Artificial Intelligence

Solving problems, growing the economy and improving our quality of life

CITATION

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Accessibility

Notes

All monetary values are given in Australian dollars unless otherwise specified.

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Artificial Intelligence Quick Facts

1. Digital technologies, including AI, are potentially worth AU$315 billion to the Australian economy by 2028 [18] and AI could be worth AU$22.17 trillion to the global economy by 2030 [11].
2. Australian industry needs up to 161,000 new specialist AI workers by 2030 in machine learning, computer vision, natural language processing and other AI technologies.
3. The Australian information, communications and technology (ICT) sector employs 663,100 workers in fields related to AI. This will grow to 758,700 workers by 2023 at a rate of 20,000 additional workers per year [3]. Today 66,000 ICT workers live in remote and regional areas [38].
4. An AI system for detecting skin cancer (which could become a smartphone app) performed “on par” with 21 certified dermatologists [17]. In Australia 13,280 new cases of melanoma were diagnosed in 2016 and 1,770 people died from the disease [16]. Earlier diagnosis enabled by AI will save lives.

5. An on-farm agricultural robot Agbot II developed by the Queensland University of Technology could save Australia's farm sector AU$1.3 billion per year by automating weed removal and improving agricultural productivity [14].
6. AI could help reduce the 1,137 deaths/year [81] and 57,000 injuries/year [82] on Australian roads. Autonomous emergency braking combined with forward warning collision systems decreased front-to-rear injury accidents on US highways by 56% [87]. When combined with lane departure correction these semi-automated technologies could prevent or reduce the severity of 1.3 million car crashes on US roads each year [86].
7. Mining operations in the Pilbara region of Western Australia are amongst the world's most automated. Fortescue operates 112 driverless trucks with a 30% productivity gain. BHP has 50 autonomous trucks at its Jimblebar site and 20 autonomous drills state-wide [131]. Launched in 2008 Rio Tinto's mine-of-the-future [132] has 140 automated trucks, over 11 automated drills, and 60% of train kilometres are in autonomous mode.
8. In 2018 there were 1,465 start-ups in Australia, 21% of which consider AI relevant to their products or services [47]. This increased 6% from 2017 [48]. Through this study we surveyed 72 AI start-up companies of which 84% report to be adapting or developing novel algorithms rather than simply using AI toolboxes.
9. AI is being used to help maintain Sydney Harbour Bridge. Data61 placed 2400 sensors on the bridge which monitor 800 steel and concrete supports under the roadway. Data generated by these sensors is analysed using machine-learning and predictive analytics to identify priority locations for proactive maintenance. This keeps costs down and minimises traffic disruptions.
10. Drones are already being used to perform rescues and spot sharks in the Australian surf. On 18 January 2018 two teenage boys in the surf 700m from land (in a 3m swell) near Lennox Head, NSW were rescued by an airborne drone which dropped an inflatable floatation device to them. Rescue drones can be equipped with AI systems which can automatically detect and help people in need. Machine learning and computer vision systems are being developed that will automatically identify rip currents so beachgoers can be warned.

Foreword

Artificial Intelligence (AI) is one of those technologies, like advances in gene editing or quantum computing, which has the power to change life itself. It has the potential to transform economies, unlock new societal and environmental value and accelerate scientific discovery. With AI estimated to generate $13 trillion in economic activity globally by 2030, the global race to lead in AI is well and truly underway.

In April 2019, Australia's national science agency CSIRO and the Department of Industry Innovation and Science (DIIS) co-developed a discussion paper for an AI ethics framework to respond to issues associated with AI, ensuring we use ethical and inclusive values to manage the deep influence it will have on the way we live, work and play.

In conjunction with the discussion paper, we have worked with DIIS to develop this report which lays the path for how AI can boost the productivity of Australian industry, creating jobs and economic growth and improving the quality of life for current and future generations.

This report leverages CSIRO's expertise, working in deep collaboration with our network of digital specialists, and incorporating feedback gathered through national consultation with government, academic and industry stakeholders.

If Australia can focus its AI activities on areas of great need that matter to all Australians, like drought and food production, areas where we already have world-leading expertise, then we can achieve the greatest impact. Through this roadmap, we highlight opportunities for AI to solve big problems that build off our strengths, with a view to exporting solutions to the world in three areas: healthy ageing; cities and infrastructure; and natural resources and environment.

AI is already a well-established technology, with applications across many industries starting to take shape. However, the success of our industries of the future will be determined by whether AI is simply used to cut costs, or whether we take full advantage of this powerful technology to grow new opportunities and create new value. We believe this value is created when AI is partnered with humans who have deep domain expertise in Australia's key industries. This allows us to channel the power of this technology to multiply our human ability.

We have already taken the first steps towards determining our future with AI, but more people, more industries, and more communities must join the conversation.

This report, Artificial Intelligence: Solving problems, growing the economy and improving our quality of life, provides the guidance and possible pathways forward to ensure our nation captures the full potential of AI in our uniquely Australian context, to create a better future for all of us.

Dr Larry Marshall
Chief Executive Officer
Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Executive Summary

- Artificial intelligence (AI) may be defined as a collection of interrelated technologies used to solve problems autonomously and perform tasks to achieve defined objectives, in some cases without explicit guidance from a human being. Subfields of AI include machine learning, computer vision, human language technologies, robotics, knowledge representation and other scientific fields. The power of AI comes from a convergence of technologies.
- AI is a general purpose technology that can be used to increase the efficiency, safety and quality of production processes in almost every industry. AI is already being used to solve challenging problems in health, welfare, safety, environment, energy, infrastructure, transport, education and other sectors.

- Global investment into AI continues to grow. In the past few years alone, 14 of the world's most advanced economies have announced over $86 billion in focused AI programs and activities. This has mostly been in the form of public sector investment but does include some private sector funds. These investments are improving the capabilities and competitiveness of governments, companies and workers in the global community and world economy.
- Australia has established world-leading capabilities in a number of core AI-related fields housed within our universities, research organisations and companies. AI is also already being widely applied and developed by Australian governments, companies and start-ups. There are untapped opportunities for Australia to develop, coordinate, consolidate and concentrate our deep, but distributed, AI capabilities on matters of national significance. We can also create new job-generating AI industries.

In the past few years alone, 14 of the world's most advanced economies have announced over AU$86 billion in focused AI programs and activities.

- To maximise the future benefits and build the right foundations for adoption, adaptation and development of AI technologies, government, industry and community should consider taking action in the following areas:
  - Develop an AI specialist technical workforce to meet the operational needs of industry. We estimate that between 32,000 – 161,000 AI specialist workers will be needed by 2030;
  - Help workers whose jobs are likely to be positively or negatively impacted by AI and related digital technologies make early and strategic career transitions;
  - Ensure effective data governance and access as AI is typically data hungry and machine learning algorithms need "training data" to be developed and tested;
  - Build trust in AI by ensuring high standards and transparency for all applications developed and applied in Australia because without trust people are unlikely to adopt AI technologies;
  - Increase the activity within the science, research and technology development pipeline to ensure advanced AI capabilities for government and industry in the future;
  - Improve digital infrastructure (for data transmission, storage, analysis and acquisition) and cybersecurity so that AI can be safely and effectively used across Australian cities and regions; and
  - Develop appropriate systems and standards to ensure safe, quality-assured, interoperable and ethical AI is developed and applied within Australia.
- Governments worldwide are taking strategic steps to achieve improved AI capability for their nations. This report identifies three high level strategies for achieving a desired AI future for Australia:
  - Technological specialisation: This involves choosing and developing targeted areas of specialised AI capability to gain comparative advantage in the global marketplace.
  - Mission directed research: This involves identifying clear goals and targets for research which are associated with solutions to major problems of national significance.
  - Business and knowledge ecosystems: This approach to organisational design aims to identify and leverage networks of expertise and resources which lie across jurisdictional boundaries.

AI development is already well underway across Australian companies, governments and community organisations.

Figure 1. High potential areas of artificial intelligence specialisation for Australia.

Artificial Intelligence Specialisations
Solving significant problems at home, exporting the solutions to the world and building-off our strengths.

Health, Ageing and Disability
Develops AI for health, ageing and disability support to reduce costs, improve wellbeing and make quality care accessible for all Australians.

Natural Resources and Environment
Develops AI for enhanced natural resource management to reduce the costs and improve the productivity of agriculture, mining, fisheries, forestry and environmental management.

Cities, Towns and Infrastructure
Develops AI for better towns, cities and infrastructure to improve the safety, efficiency, cost-effectiveness and quality of the built environment.

