AMPC

ROADMAP DEVELOPMENT FOR A MEAT PROCESSING INTELLIGENT AUTOMATION CENTRE

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1.0 EXECUTIVE SUMMARY

The following report is the final stage of a three phase Intelligent Automation (IA) roadmap project commissioned by the Australian Meat Processing Corporation (AMPC). The project is intended to facilitate the establishment of an IA centre for fostering collaboration between the meat industry and academia. The first phase covered an overview of IA and industry 4.0 technologies used by meat processing and other sectors worldwide. It focused on technologies such as virtual reality, blockchain, predictive maintenance, human and animal sensors, collaborative robots and 3D printing. The second phase covered the current and emerging automation technologies used in the meat processing industry in Australia. It looked at various projects implemented in carcass processing and packaging/storing operations and covered the latest trials in Australia. The third phase has further expanded on the previous findings and developed an IA roadmap for the meat processing sector.

In preparing this report, which includes all three phases of the project, we conducted a thorough literature review using industry sources and academic publications; engaged with AMPC; and interviewed a number of meat processors across Australia to provide a balanced and forward-looking view. The attached IA technologies roadmap will enable industry players to identify future trends and develop pathways to utilise smart technologies.

The establishment of a dedicated IA research centre for the meat processing industry has been recommended to enable a highly advanced, smart and cost-efficient meat processing sector in Australia. Two funding options under the Government's Industrial Transformation Research Program i.e. the Industrial Transformation Training Centres or the Industrial Transformation Research Hubs are deemed as the most relevant arrangements.

2.0 INTRODUCTION

The cost of processing meat in Australia has been somewhat higher than other exporting nations as a result of higher cost structures and wages placing a burden on the meat processing industry. As the final stage of a three phase Intelligent Automation (IA) roadmap project, this report is focused on developing a roadmap and proposing a research centre for fostering collaborations between the meat industry and academia towards the development and deployment of meat related IA technologies. This centre will facilitate the transition of the industry from its current stage to Industry 4.0 technologies supporting more efficiency, higher meat quality and lower costs.

This project was completed as scheduled using information from various sources as outlined in the 'Methodology' section. It has taken a critical view of the current and emerging applications of IA technologies in the industry. Although progress has been made to automate a number of processes in meat processing plants and there are trails in place for experimenting with new technologies, the applications of IA using Industry 4.0 principles are still limited. The industry has been relatively slower than other industries such as the automotive sector to adopt new smart technologies. This is mainly attributed to the inherent biological variations of meat products, the characteristics of the supply chain and the high cost involved with automation. By looking at current applications, current trials and interviewing a number of meat processors, the report provides a view of the current state of automation in the sector in Australia.

The report concludes with a roadmap that describes the current and future technological advancements. Industry 4.0 and robotics are fast moving areas and due to their rapid pace, it is easier to identify existing technological gaps than to accurately predict future trends. As such, the roadmap is an agile and life document requiring ongoing updates. Moreover, the roadmap is intended as an advisory document rather than a rigid set of facts. Abattoirs would need to make best decisions based on their individual and unique circumstances.

3.0 PROJECT OBJECTIVES

Attempts were made by industry bodies, academia and corporations to automate the meat processing industry. Significant progress has been made to automate various labour intensive and high-risk processes resulting in yield increases and cost savings. However, the world is now embarking on a new industrial revolution called Industry 4.0 (or specifically IA). As such, the project aims at developing an IA roadmap that would provide a pathway to transform current operations to intelligently automated ones.

Consequently, the establishment of a dedicated Meat Processing Research Centre is proposed based on the Government's Industrial Transformation Research Program funding arrangement. A dedicated and first of its kind, the establishment of an IA centre will facilitate the collaboration amongst industry, industry bodies and academia, and enable the sector to transition from its current state to Industry 4.0 technologies. As an independent entity, the Centre would focus on serving the meat processing industry through an agreed R&D pipeline aimed at increasing the competitiveness and long-term sustainability of the sector amongst its global competitors.

4.0 METHODOLOGY

The first milestone was completed through an extensive review of academic and business literature. The second milestone was performed by conducting a thorough search of academic databases, journals, business publications, industry reports and industry news to ensure a wide range of topics are covered. Attempts were made to contact 15 meat processors across Australia to which three have agreed to be interviewed. The combination of research with the interviews, have ensured a balanced outcome. The final phase has been completed through extensive research from a wide range of sources. Efforts were made to hold a workshop with selected stakeholders. However, due to certain constraints, this event is recommended to be held at a future date during the first half of 2019. The workshop aims to seek input about how to best implement the roadmap's findings and discuss the establishment of the Centre.

5.0 PROJECT OUTCOMES

The following report is the final stage of a three phase Intelligent Automation (IA) roadmap project commissioned by the Australian Meat Processor Corporation (AMPC). The project has been completed in three distinct phases as outlines below:

Phase 1: An extensive review for the current applications of IA technologies in meat processing and other industries worldwide.

Phase 2: An overview of current and emerging automation technologies used in the meat processing industry in Australia. Extensive research was performed in this stage and phone interviews were held with a number of selected processors.

Phase 3: Further expansion of the previous phases and the development of a meat processing industry IA technologies roadmap. The roadmap is intended to lay the grounds for the establishment of an IA Research Centre for the meat processing industry.

The meat processing industry ultimately needs to utilise the technological advancements in IA to remain competitive. Even though companies like Scott Automation have been at the forefront of digitising some parts of the supply chain, there are still significant untapped potential to ensure the sector is globally cost competitive whilst animal welfare standards are fully upheld.

6.0 DISCUSSION

Every effective project is as successful as its implementation. In order to take up the findings of the IA roadmap project and ensure the Australian meat processing industry utilises the latest smart technologies, a dedicated Research Centre is proposed. Such a facility will bring together the knowhow of the industry with academia and provide a pathway for digitising the sector. In addition, it will enable processors regardless of size and resources to access and benefit from Industry 4.0 technologies.

Amongst the existing options to structure the Centre, the Royal Melbourne Institute of Technology proposes the Government's Industrial Transformation Research Program (ITRP). This program encourages and supports the industry and researchers to collaborate to find solutions to a range of priority research areas that are updated regularly. In 2019, the 'advanced manufacturing' and 'food and agribusiness' groups are both considered priorities. In these two areas, robotics and Industry 4.0 are listed as the first sector-specific priorities – both directly relating to the IA roadmap project.

The ITRP offers funding through the Industrial Transformation Research Hubs (ITRH) scheme or the Industrial Transformation Training Centres (ITTC) scheme. These schemes foster opportunities for productivity and competitiveness enhancement for the industry. They bring together the best minds from the industry and academia together to solve problems and develop new products, processes and services that will transform the industry.

1. The ITRH scheme provides funding to engage in cutting-edge research on new technologies and economic, commercial and social transformation. Funding is provided from three to five years at an annual level of $500,000-$1,000,000.
2. The ITTC scheme fosters close partnerships between university-based researchers and other research end-users to provide innovative Higher Degree by Research and postdoctoral training vital to Australia's future. Funding is provided from four to five years at an annual level $650,000-$1,000,000.

In partnership with domestic and international companies and universities, the Centre would focus on new and emerging technologies to enable automation underpinned by the recent advances in robotics, artificial intelligence, 3D printing, blockchain and augmented reality. The intended outcome of the proposed Centre is to accelerate the transformation of Australia's red meat industry, which is faced with unprecedented challenges in terms of labour availability, electricity prices, processing costs and inefficiencies.

As a next step, it is recommended to hold an industry workshop using design thinking methodology to discuss the findings from the roadmap and seek consultation for the establishment of the Centre.

7.0 CONCLUSION/RECOMMENDATIONS

The first and second phases of the roadmap project have set the ground for a comprehensive IA roadmap for the Australian meat processing industry. Through identifying global trends and understanding the current use of such technologies in Australia, the industry can identify their position in the technology roadmap and develop pathways to transform their operations to benefit from modern technologies. However, as with every successful project, the findings must be turned into practice for the industry to make gainful advancements. Therefore, it was recommended that such a roadmap would be taken up by a dedicated Centre that connects the industry with researchers and leads to the development and implementation of IA technologies.

8.0 BIBLIOGRAPHY

For a full list of references, please refer to the reference list at the end of the report in the Appendix.

9.0 APPENDICES

The full publishable report containing all three phases is included in the Appendix.

