0 scenarios.* Paper presented at the 2016 49th Hawaii international conference on system sciences (HICSS).

Hopeland RFID. (2018). Industry 4.0 Smart Manufacturing. In.

Hot Melt Packaging Systems. (2018). Electrolux Dudley Park Final Packing Line - YouTube. Retrieved from https://www.youtube.com/watch?v=YHgKc1kDa4Q

Hydrotech. (2020). Bosch Rexroth and Tulip announce strategic alliance to bring Smart Workstation to market. Retrieved from https://www.hydrotech.com/article/smart_workstation_bosch_rexroth_tulip

IEEE Innovation at Work. (2020). The Race to the Edge of the Network. Retrieved from https://innovationatwork.ieee.org/the-race-to-the-edge-of-the-network/

IMCRC. (2019). *Innovative Manufacturing CRC (IMCRC) Annual Highlights 2018-2019*. Retrieved from Victoria: https://www.imcrc.org/wp-content/uploads/2019/10/IMCRC014-Highlights-Report-2019_final.pdf

Institute of Robotics and Mechanics. (2018). History of the DLR LWR. Retrieved from https://www.dlr.de/rm/en/desktopdefault.aspx/tabid-12464/21732_read-44586/

Robots and robotic devices – Vocabulary, 8373:2012 C.F.R. (2012).

ISO. (2014). ISO 13482:2014

Robots and robotic devices — Safety requirements for personal care robots. In. Geneva, Switzerland: ISO.

Ivantysynova, L., & Ziekow, H. (2008). RFID in manufacturing: From shop floor to top floor. In *RFID in Manufacturing* (pp. 1-24): Springer.

Jang, R. (2020). *Understanding Shipbuilding*. Presentation.

Jungheinrich YouTube. (2017). AGV - Transport More with Safety (Full Coverage). Retrieved from https://www.youtube.com/channel/UCbV9MO_qDbB57VRyOplvCXg

Kittel, A. (2019, 2019) *REDARC Celebrates 40 years of manufacturing - Interview with Owner and Managing Director of REDARC, /Interviewer: R. Electronics*.

Kloeckner Metals Corporation YouTube. (2019). RFID (radio frequency identification) Kloeckner Metals. Retrieved from https://www.youtube.com/watch?v=v7vg1IddIrA

Koren, Y., & Shpitalni, M. (2010). Design of reconfigurable manufacturing systems. *Journal of manufacturing systems, 29*(4), 130-141.

Küpper, D., Lorenz, M., Kristian, C. K., Andreas Maue, K., Lässig, R., & Buchner, T. (2019). Advanced Robotics in the Factory of the Future. Retrieved from https://www.bcg.com/en-au/publications/2019/advanced-robotics-factory-future.aspx

Lai, N. Y. G., Jayasekara, D., Wong, K. H., Yu, L. J., Kang, H. S., Pawar, K., & Zhu, Y. (2020). *Advanced Automation and Robotics for High Volume Labour-Intensive Manufacturing.* Paper presented at the 2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA).

Lee, D. (2014). Robots in the shipbuilding industry. *Robotics and Computer-Integrated Manufacturing, 30*(5), 442-450.

Lenz, C., & Knoll, A. (2014). *Mechanisms and capabilities for human robot collaboration.* Paper presented at the The 23rd IEEE International Symposium on Robot and Human Interactive Communication.

Li, W. (2014). GrabCAD Community. Retrieved from https://grabcad.com/library/ur-5-six-axis-robot-1/details?folder_id=629093

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration, 6*, 1-10. doi:https://doi.org/10.1016/j.jii.2017.04.005

Lynch, K. M., & Park, F. C. (2017). *Modern Robotics*: Cambridge University Press.

Manning, K. (2018a). Site Visit to Electrolux Dudley Park, South Australia. In.

Manning, K. (2018b). Site visit to Multislide Edwardstown, South Australia. In.