- We identified three high potential areas of AI specialisation (Figure 1) for Australia based on (a) existing capabilities and areas where we have comparative advantage; (b) opportunities to solve big problems in Australia and; (c) opportunities to export our solutions worldwide.
  The proposed areas of specialisation include:
  1. **Health, ageing and disability.** This involves the use of AI to improve human health (either via prevention or treatment), achieve healthy ageing and support people living with disability. Solutions relating to this proposed AI specialisation are of high value considering rising or high rates of chronic illness, ageing populations and unsustainable growth healthcare expenditure. Disability support enabled by AI will benefit the 4.3 million Australians who live with disability, as estimated by the Australian Bureau Statistics. AI can be transformative for disabled people by improving their life opportunities and helping them get good jobs. Australia already has world-leading capabilities in AI for health, ageing and disability support. These issues are shared by countries worldwide and we can export our solutions into the global marketplace.
  2. **Cities, towns and infrastructure.** This involves the use of AI to decrease the costs and improve effectiveness of built infrastructure planning, design, construction, operation and maintenance. There are significant shortcomings in built

infrastructure which is already impacting the operation of our towns and cities. Automation and sensory systems can improve our infrastructure. We have world-leading capabilities within this area and we can export the solutions to a rapidly urbanising world.
3. **Natural resources and environment.** Australia is already a world leader in agricultural robotics and the use of advanced data science and machine learning on farms. We also lead the way in mine site automation and environmental monitoring/management applications of AI. We can develop these technologies into industries which export to a world hungry for more food, fibre, minerals and a cleaner environment.

- Whilst specialisation is important, we note that many of the beneficial outcomes Australia could achieve through the development and adoption of AI will emerge serendipitously. These areas of specialisation should not limit, and where possible should support, the organic development of core AI research and capability within diverse segments of Australia's innovation ecosystem.
- AI development is already well underway across Australian companies, governments and community organisations. Many organisations and individuals are making their own AI plans and strategies for the future. In this document we have identified a high-level pathway for Australia's AI development starting with experimentation which eventually leads to entirely new industries (Figure 2).
- This document is intended to help guide future investment in AI and start a national dialogue on some of the ways these technologies might drive new economic and societal outcomes for Australia. It has been prepared by CSIRO's Data61 to inform the Australian Government's consideration of potential directions to support greater awareness, exploration and uptake of AI across our industries and communities.

Figure 2. Australia's Artificial Intelligence Journey – Stages on the road to the 2030

Experimentation and strategy development
Companies (large and small) and governments (at all levels) design and experiment with prototype AI systems.
They learn what works and develop strategies to build, adapt or buy AI tools to achieve their objectives. We work out our niche in the global AI landscape.

Skills and capability development
An entirely new workforce with skills in machine learning, data science, robotics and computer vision starts to emerge as people upskill. Organisations acquire the assets and capabilities they need to operate in an AI future. Advanced AI R&D builds a pipeline of future opportunity.

Productivity and quality-of-life gains
Powerful AI capabilities are unleashed into business processes and government services with major productivity gains being realised which boost productivity and improve people's quality of life. Rates of economic growth and wealth generation are boosted.

New industries, new growth and a new workforce
Existing industries are transformed with new ways of doing business and new products and service offerings. Australia exports AI technology to the world in areas of specialised capability. Millions of workers get new and better jobs in the AI economy.

1 Introduction

Artificial intelligence (AI) is a general purpose technology with the potential to be applied across almost every industry within the Australian and global economy.

AI has parallels to the invention of electricity in the 19th Century. As a general purpose technology, electricity transformed Australia and the world economy during the latter stages of the industrial revolution. It enabled and reshaped every industry whilst building an entirely new industry itself. Hundreds of thousands of Australians entered good jobs and careers building our electricity network and servicing the industries it created.

No one country will drive or decide how the forthcoming AI transformation happens – it will be a global effort. Technological innovation is set to continue at pace. The question is how we can best position our nation to adapt and capitalise on these changes for the benefit of all Australians. Many countries have already proactively moved to embrace AI, making sizeable commitments to investment in advancing their nation's technological capabilities and readiness to adopt these technologies, for the future. Australia is charting its pathway.

It is already anticipated that AI may offer the key to helping us solve some of humanity's greatest challenges such as climate change, antibiotic resistant bacteria, road accidents, cancer and food, water and energy insecurity. We are already building machines that can learn and can problem-solve without explicit guidance from a human operator. This can take us into new spaces. AI also represents a potential solution to the productivity slump which is constraining economic growth and wealth generation in advanced economies, including Australia.

The AI revolution won't be identical, but will have parallels, to previous industrial revolutions, such as the arrival of electricity. AI will continue to collide with other technologies and elevate our human knowledge and human capability to new levels. This report seeks to explore just what AI might mean in Australia's future and how we can build on our current research and industry foundations to best harness the benefits of AI and deliver improved quality of life for current and future Australians.

AI will continue to collide with other technologies and elevate our human knowledge and human capability to new levels.

2 How might AI touch the lives of Australians?

A new unfamiliar technology like AI can sound daunting and distant to the needs of everyday Australians. But it's already being used to help us on a regular basis and these uses will become more prominent and impactful over the coming decade as the technology continues to evolve.

In this section we explore some of the very real ways current AI technologies and those coming in the next decade are expected to help Australians.

Helping people living with a disability, such as impaired vision

Over 575,000 Australians are currently living with vision impairment [12], including conditions such as retinitis pigmentosa – a genetic disorder associated with gradual loss of vision and, although uncommon, complete blindness. AI is already driving advances in the diagnosis of such conditions and also the development of new technologies to restore or improve our sight. An example is the development of the bionic eye – an Australian technology which can restore the sense of vision to people with retinitis pigmentosa and other sight related conditions. The bionic eye comprises a camera (attached to glasses), a vision processing unit and an electrode array surgically implanted behind the retina. The technology converts visual images into electrical signals which lets a person experience improved vision – and see things.

Helping senior citizens live independently at home longer

More than 3.8 million Australians are over the age of 80 years [13] and many are having to consider the possibility of needing to leave the family home and move into a care facility. AI is already helping to support ageing Australians to stay in their homes longer. Sensory systems using computer vision installed in homes can monitor movement and behaviours to detect if something is wrong (e.g. a fall or sustained lack of movement) and automatically call for assistance. Robotic devices can help lift and move heavy objects. Smart devices enabled with human language technologies receive and deliver reminders about important tasks and events. A medication dispensing device can help ensure the right medications are taken, at the right times and in the right dosages. Home health monitoring equipment can save ageing Australians from having to make trips to the doctor or hospital for check-ups. And lastly, whilst it can't ever replace a human, a companion robot can provide comfort and company to loved ones with conversational capability.

Helping farmers keep their properties weed free

Weeds reduce crop, pasture and livestock productivity on Australian farms. Over the years some weeds have become resistant to herbicides and farmers must sometimes resort to ripping them from the earth. AI can help. As an example, the agricultural robot called Agbot II developed by the Queensland University of Technology is about half the size of a tractor and can drive across paddocks performing farming operations autonomously. Agbot II can save Australia's farm sector $1.3 billion per year by automating weed removal and improving agricultural productivity [14]. Technologies such as AgBot II are using computer vision and machine learning to identify and classify weeds and then determine the optimum weed removal method. Robotics can then be used to spray weeds (with the right type and amount of herbicide), mechanically destroy weeds (rip them out of the ground) or use micro-wave destruction methods. Weeds don't stand a chance. This will boost crop and pasture productivity, and save farmers time and money. Farm robots can perform a wide range of seeding, spraying, tillage, harvesting and monitoring operations.

Helping small business owners trying to juggle the day to day demands of running their enterprise

AI is already helping business owners better understand their customers, supply chains and emerging opportunities for growth. There are already numerous Australian companies (large and small) using predictive analytics and machine learning to analyse their sales data – potentially combined with other data (e.g. census data) – to quickly inform how much of what products to order and when (days, weeks, months) based on seasonal demand. These tools can also help identify in-demand products for customers or ways to monitor stock inventories and production activity on the factory floor to place automatic orders for new products or components when they're running short or demand is forecast to peak. This can add up to major cost savings and new opportunities for our businesses to compete and thrive.