INDUSTRY ROADMAP: INTELLIGENT AUTOMATION IN THE MEAT PROCESSING INDUSTRY

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1.0 EXECUTIVE SUMMARY

This report covers an overview of Intelligent Automation (IA) technologies used by meat processors and other industries worldwide. It also provides an overview of current and emerging automation and IA technologies used in the meat processing industry in Australia. The final part covers an industry roadmap for IA technologies. Through identifying the latest global IA trends and assessing the current industry state in Australia, the roadmap will provide the industry with a pathway to embark on IA technologies in their operations.

There is a history of successful projects to automate the meat processing industry in Australia and concrete progress has been made in using robots to reduce costs and drive efficiencies. However, the industrial world is now moving towards a new industrial revolution called Industry 4.0 (or specifically IA). IA is defined as automation with human intelligence and human touch. In Australia, this trend is estimated to add, directly and indirectly, between $140-$250 billion to the GDP by 2025. Therefore, this report describes IA and covers relevant case studies of how technologies such as virtual reality; predictive maintenance; collaborative robots; blockchain; sound and vision analysis; 3D printing; human and animal trackers; and collaborative robots could benefit the sector. By conducting an extensive review of academic publications, business sources, industry reports, industry news and completing phone interviews with a number of selected meat processors, a wide range of information and views were considered to provide a balanced and forward-looking perspective.

The meat processing sector in Australia is high cost and has yet to take full advantage of IA technologies. The report has assessed technologies within carcass processing and meat packaging aspects and covered technologies in areas such as carcass cutting & deboning; animal body composition detection; employee safety; and smart warehousing. After looking at the completed automation projects and current trials, it is evident that the industry is heading in the right direction. However, vast IA opportunities remained untapped that if realised could lead to increased efficiency and effectiveness in meat processing operations. By addressing and actively managing IA challenges including the human resource aspect and cybersecurity, the industry could gain tangible benefits. Improving animal welfare practices, higher yield and productivity, safer work environment, improved worker satisfaction, cost reduction and better product traceability are some of the benefits that could be achieved.

An IA roadmap for the meat processing industry is presented. The roadmap provides a guide for the likely technological direction until 2030. The roadmap will enable industry players to identify trends and develop pathways to utilise IA technologies in the future.

The establishment of a dedicated IA Research Centre for the meat processing industry has been recommended. The Centre will foster collaboration between the meat industry and academia towards the development and deployment of meat related IA technologies. It will benefit all meat processors regardless of size or resources and drive a highly advanced, smart and cost efficient sector in Australia.

2.0 INTRODUCTION

Automation, advances in technology and the deployment of robots in manufacturing are not new phenomena. In fact, during the third industrial revolution many manufacturing facilities have been automated with manual labour replaced by robotic systems. However, a new industrial revolution is on the horizon that connects the physical, digital and biological worlds (Marr 2016).

New technologies and ways of work are transforming the nature of industries and over time will change global economies (Blackburn et al. 2017). Smart factories are emerging in which machines are constantly communicating with each other and the web. Through machine learning, these machines can visualise the entire production and make decision independently (Berruti et al. 2017; Marr 2016). This new era originated in Germany in 2011 when the German Research Union for Economy and Science proposed to start a research program for computers in the industry. The initiative was funded by the government to cement the technological advancements of the German industrial sector (Roser 2015). It was named Industry 4.0 representing a combination of the Internet of Systems, the Internet of Things and cyber-physical systems. (Marr 2016).

The fourth industrial revolution provides many advantages through connecting billions of static systems, improving the efficiency of manufacturing and preserving resources through better asset utilisation and management (Marr 2016). In Australia, this trend is estimated to add, directly and indirectly, between A$140-A$250 billion to the GDP by 2025.

The red meat processing value chain is comprised of live transport, processors (abattoirs), cold transport, marketing/distribution, and distribution channels. There are approximately 135 processing plants (89 of which are AUS-MEAT certified) representing 97% of the total processing that contributed $18.8 billion to the Australian economy and $13.3 billion in exports in 2015-2016. The sector is the second largest manufacturing industry based on revenue and one of the largest employers. The industry operates at high cost due to energy costs, wages and a stringent regulatory compliance regime and runs on low to medium profit margins which is expected to further decline within the next five years (EY 2017).

Whilst knowledge intensive industries seem to be benefitting the most from advancements in technology followed by the service industries, asset intensive industries such as the meat processing industry are lagging behind and are yet to realise the full potential of the fourth industrial revolution (Balckburn et al. 2017; Mitchell 2016). Despite the automation potential and previous attempts, the inherent biological variation of meat and the commercial characteristics of its supply chain have limited the widespread use of Intelligent Automation technologies. Activities in the meat processing industry are labour intensive, repetitive, unpleasant, physically demanding and cause increased risk of worker injury. IA could act as a real solution to these challenges. Whilst there are advantages associated with these progressions, there are also new risks and challenges that need to be regulated and managed (Marr 2016).

Automation will result in lower operational costs and deliver concrete benefits. Operations costs are one of the biggest challenges facing the industry with e.g. boxed meat processing in Australia costing 1.5 times the cost of Brazil, NZ and the US. An industry-wide survey concluded that over 90% of respondents indicated that reduction in production and labour costs as either important or very important. In the same survey 'robotics' was cited as a potentially beneficial technology (Coleman 2013). The benefits of IA to the meat processing sector are multifold. There are direct efficiency gains through process automation that are easily identifiable. However, there are also additional benefits that results from IA. As an example, the vast amount of data captured using sensors can provide strategic value in decision making (Heath 2018).

This report was completed in three phases. The first phase looked at the latest IA technologies from around the world and multiple industries. In the second phase, an overview of the current state of automation and IA technologies in the Australian meat processing sector is provided. Finally, a roadmap is presented that provides guidance for the likely technology direction until 2030. It is recommended that a dedicated Research Centre be established to foster collaboration between the industry and academia to drive innovation and prepare the industry to fully utilise IA technologies.

3.0 INTELLIGENT AUTOMATION OVERVIEW

IA is automation with human intelligence and a human touch. As part of the fourth industrial revolution, it is fundamentally changing the way tasks are allocated and completed in industries. *Figure 1* illustrates the journey from when automation merely supported human actions in the 1990s to the future from 2020 onwards when robots will mimic and augment human intelligence (Sheth 2017).

With the pace of change towards IA accelerating, the question is no longer on the need to automation, but it relates to how to automate. The industry needs to integrate IA into its operations due to its tangible benefits. The use of robots that focused solely on isolated automation installations has evolved to comprehensive inter-connected automation solutions. Despite the current doubts and concerns around return on investment and security, companies must inevitably utilise and manage IA technologies to remain competitive (Sheth 2017).

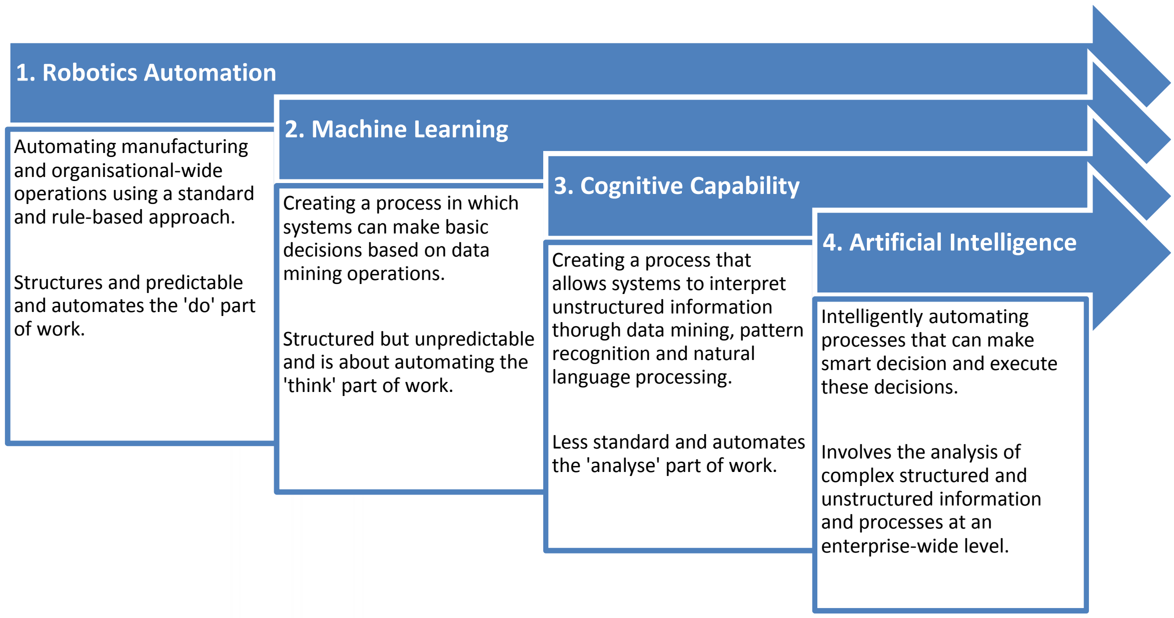

Figure 1: The Intelligent Automation Journey (Sheth 2017).