Manning, K. (2018c). Site Visit to Tonsley Manufacturing Innovation Hub, South Australia. In.

Manning, K. (2019). Premier Steven Marshall's Visit to Flinders at Tonsley SA. Travelling around the Campus using the Navya Autonomous Shuttle Bus. In.

Manning, K. (2020). RAETIG Site Visit (March 2020) at Electrolux Dudley Park, South Australia. In.

Manufacturing Automation. (2016). Avnu Alliance welcomes Kuka Robotics, Schneider Electric. Retrieved from https://www.automationmag.com/6403-avnu-alliance-welcomes-kuka-robotics-schneider-electric/

Martin, C. (2020, March 4th 2020) *RAETIG Site Visit (March 2020) at Electrolux Dudley Park, South Australia/Interviewer: C. Thomas*.

Matthias, B. (2015). *New safety standards for collaborative robots, ABB YuMi dual-arm robot.* Paper presented at the International Conference on Intelligent Robots and Systems 2015, Workshop "Robotic co-workers - methods, challenges and industrial test cases", Hamburg, Germany.

McBratney, P., Schwarz , P., & Coupe, M. (2016) *Site Visit to Seeley International Lonsdale, South Australia/Interviewer: K. Hansen*.

Micheler, S., Goh, Y. M., & Lohse, N. (2019). Innovation landscape and challenges of smart technologies and systems–a European perspective. *Production & Manufacturing Research, 7*(1), 503-528.

Montemerlo, M., Thrun, S., Koller, D., & Wegbreit, B. (2002). FastSLAM: A factored solution to the simultaneous localization and mapping problem. *Aaai/iaai, 593598*.

Murray, A. (2019, Janurary 23rd 2019) *RAETIG Site Visit Jan 2019 at SMR Automotive Lonsdale, South Australia/Interviewer: C. Thomas*.

O'Kane, J. M. (2014). *A gentle introduction to ROS*. South Carolina: University of South Carolina.

O'Keeffe, V., Moretti, C., Hordacre, A. L., S., H., & Spoehr, J. (2020). Quicker off the blocks: The role of human factors in the uptake and diffusion of advanced technologies in shipbuilding. *BAE internal publication*.

OCTOPUZ Inc. (2020). OCTOPUZ - Complex robot programming made simple. Retrieved from https://octopuz.com/

Okpala, C. C., & Okechukwu, E. (2015). The design and need for jigs and fixtures in manufacturing. *Science Research, 3*(4), 213-219.

Open Source Robotics Foundation. (2014). GazeboSim. Retrieved from http://gazebosim.org/

Ordoobadi, S. M., & Mulvaney, N. J. (2001). Development of a justification tool for advanced manufacturing technologies: system-wide benefits value analysis. *Journal of Engineering and Technology Management, 18*(2), 157-184.

Pellicciari, M., Berselli, G., Leali, F., & Vergnano, A. (2013). A method for reducing the energy consumption of pick-and-place industrial robots. *Mechatronics, 23*(3), 326-334. doi:https://doi.org/10.1016/j.mechatronics.2013.01.013

PickNik Robotics. (2020). Moving robots into the future. Retrieved from https://moveit.ros.org/

REDARC Electronics. (2016). Rethinking Robotics For Advanced Manufacturing in SA. Retrieved from https://www.redarc.com.au/rethinking-robotics-for-advanced-manufacturing-in-sa

REDARC Electronics. (2019). Implementing new technologies to succeed on a global scale. In: Manufacturers' Monthly.

ReThink Robotics. (2014). Baxter. Retrieved from https://web.archive.org/web/20140826071530/http://www.rethinkrobotics.com/products/baxter/

RoboDK. (2020). Simulate Robot Applications Program any Industrial Robot with One Simulation Environment. Retrieved from https://robodk.com/

Robot Ignite Academy. (2020). ROS Courses Library. Retrieved from https://www.theconstructsim.com/robotigniteacademy_learnros/ros-courses-library/

Rohmer, E., Singh, S. P., & Freese, M. (2013). *CoppeliaSim (formerly V-REP): a Versatile and Scalable Robot Simulation Framework.* Paper presented at the The International Conference on Intelligent Robots and Systems (IROS) 2013.