Helping firefighters fight bushfires

Putting out spot fires (small fires) before they become major conflagrations is a mission-critical activity for fire fighting teams. But where should firefighters concentrate effort and target resources? AI can help. AI is already being used to rapidly map forest fire fronts and simulate fire-spread based on fuel loads, terrain and climate, to assist firefighters in pinpointing their efforts, allowing them to save lives and property. For example, the CSIRO Data61 "Spark" system uses machine learning to map fire fronts and identify priorities. These systems offer the potential to operate in real time, providing fire fighters with regular updates and information for tactical responses as the situation rapidly unfolds.

Helping people to improve their mental health

According to Beyond Blue over one million Australians are currently suffering from depression. Some of these people won't get help and there's a risk of serious negative life outcomes, which sometimes can include suicide risk. AI can help. As an example, in October 2017 Lifeline launched the #BeALifeline Twitter Direct Message (DM) Chatbot designed to help people going through a tough time [15]. It can diagnose people at risk and, where appropriate, start a conversation to reduce the chances of negative outcomes or suicide. Researchers at the University of Melbourne [15] have found that young people suffering depression or tough life circumstances want more AI enabled chatbots. The chatbot can help someone start a tough conversation and then get human expert help. As the AI and natural language processing behind the chatbot improves it will be able to have much more realistic and helpful conversations with people at risk. AI can also reach people in remote and regional Australia at any time of day or night on a wide range of devices. The chatbot is always there and always ready to help. Chatbots can't replace human counsellors, however they can help and will play an increasingly important role in reducing depression and suicide risk. For many Australians these technologies might make it easier to open up about problems and get professional help from a human counsellor.

Helping people with cancer

In Australia 13,280 new cases of melanoma were diagnosed in 2016 and 1,770 people died from the disease [16]. If diagnosed and treated early the prognosis for treatment of these types of conditions is good. But if detected late, the chances of survival are much less. AI can help. For example, a machine learning technique using deep convolutional neural networks was developed by Stanford University scientists to identify skin cancers from images [17]. The researchers tested the AI against 21 certified dermatologists. They found the AI performed "on par" with human dermatologists. The researchers indicated that the technology could be incorporated in smartphone apps. This will allow low-cost and earlier detection of skin cancer which will improve survival rates for patients. Many Australians who are doctor-shy may be willing to use a convenient smartphone app which detects a skin cancer. They could then visit a clinician for formal diagnosis and early treatment with much better chance of survival. Many other types of cancer can be diagnosed and treated early with AI leading to better survival rates.

Creating career opportunities

As AI reshapes the economy it will create new industries and new jobs. A study by Data61 and consulting firm AlphaBeta found that digital innovation could add an extra $315 billion in gross economic value to Australia over the period 2020 – 2030 [18]. The new industries in areas such as robotics, vehicle automation and cybersecurity will drive the demand for skilled workers. It's already happening. The Australian information, communications and technology (ICT) sector workforce contained around 663,100 workers in 2017 representing a 3.5% increase from the previous year [3]. This is forecast to grow to 758,700 workers by the year 2023 which represents roughly 20,000 additional workers per year over the coming five year period. One of the most rapid-growth professions includes "software and applications programmers" which will see around 80,000 new job opening in the next five years [3].
And the salaries are good. For example, the Australian Government Job Outlook Website indicates that software and applications programmers are likely to experience very strong future growth and lower unemployment compared to the overall labour market with an annual before-tax salary
of $104,156 compared to the average worker of $73,112. These jobs will also be available to a greater number of Australians, with many of these types of jobs moving from being only present in Australia's big cities to numerous regional centres. With the right mix of technical and human/business skills, Australians will be well placed for a great career in a great location.

3 What is AI?

AI is a powerful, useful and transformative general purpose technology. In recent times the discussion about AI has shifted gears – it's less about whether or not computers can think for themselves as explored by pioneers such as the famous British Mathematician Alan Turing in the 1950s. It's more about the practical application of powerful technologies to perform useful functions and the transformative impacts this could have on entire economies and societies. In this report we define AI as:

A collection of interrelated technologies used to solve problems autonomously and perform tasks to achieve defined objectives without explicit guidance from a human being.

Machine learning lies at the core of AI and when combined with other technologies—such as computer vision, natural language processing and robotics—represents a potential step-change in what's possible for humanity and our quality of life.

There are many fields of science and technology (Figure 3) which are considered as core to AI such as:

- **Machine learning.** Machine learning is a field of study that gives the computers the ability to learn without being explicitly programmed. There are three main techniques for machine learning: statistical machine learning aims to find some type of predictive function from the training data; reinforcement learning approaches provide AI algorithms with "rewards" or "penalties" based on their problem solving performance; and deep learning approaches make use of artificial neural networks.
- **Human language technologies.** A growing number of AI applications depend on the ability of robotics and computerised systems to record, interpret and use human language. Human language is communicated either verbally or via text (handwritten or typed). These two major channels of communication are primarily studied by AI researchers under the fields of natural language processing; sometimes referred to as text analytics and voice and speech recognition. The use of these technologies is likely to grow considerably over the coming decade. For example, It is estimated by 2020 half of all internet searches will be conducted via voice [19, 20].
- **Computer vision.** This involves analysing digital images using image processing algorithms [21]. These algorithms often perform image retrieval, image recognition and visualisation. Recently, deep learning has revolutionised this area, improving the performance of some tasks to the level of human vision. A 2014 breakthrough [22] in the development of an unsupervised machine learning method, called Generative Adversarial Nets (GANs) which involves the generation of images that look authentic to humans, was a major breakthrough for this line of research.
- **Robotics.** One of the most interdisciplinary areas of artificial intelligence is robotics. It brings together engineering, computer vision, machine learning, electronics and various other disciplines to create robots which can interact with their environment through channels such as sensors, speech, vision or text, to complete tasks. This subfield of AI is often intertwined with other AI subfields of automated planning and plan recognition; as planning is often needed by a robot to guide its movement and choices [23].
- **Automated planning.** Automated planning is a field of AI investigating computational models and principles to enable an artificial agent to act deliberately [24]. For example, when a robot should decide how to perform

a specific task, such as moving an object, it should first plan the required actions. A planner identifies an ordered set of required actions to complete a task in a given environment. Automated planning has been applied in planning space missions by NASA, manufacturing (e.g. Amada Corporation), dialogue systems, smart homes, electricity consumption modelling, underwater vehicles and computer games [24-27].

- **Expert systems.** Expert systems were introduced in 1965 with the aim of approximating human expertise in decision making, allowing automation of human knowledge [28]. These systems often include two parts: (a) an inference engine and; (b) a knowledge base which includes facts and rules. Finance and healthcare are two of the main applications of such systems, with expert systems for disease diagnosis being developed since the 1970s.
- **Knowledge representation.** Underlying any intelligent system is its source of knowledge. Such knowledge of the world requires representation. Representation of domain knowledge is challenging because knowledge in the form of human expertise is large, dynamic and non-uniform. Knowledge representation is currently an active area of research within machine learning, natural language processing and computer vision communities, especially for deep neural networks [29].

Researchers have been working in AI domains for decades, so why is it gaining so much attention now? The answer is partly due to the convergence of multiple technologies. Technological innovation isn't a straight line. It's not like a skyscraper with one floor of scientific achievement built vertically on top of another. Innovation is better represented as an inverted pyramid where one idea leads to several more which support yet more ideas. In his recent book "How Google Works", Google Chairman Eric Schimdt argues humanity is entering an era of "combinatorial innovation", where the pace of change is accelerating [30]. That's why now is different. Multiple technologies are converging to create a fundamentally new capability that will open new doors.

Figure 3. Science domains of artificial intelligence.

Artificial Intelligence

Knowledge Representation

Machine Learning

- Reinforcement learning
- Statistical methods
- Deep learning

Human Language Technologies

- Natural Language Processing
- Voice and speech recognition
- Search and information retrieval

Computer Vision

Affective Computing

Robotics

Automated planning and plan recognition

Expert Systems

4 The Economic Value of AI

Productivity is the level of efficiency via which the economy converts its inputs to outputs. Productivity improvements are vital for long term economic growth and wealth generation. AI represents a significant new opportunity to boost productivity and enhance our national economy. This is because AI creates the potential for industry to make better products, and deliver better services, faster, cheaper and safer.

Like many of the world's advanced economies Australia faces medium-term growth challenges associated with population ageing and low multi-factor productivity growth. The average annual productivity growth rate in Australia over the last 10 years has been roughly half the long-term 30 year average. According to economic studies by the Australian Government, productivity growth must increase in order to maintain our trajectory of continued improvements in living standards [31, 32]. Furthermore, overall economic growth measured via gross domestic product (GDP) is also below historic performance (Figure 4). In the 1960s Australia's average annual GDP growth rate was 5.6%. In the 2010s it averaged 2.6% [33].
This phenomena, impacting all of the world's advanced economies, was referred to by José Ángel Gurría – the Secretary General of the OECD – as the "low growth trap" [34].