IA will require an enterprise-wide approach to automation, which will encompass not only manufacturing robots but will need integration with finance, HR, ERP, IT infrastructure, asset management, customer relations and many other functions. Systems will become smarter mimicking human behaviour by acquiring increasingly more intelligence from across the supply chain; enabling those to accomplish more complex tasks. The industry will continue to deploy a range of IA systems as they become more affordable and widely available (Geissbauer, Vedso and Schrauf 2016; Sheth 2017).

4.0 THE APPLICATION OF IA IN MEAT PROCESSING AND LEADING INDUSTRIES

Solid progress has been made in the meat processing sector in Australia to automate various tasks and there are examples of successfully implemented projects. However, the industry has been slower than other leading sectors such as the automotive sector to fully capture the benefits of IA. Whilst the inherent characteristics of meat and the supply chain make the shift towards IA technologies challenging, lessons could be learned from other industries that have successfully utilised IA. In this part, a wide range of such technologies from both meat processing and other leading sectors used in live animal handling, meat processing and meat packaging operations are outlined.

4.1 Applications of Intelligent Automation in Live Animal Handling

Abattoirs handle incoming animals and will hold them before processing. There are a number of IA technologies applicable in this part of the operations.

4.1.1 Animal Welfare & Behaviour

Monitoring animal well-being during off-loading and when housed in holding pens is an increasingly important area to cover due to continuous welfare concerns observed globally. Consumers are increasingly taking an active interest in how animals are treated both on-farm and off-farm before consumption. There is a common desire that animals kept for food production should be raised, treated and handled in a humane way. One of the potential solutions to overcome welfare concerns in abattoirs during the offloading and handling is through the continuous monitoring of individual animals (Van Hertem et al. 2016).

A new approach called Precision Livestock Farming (PLF) provides a real-time monitoring and management system that focuses on achieving animal welfare and health improvements (Berckmans 2014). Through the deployment and analysis of non-evasive technologies of vision, sound and other sensors, the natural response of every animals is assessed against the environment and operator behaviour. The system would detect the physical and mental state of animals and determine if freedom from hunger, discomfort, pain and fear exist and normal behaviour is expressed - all with minimal operator interference (Matthews et al. 2016).

Two promising technologies have been developed using cameras and microphones for animal welfare (Van Hertem et al. 2016). The eYeNamic system by the Dutch company Fancom can capture video feed in pig and poultry operations. Through analysing and translating the feed into an index for animal migration and activity (two important animal welfare indicators), animal behaviour is monitored and abnormal behaviour is signalled (Fancom n.d.). Vision technology can also be used to build a fully automated system e.g. capable of detecting lameness in individual cows (Berckmans 2014). Sound technology was developed by the start-up Soundtalks in Belgium to capture and analyse high quality audio sensor data. These sensors use sophisticated algorithms and by listening to animal sounds can detect issues. In an early application, the respiratory distress of pigs was analysed to detect health problems (Soundtalks n.d.).

In the US, the wellbeing of chicken is monitored in the housing environment using mobile robotics and sensing. Replacing managers who used to walk through holding areas, the new system would autonomously conduct the monitoring through small, low-cost unmanned aerial robots (GTRI n.d.b). Real-time scoring of animal behaviour is generally very challenging. However, sophisticated technology is increasingly becoming available making a fully automated animal behaviour monitoring system a reality (Nasirahmadi, Edwards and Sturm 2017).

4.1.2 Automated Cleaning

Automated cleaning of animals and the operating environment can maintain hygienic levels, keep the meat processing environment safe and prevent the spread of infections. The cleaning process is a difficult and costly part of operations when performed manually. Camera-equipped systems have the capability to identify contamination and selectively apply cleaning. Through IA solutions, systems can effectively clean animals and holding pens saving costs, reducing cleaning time and improving returns (DTI n.d.b). The Danish Technological Institute and the Royal Melbourne Institute of Technology (RMIT) have developed prototypes that could be commercialised and installed at abattoirs (DTI n.d.b; RMIT 2018).

The Danish Technological Institute developed quality control algorithms that use 2D and 3D imagery to detect dirt in animal pens and activate a robotic system that applies cleaning. Through the use of smart manipulators, indefinite cleaning is prevented and a reduction of up to 33% in water consumption is achieved (DTI n.d.b; DTI n.d.c). RMIT in a recent report published by AMPC highlighted a fully intelligent animal cleaning device intended to be installed in abattoirs to ensure automated cleaning of dirt from animal skin before slaughter. Through benchmarking various hardware and software technologies and conducting site visits, a prototype was successfully tested. By deploying optical cameras as illustrated in *Figure 2*, the system autonomously detects contamination and selectively applies water through nozzles to the impacted part of the cattle (RMIT 2018).

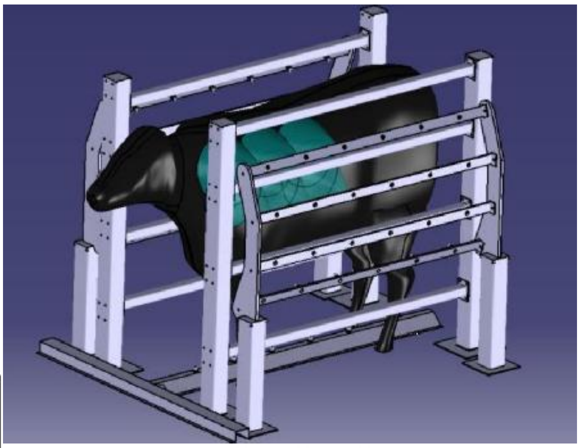

Figure 2: Intelligent Animal Cleaning Device – Final Design Concept (RMIT 2018)

4.2 Applications of Intelligent Automation in Meat Processing

Carcass processing is the most complex area in an abattoir. It covers tasks from stunning up until the packaging of meat products.

4.2.1 Carcass Cutting & Deboning

Automation in the cutting and deboning operations traditionally aimed to lower labour costs. However, the drivers are changing beyond cost to improving quality, shelf life, yield and worker satisfaction (DTI n.d.a). The Japanese developer, Mayekawa, produces robotic solutions called the TORIDAS deboner and YIELDAS-EYE chicken breast remover that through incorporated vision-systems can determine when and where to cut the meat to have perfectly-sized pieces (Mayekawa n.d.). Whilst the units carry a large price tag of over half a million US$, several hundreds were successfully implemented around the world in abattoirs resulting in yields increasing by ten-fold (RBR 2012).

One of the challenges in cutting meat has been around detecting and measuring bones hidden in carcasses and eliminating bone pieces left in cut meat (GTRI n.d.a; Paxton et al. n.d.). One solution to this challenge was developed by Scott Technologies. A fully-automated processing line was created in which whole carcasses of lamb can be processed. It uses x-rays and CT scans to create a 3D image and identify the various bones and accordingly cut the carcass in a very accurate and consistent way (Garfield 2016; Mitchell 2016).

BANSS in Germany have developed an end to end smart meat processing line for pigs with carcasses between 60-140 Kg that use six-axis robots, vision and analytics software (BANSS n.d.). Whilst most industry players use a pre-programmed carcass outlay to make the cuts, these machines use data and through artificial intelligence, amend the cut based on the individual carcass. Through the use of algorithm and machine learning, the robots continue learning and progressively delivering more accurate cuts. The machines deployed by BANSS for lamb processing have increased yield, plant safety, shelf-life and reduced injury. The company is currently working on deploying the technology on more complex carcasses for future commercialisation (Garfield 2016).