SA Health. (2017). Automated Guided Vehicles Ready for Action. Retrieved from https://www.rah.sa.gov.au/news/automated-guided-vehicles-ready-for-action

Salzer, J. R. (1986). Factors in the selection of dry docking systems for shipyard. *Journal of Ship Production*, 110-119.

Savant Automation. (2020). AGV technology truly focussed on the user. Retrieved from https://agvsystems.com/

ScienceABC. (2019). What's a QR Code And How Is It Different From A Barcode? Retrieved from https://www.scienceabc.com/innovation/whats-qr-code-how-its-different-from-barcode.html

Scott Automation. (2020). Our History. Retrieved from https://www.scottautomation.com/our-company/our-history/

Seeley International. (2017). Seeley International Capability Statement. Retrieved from https://cdn.seeleyinternational.com/wp-content/uploads/2019/02/sp_capability-_statement_2017_final_low_res.pdf

Self, M., Cheeseman, P., & Smith, R. (1988). Estimating uncertain spatial relationships in robotics. In *Machine intelligence and pattern recognition* (Vol. 5, pp. 435-461): Elsevier.

Sharma, M., & Siddiqui, A. (2010). *RFID based mobiles: Next generation applications.* Paper presented at the 2010 2nd IEEE International Conference on Information Management and Engineering.

Shen, C., H, Lin, Y., T, Agapiou, J., S, Bojda, P., A, Jones, G., L, & Spicer, J., P. (2003). USA Patent No. US6644637.

SICK Sensor Intelligence YouTube. (2016). Monitoring automated guided vehicles (AGV) - with Safe Motion Control from SICK. Retrieved from https://www.youtube.com/watch?v=Rw7D5trwza8

Simões, A. C., Soares, A. L., & Barros, A. C. (2019). Drivers Impacting Cobots Adoption in Manufacturing Context: A Qualitative Study. In *Advances in Manufacturing II* (pp. 203-212): Springer.

Smith, R. (2018). South Korea has the highest density of robot workers in the world. Retrieved from https://www.weforum.org/agenda/2018/04/countries-with-most-robot-workers-per-human/

Techman Robot. (2019). Cobot with a Built-in Vision System. Retrieved from https://www.tm-robot.com/en/tm-robot/

Thomas, C. (2020, 2nd September 2011) *ABB Robotics - Cooker door assembly line interview with Colin Thomas/Interviewer: ABB Robotics*. ABB Robotics YouTube.

Thomas, R. (2020, April 27th 2020) *RAETIG Site Visit follow up at SMR Automotive, Lonsdale, South Australia/Interviewer: K. Manning*.

Tilley, J. (2017). *Automation, robotics, and the factory of the future*. Retrieved from https://www.mckinsey.com/business-functions/operations/our-insights/automation-robotics-and-the-factory-of-the-future#

Todd, P. (2018, 19 September 2018) *Site visit to Multislide Edwardstown, South Australia/Interviewer: C. Thomas*.

Toris, R., Kammerl, J., Lu, D. V., Lee, J., Jenkins, O. C., Osentoski, S., . . . Chernova, S. (2015). *Robot web tools: Efficient messaging for cloud robotics.* Paper presented at the 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).

Ullrich, G. (2015). The History of Automated Guided Vehicle Systems. In *Automated Guided Vehicle Systems* (pp. 1-14): Springer.