As a general purpose technology AI could be the missing ingredient in the productivity equation which turns things around and returns the worlds advanced economies to stronger growth.

Figure 4. Average annual economic growth rates by decade.
Source: OECD Statistics [25]

As a general purpose technology AI could be the missing ingredient in the productivity equation which turns things around and returns the world's advanced economies to stronger growth. This is a perspective put forward in a recent working paper by economists published by Stanford University [35], and a separate report by economists at consulting firm Accenture [36]. These researchers argue AI is adding something new to an economy's productivity engine and rewriting the economic growth equation.

The potential of AI to improve productivity is supported by several economic studies which estimate the productivity gains associated with AI and digital technology application. For example, consulting firm McKinsey [37] estimates digital technologies could contribute $140 to $250 billion to Australia's GDP by 2025 and that automation technologies (a subset of AI technology) would comprise $30 to $60 billion for Australia over the same time period. Another recent study by consulting firm AlphaBeta and CSIRO's Data61 [18] estimates that digital technologies, including AI, are potentially worth $315 billion to the Australian economy by 2028.

The average annual productivity growth rate in Australia over the last 10 years has been roughly half the long-term 30 year average.

Another trend of relevance is the increasing importance of the information technology sector to Australia's economy (Figure 5). This sector is both using and developing powerful AI technology. In the past few years it has broken away from the rest of the share market and is already boosting growth in the Australian economy. Examples include companies such as Technology One, WiseTech, REA Group (including realestate.com), carsales.com, Afterpay, Xero, all of which are investing heavily in advanced digital and AI capabilities. According to the S&P ASX200 Information Technology Index, over the entire month ending July 2019 the market capitalisation of ASX200 technology sector companies ranged from $1.2 billion to $10.2 billion with a mean value of $4.9 billion which is indicative of price volatility within this sector. The breakaway of the information technology sector can be seen over a longer time period in the United States by comparing the NASDAQ with the Dow Jones Industrial Average. The NASDAQ has shown more rapid growth over the decades compared to the Dow Jones.

A recent report by consulting firm AlphaBeta [38] argues the information technology sector currently contributes $122 billion to the Australian economy employing 580,000 workers. The report suggests that we can boost Australia's GDP by $207 billion/year if the Australian technology sector grows on par with global leaders. The report also finds that 66,000 workers in the information technology sector live in remote and regional Australia and that 90% of information technology sector businesses are small to medium enterprises.

Digital technologies, including AI, are potentially worth AU$315 billion to the Australian economy by 2028.

Figure 5. The information technology sector compared to the broader market.
Data source: The Australian Stock Exchange and S&P Dow Jones Indices.

5 What's the world doing?

Recent times have seen an unprecedented level of global activity and investment in AI. In the past few years, 14 of the world's advanced economies have announced a total of $86 billion in AI programs and activity. This is mostly public sector investment but does include some private sector funds. Additional non-publicised investment is likely.

There is a widespread view among these economies that AI will boost industry and worker productivity and achieve competitive advantage in global markets. The investments are being used to fund AI research and development, boost training and education, encourage industry adoption, seed start-ups and promote ethical application.

There are opportunities for Australia to leverage offshore investments in AI technologies. There are also opportunities for Australia to fill niches in the global marketplace, creating new opportunities for our own economy and developing AI exporting industries which build-off our strengths in science and technology.

On 22 May 2019, all member countries of the Organisation Economic Cooperation and Development (OECD) Council on Artificial Intelligence (including Australia) approved a set of recommendations on AI [39]. Although not legally binding these recommendations are likely to be influential for AI at the global scale. The recommendations contain principles for the beneficial, safe and ethical application of AI. The recommendations also suggest actions for governments seeking to develop AI capability. These actions relate to research and development, digital infrastructure, business ecosystems, policy designs, skills development and cross-jurisdictional cooperation.

In preparing this document we reviewed AI developments worldwide over the past few years:

- The United States has deep, longstanding and world-leading capability in many scientific fields of AI and many areas of application. United States technology corporations such as Alphabet (Google), Microsoft, Amazon, Apple and other NASDAQ-listed companies are actively developing powerful AI systems which are becoming industry-standard across many sectors. These companies have large research and development budgets. The US Government and philanthropic-sector are investing heavily in applied and pure-discovery aspects of AI research. Many of the most influential scientific research papers on machine learning have been published by researchers at United States universities and technology companies.
- In recent years China has come to the fore with rapid development of advanced AI capability in diverse fields. Today China has broad and deep AI capabilities with widespread deployment of robotics and autonomous systems across all industry sectors. There has been an explosion of academic publishing in the field of AI from China's university and research sector. There is a mix of public and private sector AI activity in China with vast investments in pure and applied research. Companies such as Alibaba Baidu and Tencent are pouring substantial resources in to specialist AI capability development.
- The European Commission has invested heavily in AI capability rivalling the activity in China and the United States. The "Artificial Intelligence for Europe" strategy involves investment in AI research capabilities relating to robotics, quantum computing and other fields. The strategy also supports research centres across Europe with the aim of developing numerous AI centres of excellence. The European AI strategy pays considerable attention to ethics and data governance; seeing ethical AI as a point of competitive differentiation.

- The German AI Strategy was launched in December 2018 and is primarily aimed at boosting the vast and well-established German manufacturing sector. The German AI strategy seeks to achieve high levels of quality-assurance so that German-made AI is recognised by customers as high-quality; as achieved by brands such as Miele and BMW. The German Government is also sponsoring many university research teams to conduct pure-discovery oriented AI research to generate novel approaches for AI problem solving and next-generation technological capability.
- Canada was the first country to launch an official AI Strategy called the “Pan-Canadian Artificial Intelligence Strategy” in 2017. This strategy grew the number of outstanding AI researchers and skilled graduates across the nation, established interconnected nodes of scientific excellence in Canada’s three major centres for AI (Edmonton, Montreal and Toronto), supported a national research community on AI and to developed global thought leadership on the economic, ethical, policy and legal implications of advances in AI. Since launching this strategy Canada has continued to increase its AI activity and investment.
- The United Kingdom AI strategy “AI in the UK: Ready, willing and able?” was published in 2018 and aims to grow the population of doctoral researchers and the overall skills and capabilities of the UK workforce in all aspects of AI. The strategy also has a strong focus on ethical AI as a key differentiator in global markets. The area around Cambridge has emerged as a mini Silicon Valley with an explosion of high-tech digital firms. The UK is also home to the Google company Deepmind which has headquarters in London. Deepmind is credited with some of the most significant breakthroughs in the field of Machine Learning.
- The French AI Strategy was released in 2018 and is heavily focused on the social, ethical and economic aspects of the technology. The French strategy aims to upgrade the skills of industry to build, adapt and apply AI within production processes. It also aims to upskill an entirely new workforce of AI workers and researchers. The French strategy also involves reviewing and improving legislation, regulation and policies to accommodate AI within all aspects of French society.
- In addition to these countries Singapore, Taiwan, Japan, India, United Arab Emirates, South Korea, Finland and New Zealand have all announced significant AI activity.

6 What’s Australia doing?

There’s a vast amount of AI activity underway and Australia has world-leading and longstanding capabilities in many core AI research fields.

In the May 2018 Budget, the Australian Government announced $29.9 million to advance AI and machine learning, along with development of an AI Technology Roadmap (this document), a standards framework and a national ethics framework [40].

The funds support AI related Cooperative Research Centre Projects (CRC-P), PhD scholarships and school related learning. Australia’s national science agency, CSIRO, also announced a $19 million initiative on AI and machine learning “to target AI-driven solutions for areas including food security and quality, health and wellbeing, sustainable energy and resources, resilient and valuable environments, and Australian and regional security” [41]. States and territories are also investing, with prominent examples being South Australia investing $7.1 million into an AI and Machine Learning Institute at the University of Adelaide [42] and the Queensland government’s $3 million investment in an AI Hub at its innovation centre “The Precinct” in Brisbane.

Figure 6. Australian Research Council pure research funding for artificial intelligence
Data source: Australian Research Council Grants Database [43]. This represents the annual total of projects funded under the research field code 801 “Artificial Intelligence and Image Processing”. In 2014 a single large $19 million project was funded at the Queensland University related to robotic vision [44].