Advanced technology is also being developed to take over manual processes in the meat industry. However, due to the distinct biological nature of meat products, there will be tasks remaining that need to be completed by humans (GTRI 2014). Collaborative robots that can co-work and interact with human workers are one of the defining trends that set IA apart (Schatsky and Mahidhar 2014). There are currently only few instances in the industry where robots work close to humans due to safety concerns. As man and machine react to each other and because of the variability in human muscle stiffness, the machine is often unable to apply the right move (Kahl 2018). Georgia Tech in the US have been at the forefront of solving this challenge. Through developing a system that can detect and analyse human muscles, intelligent machines were developed that would predict human behaviour and accordingly correct the robot’s movement. Sensors worn on the human worker detect muscle movement and transmit the information to identify the amount of contraction. The robot then adjusts its interaction to create a safe collaborative working environment that increase efficiency and saves time (GTRI 2014).

4.2.2 Animal Body Composition Detection

Accurate identification of animal body composition enables more accurate processing. Whilst traditionally carcasses have only been processed according to batches, the DEXA (Dual Energy X-Ray Absorptiometry) technology developed by Scott Automation provides a way to measure and grade body composition and accordingly modify cuts (Scott n.d.a). By benefitting from bone density and body fat composition technologies used in the medical industry, animal fat and bone ratios are identified. This technology enables the sharing of body composition and other animal data with beef farmers in the supply chain to customise beef breeding (Scott n.d.b). In a similar example, Uniporc Ouest in France used vision technology from the company CSB-System to grade 20 million pigs directly at the slaughter line in a fully automated way (CSB n.d.).

Despite the benefits of the DEXA technology in yield assessment, it is a 2D tool and other competing technologies have also been developed to achieve similar outcomes (Farquhar 2018). The cost of installing DEXA in a meat processing plant may be as high as $3 million potentially resulting in a barrier for wide-range adoption. These costs are attributed to major changes required for the implementation of the DEXA system including setting up of barriers to protect staff from X-Ray radiation exposure (Condon 2017).

An alternative technology was developed by the German company E&V Technology that utilises vision-based cameras to analyse carcass composition in an easier and more cost effective way. The technology is being assessed by some processors. However, the E&V system is incompatible with robotics, cannot deliver precise cutting lines for robots used for rib scoring and is less accurate than DEXA. It might benefit those processors that are looking for a simpler solution to predict yield using an augmentation tool for manual grading (Condon 2017).

The University of Technology Sydney is working on technology that uses artificial intelligence to identify individual animal fat content which has been difficult to estimate with human eyes. Using off-the-shelve cameras that analyse cattle as they move through a crush, each animal is allocated a condition score based on fat and muscle depth and size. Providing computers with the ability to think and reason when observing animals will increase yield prediction accuracy to 80-90%. Processors will have the ability to use the real-time data to support individualised decision making resulting in higher yield (RIRDC 2016).

4.2.3 Manual Meat Grading and Trimming

IA technologies can assist with the manual grading and trimming of meat products when automation is not feasible. A study from the US has shown that half of all meat samples are graded incorrectly. Grading is a difficult task, involves many different parameters and requires ongoing judgement that can be subjective. It is reported that processors are concerned about the accuracy of meat grading and its impact on their reputation. In a recent project, Meat and Livestock Australia (MLA) have partnered with Wiley & Co. to explore using Augmented Reality (AR) to provide decision assistance for staff. A dedicated platform was developed, called the Augmented Reality Grading App (ARGA), by utilising vision technology to improve meat grading. The project aimed at making grading faster, more consistent and more accurate (Wiley 2018).

In another case, attempts were made in Danish abattoirs to use AR for supporting pork cutting and trimming operations. An overlay was shown for the operator to assist with cutting and trimming of meat. The application of AR has ensured pork pieces are cut in a consistent way increasing yield and also ensuring a happier workforce. Nevertheless, staff have to be trained in the correct way for using AR (Christensen and Engell-Norregard 2016).

4.2.4 Employee Safety

There are various tasks that intelligent robots will perform in a more efficient way. However, there will also be tasks that humans will continue performing in meat processing. Although humans will be increasingly involved in more sophisticated tasks, their safety and well-being must be guaranteed. Therefore, researchers are developing a Machine Motion Capture (MiMiC) system that uses smart motion sensors and smartphones to monitor ergonomics data in the processing plants. By capturing and analysing human motions, better and safer working environments would be created. Once fully developed, the system will help preventing slips, reduce stress on the body during lifting objects and deboning, and help with optimising training to improve productivity (GTRI n.d.e).

In order to improve performance and safety in manual parts of the operations, Georgia Tech researchers have developed technology that focuses on monitoring human behaviour during manual meat processing to encode actions and behaviours. Through deploying a motion sensing gaming device and a wireless sensing platform, the system measures and assesses hand movements and determines the efficiency in which the task was completed and the proficiency of the worker. The system has been trialled for bird deboning which still required delicate human effort (GTRI n.d.c; GTRI n.d.d).

4.2.5 Robot & Machine Maintenance

Ongoing data collection from processing machinery, sharing it with the Original Equipment Manufacturers (OEM) and the analysis of such information can help plant operators identify maintenance requirements before problems arise (Rockwell Automation 2018). Machine failure and downtime impacts the continuity of operations and results in financial losses (Higgins 2017). Up until now, these events were random occurrences with predictive maintenance remaining a desired goal. Whilst time-based maintenance routines have provided some remedy, these are not smart or efficient. The Shift towards predictive maintenance has been primarily inhibited by the high cost of sensors and measuring devices such as infrared thermometers, ultrasonic probes and vibration monitors. However, these prices have continued to fall putting predictive maintenance in closer reach (Higgins 2017; Rockwell Automation 2018; Sperber 2008).

In an example, West Liberty Foods as a private meat processor in the US has embarked on a two year data collection journey as part of a new maintenance management system. After collecting information from 50 slicing machines including the fault signals and repair data and turning it over to the OEM, the company identified maintenance requirements and addressed downtimes (Higgin 2017). Tetra Pak is also taking connected enterprise and predictive maintenance to another level with a remote monitoring service of 5,000 machines installed globally. Data from hundreds of sensors are uploaded to the cloud and analysed remotely in a central facility. As soon as abnormalities are detected, the plant operator is alerted to take action before a failure occurs. During a trial run, the system was able to prevent a 48 hour downtime in an American plant (Higgin 2017).

4.2.6 Spare Parts Generation

Spare parts supply is often a challenging part of the operations as most spare-parts requests are one-time orders that are impossible to predict. 3D printers can create manufacturing spare parts as needed. By using 3D printers and assessing the specifications of the parts, software and the materials needed for printing, new objects can be created. Old parts can be 3D laser scanned and automatically turned into a code readable by the printer for re-production (Schrauf and Berttram 2016). The German robot maker Kuka has been one of the leaders of deploying 3D printers to make automation smarter. The company is prototyping a robotic arm that works with a 3D printer to print, retrieve and install parts to manufacture similar robotic arms. Such technology will enable robots to print and replace their own parts to operate continuously and avoid long break-downs. Whilst still in the development phase, 3D printers will enable fully autonomous intelligent robots to operate independently (Kline 2018).

4.3 Applications of Intelligent Automation in Meat Packaging

Once carcasses are processed and meat pieces are cut, products enter the packaging and warehousing operations, which form an important part of the supply chain.

4.3.1 Inter-Connected Supply Chain

Blockchain is emerging as a tool to inter-connect the entire supply chain to drive value through traceability and improved visibility. The same technology underpinning bitcoins has the power to add value to the meat processing industry. The meat supply chain is well-placed to take advantage of this new technology as it consists of a series of transactions similar to cryptocurrencies (Shaffer 2018). Blockchain is a new way of storing and sharing data across an open virtual structure. Because the information is stored across the network, it becomes almost hack proof (Charlebois 2017). Trust in blockchain is established based on the fact that each transaction will have its own unique digital signature that is cryptographically sealed (Shaffer 2018). Blockchain users across the entire supply chain have the ability to view all transactions simultaneously and in real-time resulting in full traceability (Charlebois 2017). They could find out where the animal was raised and processed; its age; and relevant health information which are the type of data that increasingly international consumers demand (Huang 2017). The technology will prevent food fraud and false claims such as 'organic' (Shaffer 2018).