Universal Robots. (2016). *THE ROLE OF COBOTS IN INDUSTRY 4.0*. Retrieved from https://cdn2.hubspot.net/hubfs/2631781/HQ%20Content%20and%20Enablers/HQ%20Enablers/White%20papers/The%20role%20of%20cobots%20in%20industry.pdf

Universal Robots. (2017). Universal Robots enables Xiamen Runner Industrial Corporation to achieve flexible manufacturing. Retrieved from https://www.universal-robots.com/case-stories/runner/

Universal Robots. (2018). 10 Years Later, Still Reaping the Benefits of its UR Cobot Retrieved from https://blog.universal-robots.com/10-years-later-still-reaping-the-benefits-of-its-ur-cobot

Universal Robots. (2020). Universal Robots Academy Retrieved from https://www.universal-robots.com/academy/

Vanderwielen, S. (2018, October 24th) *Site Visit to Clipsal by Schneider Electric Gepps Cross, South Australia Plant Visit/Interviewer: C. Thomas*.

Vysocky, A., & Novak, P. (2016). Human-Robot collaboration in industry. *MM Science Journal, 9*(2), 903-906.

Wang, L., & Wang, X. V. (2018). *Cloud-based cyber-physical systems in manufacturing*: Springer.

Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing smart factory of industrie 4.0: an outlook. *International Journal of Distributed Sensor Networks, 12*(1), 10.

Want, R. (2006). An introduction to RFID technology. *IEEE pervasive computing, 5*(1), 25-33.

Way, T. L. (2017). The 8 Wastes of Lean. Retrieved from https://theleanway.net/The-8-Wastes-of-Lean

Wegener, K., Chen, W. H., Dietrich, F., Dröder, K., & Kara, S. (2015). Robot Assisted Disassembly for the Recycling of Electric Vehicle Batteries. *Procedia Cirp, 29*, 716-721. doi:10.1016/j.procir.2015.02.051

Weinstein, R. (2005). RFID: a technical overview and its application to the enterprise. *IT professional, 7*(3), 27-33.

World Economic Forum. (2018). *Readiness for the Future of Production Report 2018 In collaboration with A.T. Kearney*. Retrieved from http://www3.weforum.org/docs/FOP_Readiness_Report_2018.pdf

Zanchettin, A. M., Croft, E., Ding, H., & Li, M. (2018). Collaborative robots in the workplace [from the guest editors]. *IEEE Robotics & Automation Magazine, 25*(2), 16-17.

Zito, R. (2019). Flinders Autonomous Shuttle Trial. Retrieved from https://dpti.sa.gov.au/news?a=371235

# Appendix A: Advanced Technology Case Study

(Australian Centre for Robotic Vision, 2018)

| Type | Case Study | Feature | Outcome /Benefit |
|---|---|---|---|
| Cobot | Boeing Australia - Where humans and automation work together (p.54) | Enable collaboration between workers, and risk minimisation of damage to components as opposed to manual operation that could slip, resulting in rework | - Saved time (Hundreds of hours)<br>- Reduced human risk of working with robots.<br>- Reduced machining cutter consumption |
| Cobot | Rotacastor – Newcastle company manufacturing robotic wheels (p.58) | "Ball transfer tables for manual sorting of bulky international mailbags weighing up to 35 kilograms" | - Reduced the need of the push, pull forces and noise (4-7kg)<br>- Reduced downtime and maintenance costs<br>- reduced risk of injury |
| Robot | Laing O'Rourke - Lifting frontline job satisfaction (p.55) | "Deep integration of robotics systems and capabilities into frontline workflows" | - Increased "Flexibility, job satisfaction, engagement, and performance"<br>- Presented viable units |
| Robot | IR4 – Mass customisation via robotic automation (P.56) | "Real-time automation solution that "uses the system's artificial intelligence to calculate the most efficient way to process steel sections presented for fabrication" | - Provided significant customer benefits that include "cost, quality, traceability, scheduling and ease of implementation of design changes"<br>- Saved time for steel fabrication process |
| Robot | ANCA - Australia's largest user of industrial robots (p.57) | Innovative new multi-robot production cell. | - Allowed simultaneous operation within two processes<br>- Increased a cell capability<br><br>- Reduced capital equipment costs and risks<br>- Improved productivity |
| Robot | Autonomous grit-blasting robots for steel bridge maintenance (p.137) | "Autonomous robots for removing rust and old paint" | - Improved workers' OH&S by reducing "the exposure to large forces, fine dust, paint particles and the dangerous blast stream",<br>- Improved operational efficiencies |
| Traceability | Rio Tinto Mining Automation (p.46) | Autonomous haul trucks (Autonomous Haulage System, AHS) | - Reduced injuries (Zero injuries) |