Multiple Australian universities and research organisations have longstanding (decadal) robotics and AI related research and teaching units. Since 2010 the Australian Research Council has awarded $243 million on pure research projects classified as “AI and image processing” [43]. The Queensland University of Technology is home to the Australian Centre for Robotic Vision which works in partnership with CSIRO, the Australian National University and Monash University. The Australian Centre for Field Robotics at the University of Sydney is one of the world’s largest robotics teams which specialises in applications of robots in outdoor environments. Australia’s mining companies, CSIRO and partner universities also have long-established world leading expertise in mine site automation.

Since 2010 the Australian Research Council has awarded over AU$243 million on pure research projects classified as AI and image processing.

There are several active and planned innovation precincts in Australia with a specific focus on AI, which aim to foster industry–research collaboration, commercialisation and innovation. The Australian Government, working with state and territory governments, universities and research organisations, has endorsed a Statement of Principles for Australian Innovation Precincts to provide best-practice advice to encourage the right settings for precinct development [45, 46].

Existing data on the Australian start-up scene indicates there are 1,465 start-ups in total and that 21% of these consider AI relevant to their products or services [47]. This has increased from 6% in 2017 [48]. We surveyed 72 AI start-up companies of which 84% report to be adapting or developing novel algorithms rather than simply using AI toolboxes. Some of the challenges reported by the AI start-ups included accessing skills and talent; securing investment funds; industry risk aversion and market access. As the AI sector develops in Australia,
the SME Export Hubs Initiative may provide support to enable greater collaboration and realise AI export opportunities [49].

Overall, there is evidence of widespread development and application of AI technology in Australian organisations and strong AI capability across the nation. Through this project we identified 285 applications of AI technology across the entire Australian economy by companies (152 applications), governments (93 applications) and research organisations (40 applications).

7 AI Development Strategies

Enabling the entire Australian economy with AI represents a complex policy and strategy challenge. Here we identify three broad strategic approaches for technology development which could be used to realise AI objectives for Australia.

7.1 Technological Specialisation

The development of AI capability in Australia is likely to benefit from a targeted approach which focuses on areas of specialisation. This involves selecting a small number of high potential areas of AI-related technological capability and targeting resources to accelerate innovation, integration and adoption in those chosen areas.

There is much evidence that technological specialisation boosts economic growth [50-54] especially in advanced economies like Australia's. For example, a comprehensive economic study [51] of all countries comprising the European Union over the years 1969 to 1998 by researchers from the University of Wuppertal in Germany found that: "the level of relative technological specialisation in the area of R&D-intensive industries and especially in the area of leading-edge industries contributes significantly to economic growth" (p271). An earlier study of technological specialisation [50] amongst 20 OECD countries during 1975-1990 came to a similar conclusion stating that "a general positive relationship is found between the degree of specialisation in technology and higher rates of growth" (p157).

There is much evidence that technological specialisation boosts economic growth especially in advanced economies like Australia's.

These empirical studies support longstanding theories in economics about economies-of-scale, comparative advantage and trade. Specialisation allows a country to decrease the costs of production and produce a higher quality product. That makes it difficult for other countries to compete. However, there are also some risks with specialisation. The most significant risk is a failure to specialise in the correct area of science and technology due to future changes in consumer demand or the emergence of competition from other industries worldwide. This can be managed via a targeted, adaptive and balanced specialisation strategy and the Australian Government could consider leading the coordination of such a strategy with industry and researchers.

We note that whilst planned specialisation can be an effective industry growth strategy, serendipity and organic growth are also extremely effective development pathways. Many science, research and technology breakthroughs which have generated the largest social and economic benefit have been serendipitous.

Identifying and developing targeted areas of AI specialisation for Australia, along with other initiatives, could be an effective approach for building capacity across the entire economy.

Case Study – The Pittsburgh steel industry

An example of effective technological specialisation is the United States Pittsburgh steel industry.

At the height of the boom in the 1950s and 1960s, Pittsburgh was one of the largest steel producing regions in the US, however a decline in steel prices during 1970s and 1980s saw most steel mills in Pittsburgh closed.

In response, the US Government implemented a steel technology specialisation strategy, to transition the economy towards new sources of wealth and jobs. By 2010 there were two academic and eight corporate steel research centres in Pittsburgh, providing specialised expertise in metallurgical and materials science.

Specialisation in steel production, and then steel technology, allowed Pittsburgh to achieve continued economic growth, low unemployment and rising salaries.

Case Study – The 'Cambridge Phenomena'

An example of non-centralised and serendipitous emergence of a technology industry is the UK's "Cambridge Phenomena".

Cambridge University is a research and teaching institution which has long pursued excellence, but with negligible centralised control. Academics and schools within the university are expected to meet high standards of competency and achievement, but can largely pursue their own directions. The results have been spectacular:

- Following explosive growth in the 1980s and 1990s, by year 2000 there were over 1,200 high tech firms employing 36,000 people (or 10% of the entire Cambridgeshire workforce) [7].
- The ecosystem continued to grow over the global financial crisis years of 2008-2009 and by the year 2013 had 1,500 firms, five of which had valuations over US$1 billion [9].
- The success of the tech start-ups attracted larger companies with larger investments. Microsoft, Google and Toshiba are a few of the companies setting up major R&D labs in Cambridge [9].

7.2 Mission Directed Research

A mission-directed approach to technology development aims to identify, and solve, national problems and challenges. For example, Australia might want to set a bold target around using AI to rapidly boost early diagnosis of cancer. This can have the effect of consolidating national capability and generating spin-off companies and industries. Concepts of mission-directed research have been developed by the Australian Government [55] and Mariana Mazzucato from the University of Sussex and the University College London [56]. It is possible that mission-directed research designs could be used to concentrate AI capabilities whilst building industries which export the solutions globally. Missions could complement
the specialisations.

An example of a mission directed AI program comes from the United Kingdom. This year the UK Government Department of Business, Energy and Industrial Strategy announced a missions-based approach to build the nation's future industries [57]. As stated on the department's website "each mission will focus on a specific problem, bringing government, businesses and organisations across the country together to make a real difference to people's lives" [57]. The first mission involves the use of AI and innovation to improve the prevention, diagnosis and treatment of chronic diseases by the year 2030. This mission involves quantifiable outcomes. For example, the UK government estimates that AI and other innovations could result in 50,000 more people having their cancers diagnosed early-stage (rather than late-stage) which would mean 20,000 fewer deaths (within 5 years of diagnosis) compared to the situation today [57]. This is a mission to not only improve people's quality of life, but also to grow new industries and new jobs.

A missions-based, or grand-challenges, approach could be an effective way of developing Australia's AI capability whilst also solving problems of national significance.

7.3 Business and Knowledge Ecosystems

Ecosystem strategies aim to map and model the entire network of institutions, resources and/or individuals relevant to business objectives. They look beyond organisational and/or jurisdictional boundaries to the flow of ideas and resources. Ecosystem designs may be an effective approach for the AI enablement of Australian industry given that our AI capability is distributed across multiple public and private sector institutions, research organisations and diverse geographic locations. There is also considerable connectivity with overseas research capability.

Ecosystems avoid or reduce the need to create new centralised institutes. An ecosystem approach is of growing popularity in the fields of organisational design and management strategy [58-60]. The concept of a "business ecosystem" was introduced by James Moore in the 1993 May-June issue of the Harvard Business Review [61]. It was based on a study of a company called Apple Computers. Moore wrote that "Apple Computer is the leader of an ecosystem that crosses at least four major industries: personal computers, consumer electronics, information, and communications. The Apple ecosystem encompasses an extended web of suppliers that includes Motorola and Sony and a large number of customers in various market segments". At the time Apple Computers wasn't worth much. However, by August 2018 Apple was the world's first company to reach market capitalisation of US$1 trillion. It was accompanied by unprecedented growth in the information technology sector with companies such as Google (Alphabet), Microsoft, Facebook, Amazon and others seeing unprecedented rates of growth. All adopted similar ecosystem models within their organisational structures and cultures.

Ecosystems of AI activity which span existing public and private sector organisations could be an effective way of developing AI capability rather than building entirely new institutions.

Case Study – Commonwealth Bank of Australia

Ecosystems are being increasingly used in organisational design within Australian companies. On 28 May 2019 the Commonwealth Bank of Australia announced a new business ecosystem structure for its Institutional Banking and Markets function [1]. The new structure is based on six ecosystems: connected services; efficient supply chains; future cities; future resources; intelligent finance and smart networks.