Retailers have already started setting up and using their own blockchain platforms. As example, Wal-Mart has been tracking pork across China and packaged meat products in the US since 2016 (Inside FMCG 2016). In two other examples, the Ali Baba Group is piloting blockchain to improve the transparency of Australian and New Zealand products across the supply chain to China and another Chinese E-Commerce giant, JD.com will track meat from Australian farms through to consumers in China in the future (Huang 2018; McIlvaine 2018).

4.3.2 Smart Warehousing

Warehouses are important parts of the meat processing supply chains and will be transformed as part of the fourth industrial revolution. By automating every element within the warehousing operation, efficiency and safety will be drastically improved. It all starts from when in-bound trucks communicate and let the central system know when they expect to arrive. The intelligent warehouse management system will reserve a loading dock and optimise just-in-time and just-in-sequence delivery. Once the supplies are offloaded autonomously, sensors will send relevant information to the system. Storage space will be allocated and robots will move the parts. The central management system will have real-time inventory information and update it as soon as changes occur (Schrauf and Berttram 2016).

In the smart warehouse of the future, temperature, humidity and light – important characteristics due to the perishable nature of meat products – are optimised. Moreover, energy savings could be achieved by turning lights off in areas when only robots operate (Schrauf and Berttram 2016). The food service supplier Golden State Foods in California is managing its warehouse using IA. Through deploying various sensors and robots, routines are improved, food quality monitored and warehouse assets optimised by dynamically scheduling vehicles (Javaheri 2017).

5.0 CURRENT APPLICATIONS OF AUTOMATION AND IA TECHNOLOGIES IN MEAT PROCESSING IN AUSTRALIA

The following sections look at the current use of automation and in particular, intelligent automation technologies in the meat processing sector in Australia. These technologies are split into their applications in meat processing and meat packaging operations in abattoirs.

5.1 Current Applications of Intelligent Automation in Meat Processing

Carcass processing covers activities ranging from stunning up until the packaging of meat products.

5.1.1 Carcass Cutting & Deboning

Automated meat cutting technology results in higher safety, more precise cuts and lower costs (MLA 2016). The X-Ray Primal System developed by SCOTT Automation delivers precise lamb primal cuts through adjusting the angle and height of every cut to a precise location. The Middle System automates the bone-in processing of lamb middles for optimised product output and higher yield. The system was successfully installed at JBS Bordertown (MLA 2017).

After automating lamb processing, similar technology has been applied to beef processing. To ensure the safety of workers and drive down processing costs, an automated beef cutting system was deployed using DEXA, colour cameras and 3D cameras to apply consistent cuts. The cutting system reads the RFID of every carcases previously graded using the sensors and determines the precise cuts it needs to apply. This technology operates at the JBS Dinmore plant and has replaced manual cutting operations of large and complex beef carcass structures (MLA 2016).

Another promising technology is the Robotic Bandsaw Operation prototyped to focus on improving existing manual meat sawing by integrating a robotic arm (AMPC 2017a). It was highlighted in the AMPC 2016/2017 Annual Report as a key research outcome in the Processing Technologies program. It solves partial automation through a hybrid approach incorporating 3D vision sensors, algorithmic cut path generation and computer visualisation to increase safety, productivity and reduce processing waste (AMPC 2017b). The trialled system leverages automation techniques to increase safety and speed of manual sawing operations and through the display of augmented interfaces, informs human operators of errors in manual or automated operations (AMPC 2017a). The research sought to improve existing processes by proposing hybrid solutions which leverage automation techniques to improve the speed and safety of manual processing. Intuitive interface design was used to allow operators to quickly diagnose and correct errors in partially or fully automated robotic systems.

5.1.2 Body Composition

Effective carcase measurement and analysis will lead to greater efficiency in the meat processing industry (Himmelreich 2017). Meat & Livestock Australia (MLA) has been developing leading technologies for Objective Carcass Measurement (OCM) that uses DEXA. Such technology will increase accuracy and transparency of value assessment (Parliament of Australia 2017). A co-funding model has been established that contributes up to $10M towards the installation of DEXA OCM in Australian abattoirs (Wiley 2017).

This technology will enable processors to adjust their operations to maximise yield and better meet customer requirements. An independent report has found that the benefits could be as high as $420M a year to the sector if fully adopted (Himmelreich 2017). In addition, the system will collect and store data from across the supply chain and share it in an open innovation system with stakeholders to drive collaboration amongst processors, universities and businesses. It will drive future research and development in processing automation, productivity improvement areas, animal health and genetics (Wiley 2017).

The first DEXA system for beef has been launched at the Teys abattoir in Rockhampton in May 2018. The OCM will measure lean meat yield, bone and fat content and accordingly provide feedback to producers regarding the carcass. Such feedback will result in a value-based payment scheme in the future and ensure cattle producers make better genetic decisions (The Weekly Times 2018).

5.1.3 Employee Safety & Satisfaction

The use of modern technologies can prevent injuries and reduce safety concerns in critical processes such as the cutting of meat by band saws. Abattoirs might process thousands of carcasses per day and the use of band saws to cut meat pieces to the desired sizes have led to an increased risk of severe cuts and injuries (SCOTT 2017a). BladeStop developed by Scott Automation uses vision/camera sensors and body sensing technology that detect when a body part comes in contact with the blades resulting in the immediate shut down within 9 milliseconds to minimise injuries.

Diamond Valley Pork has used this technology and successfully prevented injuries that would have otherwise resulted in serious consequences (SCOTT 2017b). In another example, Meat Co processes around 125,000 cuts every day across 10 BladeStop band saws proving invaluable in operator safety (SCOTT 2017c). 26 BladeStop band saws were installed in Australia by late 2017 benefiting the sector through reduced production time loss, workers' compensation costs, insurance premiums, staff turnover and product wastage whilst improving morale, company reputation and plant safety (SCOTT 2017a; SCOTT 2017c).

5.2 Current Applications of Intelligent Automation in Meat Packaging

Once carcasses are processed and meat pieces are cut, products enter the packaging and warehousing operations.

5.2.1 Supply Chain Traceability

Traceability of meat products across the supply chain is increasingly demanded by consumers in Australia and in export markets. Traceability will ensure higher safety, assurance about provenance and increase trust. Australia has built a robust system to ensure the consistent traceability of meat products to comply with Federal and State legislations (MLA 2014). The National Livestock Identification System (NLIS) is the national system for traceability of cattle. Since its introduction around 20 years ago, it has tracked cattle, sheep and goats for the purpose of enhancing the ability to define the location of animals during incidents and diseases. The system is supported by a framework underpinned by local and federal legislation. NLIS uses an animal tracker, identifies animal location using a Property Identification Code (PIC) and stores all the information in an online database. Whilst the system tracks animals across the supply chain as they are moved or sold, it will require the input of people with access to the NLIS database to record any movement or change (NLIS n.d.).

The pork industry has developed a robust traceability system called the Physi-Trace® that can provide provenance information about the country, state and farm to provide assurance that products were made from Australian pork (Australian Pork 2017b). The system extends its tracking to unpacked products without a label affixed through identifying and analysing trace elements, chemicals and organic markers of samples against a database of known references. The overall success rate of tracing a meat sample to its origin has been greater than 90%. However, more work has been deemed necessary to improve success rates through further validating the algorithms and extending the analysis to other meat varieties (Australian Pork 2017a).

5.2.2 Automated Warehousing

Automated Guided Vehicles (AGV) provide an innovative and effective solution to material handling in meat processing facilities. AGVs work in a similar way to self-driving vehicles and can transport pallets, cartons and products throughout a warehouse in a cost effective and safe way. The system has the ability to run continuously with only having to return to a charging station when out of battery. These can be installed without modification into existing facilities replacing forklifts. A fleet of 12 AGVs are in use at

Kilcoy Pastoral in Queensland that collect pallets from the palletising machines, shrink wrap the load, control barcodes, attach documents and transport to loading docks (Condon 2017).

6.0 CURRENT AUTOMATION AND IA TRIALS IN AUSTRALIA

The following table lists a number of selected automation projects currently or recently trialled by AMPC, MLA or its partners.