# Appendix B: Software packages for programming and simulation of Cobots

| Name | Cost | Features | User Experience |
|---|---|---|---|
| Actin SDK (Energid Technologies, 2020) | Licensed | Actin SDK is a software tool for designing, simulating and controlling robotic systems. It offers functionality ideal for use by Cobots.<br>It offers integrated kinematics solutions, path planning, tool-path generation from CAD data, and adaptive tasking relative to robot tool centre point. | Actin SDK offers automatic path planning which enables the user to not need an in-depth understanding of inverse-robotic kinematics and path planning. As the program offers CAM support and CAD to path, it is ideal for projects that have CAD data of the geometry of the parts they are working with. |
| AutoMappps (Convergent Information Technologies, 2020) | Licensed | AutoMappps is a suite of offline robotic programming software. It is marketed as a “fast and easy offline robotic programming tool” and offers some speciality in bin picking processes. The software supports a multitude of robot platforms and can use CAD data for path planning. The program also offers automatic motion planning and automatic collision avoidance for the robot’s program as well as CAM support and multi-robot simulation. | AutoMappps offers automatic path planning which enables the user to not need an in-depth understanding of inverse-robotic kinematics and path planning. As the program offers CAM support and CAD to path, it is ideal for projects that have CAD data of the geometry of the parts they are working with. |
| CoppeliaSim (Rohmer, Singh, & Freese, 2013) | Free and Licensed versions available | CoppeliaSim is based on “a distributed control architecture which allows for each object/model to be individually controlled via an embedded script, plugin, ROS or BlueZero node, as well as remote API clients”. It boasts that it is “versatile and ideal for multi-robot applications. Controllers can be written in C/C++, Python, Java, Lua, MATLAB or Octave”. It claims it is also effective for fast algorithm development. | Using of CoppeliaSim requires knowledge of ROS and familiarity of C/C++, Python, Java, Lua, MATLAB or Octave programming languages, which can be used to program robot with.<br>Online videos can be viewed to learn how to use the package. |
| Gazebo (Open Source Robotics Foundation, 2014) | Free | Gazebo is a simulation package for ROS that can be used to simulate any robot, provided the OEM has made the robot model available to be used. The writing of robot programs for scripting can be done in a multitude of languages, notably using Python or C/C++ programming languages. There is almost nothing that can’t be done using Gazebo as it (and ROS) are open source. GitHub is a resource where users can post their software and share it with other roboticists, free of charge. It is an excellent ecosystem to use, provided the programmer has the skills. Most recently, Microsoft have been working to bring Linux subsystem to windows, enabling ROS & Gazebo to be installed and used on Windows natively, instead of requiring the user to have a computer with a Linux-based operating system such as Ubuntu. | Learning ROS is a steep learning curve for beginners. It is advised that beginners seek a course or read a book to assist in learning how to use it. Such books are recommended:<br>A gentle introduction to ROS (O'Kane, 2014) & Robotics, vision and control: fundamental algorithms in MATLAB (Corke, 2017)<br>A powerful computer with a discrete graphics card is recommended for using Gazebo. |