The bank has used an ecosystems approach because it is the most effective way of supplying data-driven insights to their customers in a digitally transformed global economy. The Commonwealth Bank's Group Executive of Institutional Banking and Markets Andrew Hinchliff is quoted in the Australian Financial Review (28 May 2019) saying "These [ecosystems] are designed to understand the interdependencies of a business with the surrounding businesses and environment around it" [1].

The ecosystem may become a common approach to organisational design considering digital transformation and data-driven decision making.

7.4 A Story of Transition – From Selling Steel to Selling Steel Know-How

It's not just the technology giants such as Google and Microsoft benefiting from AI enablement. It's happening across the spectrum. Successful technology transitions are underway in small and large companies across Australia in very traditional sectors. One of the most striking examples comes from Brisbane based father-son company Watkins Steel. What's remarkable about this case study is that not a single employee was lost in its process of transforming; rather the company grew its workforce and created more jobs as it switched from steel manufacturing to steel technology.

Based in Brisbane, 50-year old company Watkins Steel specialises in small to mid-size structural steel, metal work, urban arts scapes, architectural structures and refurbishments. Three years ago, recognizing the potential of digital technologies, the company started its transformation from traditional steel fabrication to technology services offering 3D laser scanning, design and data collection.

Watkins Steel has developed a unique digital workflow that links the entire fabrication and installation process from start to finish, connecting digital equipment, software and people, for improved steel detailing. The CEO Des Watkins characterises the transition between old and new, as going from the shop floor to the up-stairs office, where traditional hard-hats are replaced with cutting-edge HoloLens (augmented reality) technology.

As the company adopted new technology, the business doubled in size and for every new piece of automated equipment installed another 10 people have been employed. Des highlights the fact that no jobs were lost through the technology transition and some boiler makers are now the company's technology experts.

As 1,500 staff hours were removed from the factory floor through the automated equipment, staff undertook new roles using their expert knowledge of steel and the fabrication process. Investment in staff retention and professional development has allowed the company to expand its capabilities, continue to learn and opened new business opportunities.

Watkins Steel has grown beyond humble South East Queensland beginnings to enter global markets. The staff have built global networks and participate in international networks to tap into the latest developments.

8 Possible AI Specialisations for Australia

We have identified three domains of AI development and application where Australia is well positioned to transform existing industries and build new ones. These specialisations have been selected based on (a) existing strengths and capabilities where we have comparative advantage; (b) opportunities to solve big problems for Australia and; (c) opportunities to export the solutions worldwide to other problem holders. We stress that this is an early and emerging analysis. We expect these areas of specialisation will be refined as more information about the breadth and depth of AI capability is identified.

8.1 AI for Better Health, Aged Care and Disability Services

AI is being widely applied and developed within the healthcare sector in Australia and worldwide. In surgical applications robotics are being used to improve the precision and efficacy of operations. Machine learning, data science and predictive analytics are being used to provide earlier and more accurate diagnosis of cancer, infectious disease and other forms of illness. Sensory systems combined with other technologies are being used to monitor and assist older Australians creating the possibility of living at home for longer before going into a retirement home. There is much that AI systems can do to improve our health and wellbeing.

8.1.1 Problems to Solve

Australia faces acute challenges in meeting the health and aged care needs of the future. This includes both physical and mental health. Total healthcare expenditure in Australia reached $181 billion in financial year 2016/17 representing more than $7,400 per person and 10% of overall economic activity [62]. This is associated with 4.7% annual growth in real expenditure [62] which is above the rate of real income growth in the economy. A CSIRO report on the future of health states ongoing cost pressures will continue and without intervention Australian governments will need to double spending on healthcare per capita by 2055 to finance current levels of service [63].

Already we can see patients and senior citizens struggling to get the level of care they require. Median wait times for elective surgery increased from 36 days in 2014 to 40 days in 2018. The number of people who presented to emergency departments and were "seen on time" decreased from 75% in 2014 to 72% in 2018 [64]. The median wait time to enter residential aged care facilities has increased to 121 days in 2018 up from 84 days in 2016 [65]. Approximately seven million Australians, representing 29% of the population, live in regional and remote areas which have unique healthcare challenges [66]. Compared to major cities, remote areas have 5.4x the rate of deaths due to land transportation accidents and 1.3x overall mortality rates [67].

Australia's ageing population and demographic pressures are also high priority challenges. The number of Australians aged 65 and over is predicted to increase from 3.8 million to 5.2 million by 2027 [68]. This is associated with increasing prevalence of certain types of disease. For example, without a medical breakthrough, the number of people with dementia is expected to increase to 536,164 by 2025 [68]. In the four year period from 2012 to 2016 palliative care provided in hospitals rose by 28%. The rate of subsidised palliative care-related prescriptions rose at an average annual rate of 17% [69]. Our ageing population could increase public health expenditure by 1-4% of GDP [70] placing further pressure on strained budgets.

The same five health issues continue to cause most deaths of Australians (male and female) and have remained relatively stable over the preceding decade (2006-2016). Coronary heart disease, dementia & Alzheimer's disease, cerebrovascular disease, lung cancer and chronic obstructive pulmonary disease led to 58,276 of 158,500 deaths in 2016 [71]. Collectively, chronic conditions account for 87% of deaths, 61% of total disease burden and 37% of hospitalisations [69]. In 2018 an estimated 138,300 Australians will be diagnosed with cancer and 48,600 will die from cancer [69]. The Australian Institute of Health and Wellbeing found that in 2016 there were over 26,600 potentially avoidable deaths [72].

Already AI systems are matching, or even outperforming, human experts in areas such as oncology, radiology and retinal disease. For example, a machine learning technique using deep convolutional neural networks was developed by Stanford University scientists to identify skin cancers from images [17]. The researchers tested the AI against 21 certified dermatologists. They found the AI performed "on par" with human dermatologists. The researchers indicated that the technology could be incorporated in smartphone apps. This will allow low-cost and earlier detection of skin cancer which will improve survival rates for patients. Such technology would be hugely beneficial in Australia which has amongst the highest rates of skin cancer in the world.

Overall the demand for health and aged care services in Australia is set to escalate and expenditure will continue to rise. Innovation is essential to ensure improved, or even, maintained quality of services. AI will be an important technology which allows us to deliver better healthcare in a cost efficient manner.

Already AI systems are matching, or even outperforming, human experts in areas such as oncology, radiology and retinal disease.

Case Study – AI for Disability Support Services

According to data from the Australian Bureau of Statistics 4.3 million Australians live with some type of disability. There is considerable scope for AI to help these people live better lives as documented in a recent publication in the Disability Support Guide [2]. For example, the new Soundscape app by Vision Australia and Microsoft allows people who are blind (or vision impaired) to receive audio prompts about objects in their immediate surroundings. Soundscape uses computer vision and headphones to tell the person whether they're looking at a road, café, railway station, bike track or other object. This is part of Microsoft's $25 million 5-year program called AI for Accessibility. In another case the Endeavour Foundation has launched 15 training programs which use virtual reality (VR) to help people with intellectual disabilities learn a wide range of skills including road safety, how to use an automatic teller machine and how to be a barista.

Case Study – AI for Mental Health

Mental health can also be improved by AI. For example, an Australian CSIRO Data61 technology uses AI techniques and simple computer games to diagnose mental disorders. The computer game presents patients with choices and tracks their behaviour. Based on how they respond the AI system can diagnose whether they are likely to have a mental disorder and what type. The AI system uses a machine learning technique called artificial neural networks to record and analyse a vast range of subtle behavioural responses in the patient. By analysing this data, the AI system can make a reliable diagnosis. It has already been applied to accurately diagnose patients with depression and bipolar disorder. This represents an improvement on standard questionnaires used by clinicians in the Diagnostic and Statistical Manual (DSM) and the International Classification of Diseases (ICD).

8.1.2 Australian Capability

Australia already has strong capability relating to the application of AI and related digital technologies for healthcare and aged care. In this section we provide a few examples of research teams and companies doing exemplary work. But we note a much larger number of research organisations, companies and governments applying AI to improve the efficiency and effectiveness of health and aged care services.

An outstanding Australian invention is the bionic eye [73]. This is a retinal implant placed at the back of the eye. Sensors built into glasses capture visual input and feed it into the optic nerve and onto the brain. This can restore some level of sight to a visually impaired person. The bionic eye has been developed by the National Vision Research Institute in partnership with the University of Melbourne, Monash University and Lions International. The bionic eye represents advanced application of computer vision which is a field of AI research. There is huge potential to develop, apply and export this technology.