	Project Name	Project Application	Project Description	Source
1	**A Boning Line Modular Processing Unit**	Evaluating the potential concept of a Modular Processing Unit (MPU) and its application at workstations in abattoirs.	MPU provides compelling advantages in the manufacturing sector. This project looked at whether such technology can be used in the abattoir environment. It was aimed at boning like activities to break-down its entire suite of operations into elemental functions to increase efficiency.	(AMPC 2018)
2	**Australian livestock spatial innovation program**	Creating a national program to deliver spatial innovations through the red meat value chains.	The project will deliver benefits through increased value, reduce costs and increase production volumes in the supply chain. It focuses on spatial technologies such as gps, satellite imaging, robotic vehicles, unmanned aerial vehicles and aims to accelerate innovation through establishing a technology launch-pad. The resulting innovations will complement sensor data and improve decision-making.	(CRCSI 2017)
3	**Automated Beef Ribset Deboning**	Exploring automating manual beef ribset deboning to increase yield and reduce labour injuries.	This initiative explored the use of a single-side prototype machine to debone the beef ribset and assessed its impact on the quality of meat products and reducing the rate of worker injuries.	(AMPC 2018)
4	**Applications of Deep Learning for the Red Meat Processing Industry**	Developing a roadmap for integrating recent machine learning techniques into image and data processing.	The project conducted a literature review, looked at case studies of training with sample datasets and developed a roadmap of possible applications of deep learning.	(AMPC 2018)
5	**Automated container loading**	Automated loading of packaged meat into refrigerated containers.	The project intended to develop, install and test an automated container loading system pilot for the packing of meat cartons into containers to address OH&S and product loss challenges.	(AMPC 2017f)
6	**Automated forequarter deboning system**	Developing concepts for automated de-boning of lamb forequarters.	The project reviewed existing methods of manually de-boning lamb forequarters to use the results to develop an automated processing solution.	(MLA 2018d)

7	**Automated lamb frenching**	Automated solution to french lamb racks.	The project automated the manual frenching of lamb racks that would otherwise require skilled knife-work and consume considerable resources.	(AMPC 2017g)
8	**Automation of Primal Cut Bagging**	Examining the most effective way of bagging and labelling naked primal cuts.	The project intends to develop an automated naked primal cuts packing system to reduce manual labour operations in the boning room.	(AMPC 2018)
9	**Blockchain for the Meat Industry: Where and How?**	Exploring the use of blockchain technology for the red meat industry.	The project focuses on mapping the current red meat supply chain and understand the physical products, information and finance exchanged across the chain. It then looks at the feasibility of using blockchain technology to streamline operations and reduce redundancies across the supply chain.	(AMPC 2018)
10	**Desk top review into collaborative robot applications in the red meat industry**	A review of the current collaborative robot applications in the red meat processing industry and other industries.	The project assessed the implications for applying collaborative robots in the red meat processing sector in terms of product consistency, nature of sensing, control systems, safety and hygiene.	(AMPC 2017o)
11	**Development of primal cut recognition and localisation software for use in robotic pick and pack systems**	Automated solution capable of packing vacuum sealed primal cuts into cartons.	The project involved the design, development and implementation of an intelligent vision system and analysis software for the identification, geometric profiling and localisation of sealed primal cuts.	(AMPC 2017m)
12	**Feasibility of shoulder de-boning**	De-boning lamb shoulder primal pieces.	The project conducted a feasibility of de-boning lamb shoulder pieces. In particular, the separation of the rib cage was evaluated and a prototype designed. In the second phase, an automated deboning system was developed.	(AMPC 2017l; AMPC 2018)
13	**Feasibility study into a high volume cellular processing plant**	Considering the possibility of transitioning an existing abattoir into a cellular format.	The project looked at the feasibility of a high volume cellular plant utilising robots, collaborative robots, special purpose machines and human operators.	(AMPC 2017k)
14	**Integrated robotic picking and packing of primal cuts**	Development and testing of an integrated vision and robotic pick and pack system.	The project focused on selecting a suitable robotic gripper, the hardware componentry for complete integration between robotic, transportation, and vision systems, and the creation of algorithms.	(AMPC 2017i)
15	**Internet of Things (IoT) solution for real-time computation and delivery of plant Key Performance Indicators (KPI)**	Introducing IoT solutions aiming to improve plant productivity.	The project developed an IoT solution for real-time computing of knife sharpness and plant yield KPIs.	(AMPC 2017c)
16	**Investigate Augmented Vision Technologies to**	Developing a proof of concept to use	The project used an augmented reality head mounted display to reduce the subjectivity in	(MLA 2018b)

	improve subjective carcase assessment	augmented reality to improve MSA grading.	meat grading in a processing environment. The aim was to increase the precision of grading and increase trust.	
17	**Livestock Data Link (LDL) trials & implementation**	Developing a web application to enhance the exchange and utilisation of information by meat processors.	The project aimed at developing a national standardised carcass feedback system. It linked slaughter data from NLIS, Meat Standards Australia and Central Animal Health databases with analytical tools, benchmarking reports and solutions to feedback.	(MLA 2018f)
18	**Miniaturised snake robotics for spinal cord removal prior to splitting beef carcasses**	Automating the spinal cord removal prior to splitting in carcasses by a robotic arm.	The project aimed to develop an experimental miniaturised snake arm capable of entering the spinal cavity from the neck and removing the spinal cord.	(AMPC 2017j)
19	**Naked Primal Cut Recognition Vision System trial in plant**	Developing of Naked Primal Cut Recognition Software in a meat processing plant.	The project developed a system capable of rapidly identifying a range of pre-packaged red meat primal cuts from a predefined database by using advanced software and algorithms. Through analysing 3D images and measuring meat weight, information such as primal cut type, dimensions, orientation and mass were produced in real time.	(AMPC 2018)
20	**Objective Primal Measurement OPM - pack-off primal pick and pack fundamental vision and sensing evaluation**	Investigating the suitability of different sensing technologies to enable pick and pack automation.	The project assessed the use of hyperspectral imaging, DEXA, colour/3D camera and MRI to determine the usefulness of these technologies to enable pick and pack automation.	(MLA 2018a)
21	**Prime X Connect – automated boxed beef market place**	Developing an online marketplace to streamline the sale of beef	The project conduced a PoC and trial to set up an online platform for the sale of Australian beef. Benefits of the platform include streamlining sales processes, improving the ease of conducting business across the world and providing feedback about consumer preferences.	(MLA 2018e)
22	**Technology evaluation of fat removal for beef striploins**	Technology evaluation of fat removal for beef striploins leaving a uniform thickness behind.	Researched the process of fat trimming to determine the feasibility of automating trimming to leave a uniform layer of fat on beef striploin primal pieces.	(AMPC 2017e)
23	**Wearable technology for the red meat processing industry**	Investigation to determine the application of wearable technology in meat processing.	The projects looked at the benefits of wearable technology to exploit worker proximity, location and/or perspective in order to acquire new information about the worker, the product and processes in real time.	(AMPC 2017n)
24	**3D Dynamic skeletal modelling**	Extending the usefulness of X-ray scanning to down-stream carcass break-up operations.	The project explored the feasibility of X-ray scanners installed at the start of the boning line to share data with other automation stations through the use of a 3D Dynamic Re-Pose-able Skeletal model.	(AMPC 2017d)

7.0 INTELLIGENT AUTOMATION (IA) ADOPTION CHALLENGES

IA results in numerous benefits for the meat processing sector such as improved animal welfare, increased speed of production, cost reduction, improved worker safety, cut accuracy, higher visibility of operations and product traceability. However, it also creates new challenges that need to be managed and mitigated (Sheth 2017).

The adoption of Automation and IA technologies has proven to be challenging, difficult and time consuming (Sun, Hyland and Bosch 2015). Previous industry research into the meat processing sector indicates that there are two types of barriers to the adoption of new technologies. One are mentally-related and might include resistance to change, uncertainty, tendency to avoid risk of being an early adopter and a focus on resolving day to day challenges. The second are objective and include cost/benefit doubts (the highest barrier), compliance with regulatory requirements, market challenges and the effectiveness of new technologies. Results from an earlier survey looking at 63 processors indicated that the industry decision makers and the meat processing industry have a broad reluctance to adopt new technologies (Coleman 2013).