| Name | Cost | Features | User Experience |
|---|---|---|---|
| MoveIt (PickNik Robotics, 2020) | Free | MoveIt is a ROS software package that provides solutions for motion planning, manipulation, robot inverse kinematics, collision checking and other functionality such as understanding point clouds.<br>Functionality such as perception of the 3D environment is an important part of robotic programming and hence it would be desirable that this ROS package is investigated if ROS is used as a platform during this project. | As MoveIt is a ROS package, for it to be used, a sound understanding of ROS would be ideal. Otherwise, there are many online ROS forums and videos which would assist in gaining an understanding into how to use this package, and to aid for use within the project. |
| Octopuz (OCTOPUZ Inc, 2020) | Licensed | Octopuz is an offline robotic programming and simulation tool that enables robot programs to created based of paths from CAD programs. It offers the ability to program multiple robot brands in "a virtual, offline environment and output code for use in a real-world cell application". | Octopuz is marketed as a platform that is easy to use for people who do not have the high-level programming skills that a package such as ROS would require. It does require some training to learn how to use. |
| RoboDK (RoboDK, 2020) | Educational and commercial Licensed versions available | RoboDK provides a simulated environment for programming and testing of industrial robots and Cobots. RoboDK offers the ability to use a robot like a 5-axis milling machine (CNC) or a 3D printer. It also offers path optimization, avoiding points of singularity and collision avoidance. There is an extensive library of robots, cobots, turn tables and end effectors available for the user to program and simulate. Visual effects are available for welding, glue dispensing and painting applications for validation of offline programming. | RoboDK is marketed as an easy-to-use program, even for use by people who do not necessarily have tertiary qualifications in robotic programming. Another advantage of RoboDK's is that it allows you to program robots outside the production environment, from the comfort of your own home on your own PC. It also allows for the importation of CAD STEP files. |
| Robot Web Tools (Toris et al., 2015) | Free | Robot Web Tools is a software package for ROS that<br>allows web applications to interface with a variety of robots running ROS. It can provide functionality such as interfacing with a variety of sensors and actuators for use by algorithms for navigation, perception, and manipulation. | Using of Robot Web Tools requires knowledge of JavaScript libraries such as roslibjs, ros2js, and ros3djs as well as knowledge of how to use WebSockets.<br>Online videos can be viewed to learn how to use the package. It requires familiarity with ROS and has a learning curve. |
| RobotStudio (ABB Robotics, 2020b) | Currently Free (as of April 2020) | RobotStudio by ABB is a package that allows for offline programming of ABB robots. It provides tools that allow for "risk reduction, quicker start-up, shorter change-over and increased productivity".<br>Like URSim, RobotStudio's GUI is built based on the "ABB VirtualController -, an exact copy of the real software that runs on the ABB robots". This allows for "realistic simulations to be performed, using real robot programs and | The simulator is marketed as an easy to use package as it is a re-creation of the robot's pendant GUI. As it has been made free for use to the public, as a result of the COVID-19 pandemic, it would be highly advised that it is investigated, should ABB robots be used in the project. |

| Name | Cost | Features | User Experience |
|---|---|---|---|
| | | configuration files identical to the real models". | |
| URSIM (Universal Robots, 2020) | Free | URSim is an offline simulation package for programming and simulating of UR Cobots. There are a number of UR models that can be programmed and simulated. The simulation tool presents the user with all the features that the Cobot has out of the box such as URScript and TCP. | The simulator is easy to use as it is a is a re-creation of the Cobot's pendant GUI. It can run natively in Linux or run through a Virtual Machine in Windows. |
| Webots (Cyberbotics, 2020) | Free | Webots is an open source simulation package for robots. It is available on multiple platforms and provides "a complete development environment to model, program and simulate robots". It allows for the user to design their own robot, as well as import official robot models from OEMs for programming and simulation purposes. Simulations can be exported as movies and animations for presentations. Robots can be "programmed in C, C++, Python, Java, MATLAB or ROS with a simple API covering all the basic robotics needs". | Using of Webots requires knowledge of the programming languages and proficiency in using them. Online courses and tutorials can be viewed to learn how to use Webots. There are many demo simulations that can be viewed, out of the box such as how to program a UR10e. |

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