The University of Melbourne will become home to the Australian Research Council (ARC) Training Centre in Cognitive Computing for Medical Technologies, receiving $4.1 million in government funding. The centre aims to breed commercially savvy AI researchers with deep expertise in medical technologies [74]. At Deakin University the Applied Artificial Intelligence Institute (A2I2) in partnership with the Alfred Hospital has developed an AI decision support system to assist doctors and nurses within the hospital's trauma bay to make better decisions when stabilising a patient [75]. At Monash University the Information Technology department has a project focusing on "Multi Modal Medical AI" which centred on how computer-based decision procedures under AI can assist in improving health and wellbeing [76].

Australian company Saluda Medical is pioneering technology using novel AI and electroceutical technology to record and measure the body's response to electrical nerve stimulation travelling up and down the spine in real time, to enable better targeting and management of chronic pain. Australian start-up Maxwell Plus is working with CSIRO, radiology specialist I-MED and Austin Health to develop and commercialise technology for identifying early-stage Alzheimer's disease [77], using Maxwell's AI platform to automatically form a view of a patient's overall health and combine this with brain imaging tools.

The global digital healthcare market is expected to exceed AU$521.22 billion by 2024.

8.1.3 Opportunities to Export

A recent report by the World Health Organisation [78] reveals the size and growth of global health expenditure. In 2015 the world spent $10.6 trillion on healthcare representing 10% of global GDP with an annual growth rate of 4% compared to the overall economic growth rate of 2.8%. Continued growth in expenditure can be expected as the world's economy and human population grows. There are significant technology markets within the global healthcare sector. Recent analysis by AlphaBeta has identified safe and secure precision healthcare as a $140 billion to $190 billion global market by 2028 with $30 billion to $50 billion of revenue generated in Asia-Pacific alone [70]. The global digital healthcare market is expected to exceed $521.22 billion by 2024 [79]. Furthermore, the world will experience population ageing. The global share of over-60s is expected to increase to 21% by 2050 up from 13% in 2017 [70, 80]. In summary there is strong evidence for massive growth in demand for healthcare and aged care solutions at the global scale. Australia is well positioned to develop and supply AI products into the global market.

8.2 AI for Better Towns, Cities and Infrastructure

This specialisation captures all the ways that AI can be used to improve our built environment capturing social, economic and environmental benefits. This includes improved design, planning, construction, operation and maintenance of infrastructure and buildings. It also includes all the ways that AI can be used to improve the efficiency and safety of transportation, electricity and water services.

8.2.1 Problems to Solve

In 2018 there were 1,137 road deaths in Australia [81]. Many of these deaths resulted from human error including speeding and drunk driving. In 2014-15 nearly 57,000 Australians were hospitalised as the result of injuries sustained in car/vehicle crashes [82]. The estimated annual economic cost of road crashes in Australia is $27 billion with significant and devastating social impacts [83]. Furthermore, traffic congestion in the year 2015 cost the Australian economy an estimated $16.5 billion [84]. Without major policy changes or advancements, congestion costs are predicted to be between $27.7 billion and $37.3 billion per annum by 2030 [85].

The application of AI and related technologies could be transformative for safety. A study drawing upon United States Federal Government road safety datasets found that collision avoidance technologies such as autonomous emergency braking, forward collision warning and lane departure correction could prevent or reduce the severity of 1.3 million crashes per year [86]. Another study of US highways found autonomous emergency braking combined with forward warning collision systems decreased front-to-rear injury accidents on United States highways by 56% [87]. There are also significant improvements to travel speed and convenience. Traffic light optimisation systems can reduce travel time by 25%, braking by 30% and idling by 40% [88].

Autonomous emergency braking combined with forward warning collision systems decreased front-to-rear injury accidents on United States highways by 56%.

Energy security concerns and power outages continue to impact Australian towns and cities. Australian electricity consumers pay retail prices that are 44% higher than a decade ago with network costs (poles and wires) contributing 40% of the price increase [89]. Further price rises are likely. In 2016 electricity generation accounted for 35% of Australia's national greenhouse gas emissions [90]. AI could help us use electricity more efficiently with economic and environmental benefits.

Cybersecurity will be critical to the future of Australian cities. From the risk of compromised motor vehicles [91] to protection of the energy grid and healthcare systems, Australia will need to address a growing and complex arena of threats and challenges in the digital age. According to the Australian Cybersecurity Centre's 2017 Threat Report, losses of over $20 million were incurred by Australian organisations due to business email compromise (up from $8.6 million in 2015/16) and government agencies responded to 734 individual cyber incidents affecting private sector systems of national interest and critical infrastructure [92]. Despite Australian investment in security infrastructure increasing by 8% in 2017 (now totalling $89.1 billion) the number of targeted attacks doubled from the preceding year [93]. Approximately five million Australians are victims of cybercrime each year [94]. The potential for AI to help accelerate Australia's fight against cybercrime is high.

High construction costs and unplanned cost overruns are limiting our ability to improve our cities and infrastructure. A recent study by the Grattan Institute [95] found that Australian Government expenditure on transport infrastructure over the last decade has been "unprecedented" exceeding 1% of GDP each year since 2009. The Grattan Institute study also found that 65% of major road infrastructure projects had cost overruns representing billions of dollars. A recent Productivity Commission report [96] into public infrastructure in Australia found that "there are numerous examples of poor value for money arising from inadequate project selection, potentially costing Australia billions of dollars" and that "there is an urgent need to comprehensively overhaul processes for assessing and developing public infrastructure projects". A study by the University of Sydney reports that $63 billion of road infrastructure projects in Australia delivered no identifiable improvement on economic output [97] and were of questionable economic value.

AI can be used to help us plan, build and operate our infrastructure more efficiently. AI can allow us to sweat existing infrastructure assets harder and ensure we prioritise new infrastructure projects of maximum benefit to the nation.

8.2.2 Australian Capabilities

The shift toward smart cities and infrastructure is a global phenomenon with many actors developing and implementing solutions. Our analysis has identified Australian organisations and teams who are world leaders in developing, advancing and deploying AI solutions which improve cities and infrastructure. While not wholly exhaustive, the following examples and applications illustrate the foundational basis from which Australia can amplify its capability and establish comparative advantages.

There is an opportunity in Australia to develop connected and automated vehicle (CAV) technology using both cellular V2X and dedicated short range communications (DSRC) [98]. V2X is a technology which allows vehicles to communicate with traffic infrastructure and other vehicles. The connectivity component of automated vehicle design is where Australia could potentially play a role in the global marketplace. This is an area in which Australia is developing world-leading capability. For example, the Queensland Department of Transport and Main Roads is trialling Cooperative Intelligent Transport Systems (C-ITS) in the City of Ipswich. This will see 500 vehicles retrofitted with C-ITS devices to improve their safety and the efficiency of the road-network [99]. In another example the Adelaide based company Cohda Wireless supply hardware and software used in over 60% of V2X trials globally [100, 101].

A related longstanding Australian innovation is the Sydney Coordinated Adaptive Traffic System (SCATS). This can be used to coordinate road signals and optimise vehicle flow across an entire town, city or region. This Australian developed technology has been in use for 40 years in 27 countries worldwide [102].

In another area of AI application, a University of Newcastle team is researching crowd movements, specifically pedestrian flows, and is including insights into a statistical model which can simulate the movements of crowds [103]. These insights and models could be used to improve public safety as well as building use via improved design of urban and architectural space. PSMA Australia is leveraging satellite imagery, big data and artificial intelligence technologies to create a digital representation of Australia's built environment (mapping buildings, solar panels, swimming pools, tree heights and other features) [104].

Perth is currently undergoing a trial of on-demand automated cars, with the Western Australia government partnering with the Royal Automotive Club and French company NAVYA [105]. Rio Tinto is also leading the way in developing an automated train consisting of three locomotives capable of carrying approximately 28,000 tonnes of iron ore over 280 kilometres [106].

Emesent, a spin out from CSIRO's Data61, has developed an AI-driven LIDAR system, which is mounted to a drone to quickly produce 3D maps of assets, offering better and faster 3D modelling for construction, maintenance and mining applications. The system is capable of navigating complex
GPS-denied underground mines and tunnels while creating three dimensional maps, or can be sent to map physical assets such as towers, limiting the need for humans to perform these tasks, which are often risky or time consuming [107].

8.2.3 Opportunities to Export

Analysis by AlphaBeta advisors indicates data-driven urban management will become a $20 billion to $30 billion global market by 2028 (with $5 billion to $10 billion in Asia-Pacific), while the market for cyber-physical security is likely to generate global revenue of $30 billion to $40 billion and Asia-Pacific market revenue of $10 billion to $15 billion [70].