5.1 Jobs versus Robots

There are also valid concerns around the immediate impact of robots taking over manual processes leading to worker reductions. However, history suggests that there is no reason for automation to result in broad and long-lasting job losses. There has been a long-standing debate around the impact of automation on employment in the meat processing sector and agriculture more broadly. Previous cycles of major technological change suggest that despite being a difficult process for the impacted workers in the short-term, ultimately such change will lead to increased employment and productivity. The example of substantial technological change in the US agricultural industry during the 1950s and 1960s proved that whilst machines started to replace unskilled workers, the overall unemployment rate was not negatively impacted (Alphabeta 2017). Australia meat processing industry, on the other hand, appears to have difficulty in sourcing and maintain required manual labour.

An intelligently automated industry will be more competitive and create new jobs and up-skill existing ones. As technological advances lead to greater competition between humans and machines, meat processors might face a range of new human resource challenges as more tasks start to become automated (Pawar, Law and Maple 2016). Worker support is essential to the success of IA adoption as they need to be prepared for such change. Tangible benefits of such a transformation journey must be well articulated to prepare workers for the transition to a new range of job requirements (Sheth 2017). Whilst some roles will inevitably become redundant, a new set of skills will be required to manage the robotic workplace and operating systems (Pawar, Law and Maple 2016).

5.1.1 Safety Improvement

As more robots are deployed that automate physical tasks in meat processing plants, workplaces become safer environments (Alphabeta 2017). According to the Bureau of Labor Statistics in the United States, workers in the animal slaughtering and processing industry have a higher likelihood of injury or illness that the overall average for private industry workers (Smith 2017). Workplace injuries are predicted to decline by 11% in Australia as dangerous activities will be carried out by robots (Alphabeta 2017; Australian Centre for Robotic Vision 2018). Intelligent robots have the potential to improve safety and reduce injuries and absenteeism. By taking over dangerous tasks with high injury risk such as heavy lifting and bandsaw operations, a safer working environment can be created.

5.1.2 Productivity and Satisfaction

IA technologies can help maintaining the current standard of living in local communities. In fact, to continue benefitting from the current quality of life, productivity needs to be increased by 2.5% every year. Only IA can boost productivity as labour productivity has already peaked. IA will create new jobs that are safer and more engaging. In fact, the transition of existing jobs to higher skilled ones as a result of robotics-driven productivity gains overall is expected to boost the national income by $1,200 billion by 2030.

Through requiring workers to perform less repetitive tasks, time could be allocated to more meaningful activities. Jobs will become more valuable as IA technologies will take over the least productive tasks. Through a shift from repetitive tasks to more advanced tasks requiring creativity and interpersonal skills there is the potential to increase job satisfaction for every worker. This improvement will be strongest for low-skilled workers who perform automatable activities leading to 62% of these workers in Australia becoming happier in their roles by 2030. If low-skilled workers would be trained to perform unique tasks that are not automatable, real wages could increase by 10% in the same period (Alphabeta 2017).

5.1.3 Workforce Skills

How should the future workforce be prepared for industry 4.0? This is a real question facing governments and the industry around the world and it touches the entire educational system from primary schools to vocational institutions and universities.

IA technologies will result in the up-skilling of existing workers across Australia. As the cost of automation continues to decline, it is expected that the rate of adoption increases leading to potential employee reductions. However, through embracing IA related change, and developing strategies for retaining and supporting the development of staff, employees impacted by disruption can be re-skilled and engaged in new ways. The education system plays an important part to develop the next generation of talent and up-skill existing workers. IA has the potential to make the Australian economy more competitive and create a wide range of new jobs (Australian Centre for Robotic Vision 2018). In this context, the proposed research and training centre will be a significant step in solving this problem.

5.2 Cybersecurity

Advances in IA and the wide-spread deployment of thousands of sensors and data capturing devices will require a robust risk management regime. As more data are collected from across the meat processing operations and stored in cloud-based repositories, the need to effectively manage data security, privacy and prevent cyber-attack becomes a crucial part of reducing risks (Schatsky and Mahidhar 2014). The inter-connected nature of supply chains operations, customers, factories makes businesses potentially far more vulnerable to cyberattacks and their impacts will be far more serious. Implications of such attacks could reach far beyond downtime and can lead to plant damage, monetary losses, fines, litigation and brand damage. Therefore, relevant cybersecurity strategies should become part of the company-wide business strategy to ensure secure systems are designed with vigilant data protection measures that are resilient against cyberattacks (Waslo et al. 2017).

8.0 CASE STUDIES

The following four case studies have been completed using dedicated interview sessions with three meat processing Managers and one publicly available interview with a meat processing plant Director.

8.1 Case Study 1

Small-Medium Lamb Processor

Technology Adoption: an early adopter of robotics in the past five years on the slaughter floor. Engages in R&D and trials with new automation technologies. Has three robots on the slaughter floor. The first two conduct a carcass sanitation process called Sani-Vac and the third completes brisket cuts which was deemed as a high risk process previously done by operators.

Aims of Technology Adoption: When considering automation, has a particular focus on looking at critical safety points and where an operator impacts the quality of the meat products. The main objectives of automation are to enhance product safety, increase shelf life and reduce costs of production.

Automation Challenges: Automation and robotics will increasingly require more advanced technical skills for maintenance of equipment such as electrical controls and programming. There is an opportunity for new skills in this area.

Automation Opportunities: There will be new career opportunities for staff skilled in continuous improvement practices such as reducing waste and increase process efficiencies.

8.2 Case Study 2

Small-Medium Beef Processor

Technology Adoption: processes are mainly done manually in the abattoir. Operators work with band saws for meat cutting. Has Scott BladeStops in place to reduce band saw operators' injuries.

Aims of Technology Adoption: major aims of technology adoption would be to address staff availability and safety. In addition, technology would enable the automated tracking of animals using electronic tags. Automation can also help with reducing energy and resources required for meat processing.

Automation Challenges: The cost of automation provides a major challenge for its adoption. New technologies need to be evaluated based on the return on investment they provide.

Automation Opportunities: Has ongoing discussions with major automation technology providers about upcoming technologies. The ability to use vision cameras and analytics software to automatically identify and count animals would be beneficial. In addition, the scanning of meat to determine product quality is useful.

Automation Planning: has a master plan in place that includes a technology roadmap based on risk and return assessment.

8.3 Case Study 3

Small-Medium Lamb Processor

Technology Adoption: plans in place to implement DEXA scanning technology in the near future. Trials with ear-tag technology to collect info around carcasses and yield reports. The packaging operations and vacuum packaging are already automated.

Aims of Technology Adoption: Automation technologies would make the working environment safer and address labour availability. Another major aim is to use technology to reduce energy costs.

Automation Challenges: robots will make meat processing more efficient but will require a new set of skills. Additionally, the cost of automation technologies are generally expensive and this places a major barrier for adoption. The current high prices of livestock has placed a burden to the sector to manage its revenues and costs.

Automation Opportunities: Would support efforts to make the industry more automated. However, believes that a one-size-fits-all approach might not be suitable due to the varying requirements of retailers in terms of the product.

Automation Planning: has a 3-5 year automation technology roadmap in place.

8.4 Case Study 4

Medium Beef and Pork Processor

Technology Adoption: trials with carcass processing and vision-based automation systems. Uses DEXA technology for animal grading. Conducted a major upgrade in the cold store operations area. Also uses the Scott BladeStop technology to reduce worker injuries.

Aims of Technology Adoption: major objectives of adopting automation technologies include reducing energy costs; improving access to overseas export markets through simplifying regulatory framework; product tracking along the supply chain; staff tracking to reduce fatigue and increase safety; and improving animal welfare practices and the social license of the sector.

Automation Challenges: attracting and retaining highly skilled staff to maintain automation equipment.

Automation Opportunities: There are a number of areas of interest including the automated cleaning of animals, marble score and meat colour identification. All aspects of the operations need to communicate and align to prevent bottle necks. Moreover, would benefit from a smart predictive maintenance solution.

Automation Planning: has a high level five year plan in place.

9.0 ROADMAP

The field of robotics and IA is rapidly evolving and cementing its place in meat processing and other agricultural sectors. Due to the pace of change and the underlying uncertainties, it is easier to assess current technological gaps rather than future requirements (Australian Centre for Robotic Vision 2018). Therefore, this roadmap is a living guide to the future possibilities of intelligent automation technologies in the meat processing industry in Australia. The roadmap provides guidance rather than instruct a defined path. The current state along with an outlook of the next 12 years with possible future developments along the journey have been provided. Individual decisions regarding the uptake of technologies need to be made based on economic and business factors at each processing plant.

The Red Meat Processing Industry - Intelligent Automation Roadmap

Area	0-2 Years	2-6 Years	6-12 Years
General	Limited use of Industry 4.0 technologies	Some use of individual Industry 4.0 technologies. Some inter-connection between solutions. Stakeholders increasing their readiness for transition.	Sophisticated use of Industry 4.0 technologies. Beyond 2030, transition to true Industry 4.0 will start to be more comprehensive when hardware, software and employees are Industry 4.0 ready.
	Automation technologies developed in isolation as stand-alone solutions	IA Research Centre established to accelerate the development of IA technologies	IA technologies fully interoperable to create flexible systems
	No industry-wide standards for the development and deployment of IA technologies	Industry standards and requirements are documented and defined	
	No database of approved vendors and IA technologies	IA Research Centre to create a pool of approved technology providers helping the industry make better investment decisions	
	Robots have very limited perception capability performing limited tasks in structured environments	Robots to receive information from many sensors with higher perception capability	Robots to operate effectively in unstructured environments and have dynamic adaption capabilities
	Limited integration of robot perception with action	Improved integration of robot perception with action and cognition. Limited machine learning	Fully autonomous and learning robots with decision making capability. Deep learning fully utilised.
	Robots are separated from humans due to safety concerns and operational issues	Some interaction between robots and humans in defined environments	Ability of smart robots to operate in fully collaborative environments with humans
	Limited communication between robots and other systems	Some level of interaction amongst robots for better coordination and higher efficiency	Heterogeneous multi-robot systems seamlessly interfacing between manual systems and different robots from multiple manufacturers
	Processes within abattoirs are done in a batch-oriented setting. Ongoing management and control is required.		Moving to a flow-oriented setting and continuous processing. Enabling the 24/7 operation of an automated smart meat plant and remote management

	IA technologies developed by individual equipment vendors and system integrators	Some adaptability between robots from different vendors and internal business systems	Robots compatible and be collectively configurable based on the required tasks with the ability for reconfiguration. Robots communicate with other internal business systems
	Robots with no self-configuration capability.	Robots with very limited self-configuration capability.	Robots with decision making capability (through machine learning) that can self-configure and make adjustments to achieve optimal output.
	Formal programming is required to instruct robots to perform tasks	Humanoids (human-like) robots to have Natural Language Processing (NLP) capability, understand human speech and act accordingly	Humanoids with the ability to interpret non-verbal communication and body language
	Meat processors manage production in real-time due to the complexities involved in production planning.		A central command system collects and forwards all movements inside and outside the plant through a set of algorithms to a central cloud. By consolidating information analysis, planning is accomplished by autonomous systems
	Unpredictable system errors and machine down-time		Networked sensors deployed in machines. Intelligent information analysis software can constantly monitor systems performance, self-diagnose and predict problems. This will minimise down-time
	Robots require human intervention and action for maintenance	Robots connect with equipment manufacturers for diagnosis and spare parts ordering	Robots to autonomously maintain using spare parts generated by 3D printers
	Limited number of sensors are used to measure plant operating information	Sensors with direct or networked connections are deployed across various parts of plants that measure advanced information in real-time for better decision making	
Live Animal Handling	Livestock are tagged and traced along the supply chain using the National Livestock Identification System (NLIS). Input is entered by NLIS account holders	The radio frequency ear tags part of the NLIS track and store additional information such as weight gain and animal activity	Cattle to be monitored and tracked using real-time information captured by IoT-enabled sensors
	Manual handling and monitoring of animals in abattoirs	Some autonomous systems to be deployed for monitoring animal welfare and health prior to slaughter	Autonomous robots taking over off-loading and handling of animals prior to slaughter. Vision and sound sensors used to automate animal health and well being monitoring for optimal animal welfare.
	No sensor or very limited amount used for monitoring animal conditions in abattoirs	Sensor network deployed to monitor every individual animal with basic information captured and recorded	Advanced sensor network deployed to monitor every animal with advanced information such as live health data for better management
	Manual cleaning of animals before processing and holding pens	Fully automated systems that selectively apply cleaning to animals and holding pens to reduce water consumption and waste. Washing will include automated health and disease monitoring.	
	Some smart technologies utilised to minimise worker injuries	More advanced IA technologies utilised to replace workers with robots in all high-risk areas to eliminate injuries in abattoirs	

Meat Processing	Some vision technologies (mostly 2D) used for carcass cutting/deboning	Advanced 2D and 3D imaging technologies for health diagnosis, precision carcass cutting and robotic meat from bone separation. Transition from the use of active (e.g. X-ray and CT scan) to passive (pure observers) vision systems	
	Meat quality is graded manually with some application of the DEXA technology in certain abattoirs	Widespread roll-out of DEXA in most abattoirs across Australia for better meat quality grading and measuring. The systems also provide feedback back to livestock farmers.	Objective Carcass Measurement (OCM) tools using 2D and 3D technologies will inter-connect with robots and integrate into the overall operations of abattoirs acting as a unified smart system.
	Meat processing workers are not tracked.	Using limited sensors, meat processing workers are tracked to increase safety and well-being.	Smart vision cameras and algorithms identify individual staff and measure their action and performance.
	Training programs in the meat processing areas are designed and completed in traditional settings	Interactive employee training programs utilising modern technologies such as Augmented Reality (AR) and Virtual Reality (VR). Worksite simulation training to be utilised.	
	Employees are prone to risk and injury in processing plants	Reduction in the level of injuries through the use of IA.	Use of IA and real-time monitoring to predict problem areas and reduce injuries to a minimum
Meat Packaging & Supply Chain	Some automated tools used in the warehouse and for logistics.		Autonomous guided vehicles operate the entire warehouse and logistics. Continuous running of robots under cold storage conditions.
	Limited ability to adjust operations based on customer requirements	Robots can deliver products based on specific large customer requirements	Smart inter-connected robots can deliver precise products based on individual consumer requirements
	Some automation in the picking and packing operations.	3D imaging for robotic meat cut recognition and automated picking and packing into retail/export cartons.	
	Barcode and readers are used to capture and record limited product information.	Contactless labelling such as RFID technology used for simplification and increased reliability	Intelligent and flexible labelling systems used for processing, packaging and transport that capture and store sophisticated product information. The use of edible sensors in meat pieces is a possibility
	Disconnected supply chains	Some inter-connection in the supply chains	Inter-connected supply chains linking systems across the chains to facilitate optimum decision making.
	Supply chain constrained by manual paperwork, complex processes and lack of transparency	Automation of some supply chain activities. Use of blockchain technology for limited use cases such as authenticity and traceability.	Supply chain fully utilises blockchain technology to fully automate processes, payments and contracts.

10.0 RESEARCH CENTRE FOR IA TECHNOLOGIES

The commercialisation of automation technologies has been identified as a weak link preventing the transformation of ideas into market-ready products and solutions. Developments of IA technologies are often time consuming and require large amounts of financial capital resulting in a burden for the wide-spread adoption of such technologies (Australian Centre for Robotic Vision 2018). Automation in red meat processing must evolve in a way that makes technologies accessible for all meat processors in Australia regardless of their size, resources or capital.

The establishment of a national Intelligent Automation Research Centre for the Australian Red Meat Processing sector facilitates the development of new technologies and the implementation of the roadmap. By combining a pool of talent and resources from the industry, academia, industry bodies, start-ups and other stakeholders, an ecosystem would be created with an agile development pipeline benefitting meat processors. These projects upon attracting collaborative funding, will enable the industry to realise new IA technologies and facilitate the wide-spread adoption of Industry 4.0.

11.0 SUMMARY

The meat processing industry is about to undergo a major transformation towards Intelligent Automation. In the past, various efforts were undertaken to automate parts of the operations. However, new changes resulting from Industry 4.0 will inter-connect the supply chain and result in paradigm shift in how meat is produced, processed and consumed. Technologies such as vision and sound analysis, augmented reality, blockchain, collaborative robots, 3D printers, smart warehouses and trackers will transform animal handling, carcass processing and meat packaging and warehousing in abattoirs. IA will result in concrete benefits such as improved animal welfare, higher production yield, better work environment, improved productivity, reduced costs and better traceability. However, in order to maximise the benefits from IA, its challenges such as security and human resource aspects need to be managed. It is recommended that a dedicated research centre be established to foster collaboration between the industry and academia and drive IA and automation technologies in the meat processing industry in Australia.

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