Increasing rates of urbanisation, growing populations, limited resources and digital connectedness of critical infrastructure systems is a global phenomenon. By 2050 the global population will reach 9.8 billion with two-thirds living in cities [108] and almost 52% of the world's people will live in water-stressed areas [109]. By 2040 energy consumption will increase by almost 50% [110].

By 2030 it is expected the world will have 43 megacities with more than 10 million inhabitants [111]. In Asia alone, more than 600 million additional people are expected to move to cities by 2030 [112]. By 2020 it is estimated 20 to 30 billion objects will be connected to the internet-of-things requiring enhanced cyber-physical security solutions. According to the World Bank, global infrastructure spending needs to reach US$97 trillion by 2040 and current predictions identify a shortfall of US$19 trillion [113].

Worldwide the automated vehicle market is expected to be worth US$173.15 billion by the year 2030.

Worldwide the automated vehicle market is expected to be worth US$173.15 billion by the year 2030 [98, 114]. Whilst counties such as South Korea, Germany and the United States are taking the lead in the design and manufacturing of automated cars there is much opportunity for Australia. This is a huge and diverse marketplace with countless niches and satellite industries which go beyond just making automated cars. For example, vehicle-to-vehicle and vehicle-to-infrastructure communication is an important niche within the automated car sector which Australia could fill.

The rapid rate of urbanisation across the globe combined with the increased human mobility and the digital connectivity of city infrastructure will be associated with strong demand for AI solutions.

8.3 AI for Better Natural Resource Management

This specialisation involves the use of AI technologies to improve the economic efficiency and decrease the ecological footprint of agriculture, mining and environmental management. For agriculture this could involve on-farm robotics for harvesting, seeding, soil tillage, crop monitoring, weed removal, pest removal and chemical treatment (fertilisers, herbicides and pesticides).

AI enabled information tools and robotics could be used for more precise agricultural operations to enhance the productivity, resilience and environmental performance of farms. Automated mine site operations including haulage, extraction, processing, digging and drilling may use robotics and a range of related AI technologies. Computer vision and automated systems could be used for monitoring and improving the safety of minesite operations. Enhanced mineral discovery will be possible using machine learning and computer vision techniques to process remote sensing imagery and geological data. Within the environmental management sphere, improved weather and climate forecasting systems which use machine learning and data science approaches could more accurately predict temporal and spatial weather patterns. AI will also allow enhanced systems for monitoring the condition of biodiversity and ecological assets and robotic systems for predicting, detecting and physically managing threats.

8.3.1 Problems to Solve

One of the challenges (and opportunities) already facing Australian agriculture is its shrinking and ageing workforce. The median age of the Australian farmer is 56 years, which is up from 54 years a decade ago, and 17 years above the average worker age of 39 years [115]. The agricultural workforce has shrunk by 23,000 workers in the last decade from 356,000 persons in 2008 to 333,000 persons in 2018 [116]. Over the longer term it shows a declining trend. A smaller workforce requires increased productivity per worker. AI enablement can help. For example, robotic harvesting, seeding and weed removal devices can reduce the workload for human farmers. Robotics can remove many of the hard manual on-farm tasks. This can allow continued growth in agricultural production despite a declining and ageing workforce.

In addition to a shrinking workforce, rural industries are confronted with a cost price-squeeze. Also known as the declining terms of trade, this is a well-known challenge for Australian farmers. It relates to the prices of inputs (such as fuel, machinery, fertiliser) growing faster than the prices received for outputs (the food and fibre they sell). The Australian Bureau of Agricultural and Resource Economics and Sciences notes over the past 40 years farmers have faced a general decline in their terms of trade [117], which is likely to continue. To stay profitable, farmers need to boost productivity and/or reduce costs. AI enablement via information tools, precision agriculture, robotics and other technologies allows for more efficient and less labour intensive farming models. It can help Australian farmers beat the cost-price squeeze. Australian agriculture will also benefit from AI enabled logistical efficiency. Many agricultural supply chains are relatively inefficient due to relatively low volumes and high transport distances.

Drought will be a challenge for future farmers. According to the Bureau of Meteorology, 2018 was the third hottest year on record, and rainfall was approximately 11% below average with significant agricultural areas experiencing severe drought conditions [118]. Long range climate forecasts suggest Australia will become hotter and drier with more extremes. AI technologies will improve weather forecasts and climate adaptation via more controlled and precise farming systems. Advanced irrigation systems can improve the timing and location of crop and pasture watering. AI may also help crop geneticists identify strains of wheat and other species that are drought resistant.

Many species of pest animal and weed have become partially or fully resistant to pesticides and herbicides. This means spraying is ineffective. For example, the Grains Research and Development Corporation recently found “Australia has the second highest number of herbicide-resistant weeds in the world—sitting only just behind the United States [and that] twenty-five weed species have been confirmed resistant to one or more herbicides across Australia’s cropping regions” [119]. This is a significant problem for farmers who have previously relied on chemical treatment.

In mining there’s an opportunity to reduce production costs via automation and AI technologies. The Australian Government Resources 2030 Taskforce report [120] outlines how multiple technologies (including automation) can be used to improve productivity and safety, while maintaining environmental and labour practices. The taskforce report notes that data science and predictive technologies will play an increasingly important role in Australian mining. AI technologies could also assist mine restoration activities once mining operations cease.

Another challenge is the discovery of new mineral resources. Australian mineral ore grades are in gradual and permanent decline [121]. For example, the gold ore grade in Australia has fallen from around 30 grams per tonne in the late 1800s, to around 3 grams per tonne today [121]. Discovery of economically viable new mineral deposits is becoming more difficult. Data from MinEX [122] consulting show that discovery costs for major metals such as gold, nickel, zinc, lead and copper have all been increasing over the past 20 years and are forecast to continue rising. Finding ways to explore and discover minerals at lower costs is an important priority for the mining sector. Machine learning techniques will play an increasingly important role in discovering harder-to-find mineral deposits [123].

Within all primary industries there is an imperative to improve worker safety. According to Safe Work Australia [124] the accident fatality rate for workers in agriculture, forestry and fishing industries in Australia is the highest of all our 19 industries at 16.9 fatalities per 100,000 workers (averaged over the ten year period leading up to 2016). The mining industry has the third highest fatality rate (after transport, postal and warehousing) of four fatalities per 100,000 workers. The national average across all industries is 2.1 fatalities per 100,000 workers. Our primary industries have much higher fatality rates. There is an urgent need to reduce these fatality rates. AI has an important role to play. It can upgrade onsite safety via automated risk detection and management. AI can also remove people from hazardous environments.

In terms of our biodiversity and ecosystem assets we face some intense pressures to protect and conserve. Australia has 426 animal species and 1,339 plants currently threatened under the Environment Protection and Biodiversity Conservation Act 1999 [125]. Deforestation across Australia is a major contributor to biodiversity declines. In 2015/16 Australia was one of the world's top 10 countries in terms of deforestation – and almost 50% of Australian forests and woodlands have been cleared since European settlement [126]. The Great Barrier Reef is a national icon under threat. According to the Australian Institute of Marine Science (AIMS) coral cover on the central GBR declined from 22% in 2016 to 14% in 2018 with coral bleaching and crown of thorns starfish being the culprits [127].
The Queensland University of Technology's COTSbot is an example of an AI technology already being used to protect the reef. This mobile aquatic device uses computer vision, machine learning and advanced robotics to autonomously detect and remove the crown-of-thorns starfish. Other such AI technologies are likely to be developed and applied to protect the reef.

8.3.2 Australian Capabilities

We found considerable expertise, arguably at the forefront of the world, within Australia relating to agriculture, mining and environmental management AI technologies. One of the world's leading agricultural robots is AgBot II developed by the Queensland University of Technology. Fully designed and developed by Australian researchers, AgBot II is a solar powered robotic device which can (a) detect and mechanically remove weeds; (b) apply fertilisers and chemical treatments; and (c) gather detailed information about growing conditions and crop vitality. There is a comprehensive body of AI research behind AgBot II which has been published in international research journals [128, 129]. The QUT Robotics and Autonomous Systems Group is a large team of researchers, academics and students located in Brisbane.

The Australian Centre for Field Robotics (ACFR) at the University of Sydney is one of the largest robotics centres in the world.

The Australian Centre for Field Robotics (ACFR) at the University of Sydney is one of the largest robotics centres in the world. The ACFR "focuses on the research, development and application of autonomous and intelligent robots, and systems for use in outdoor environments" [130]. The technologies developed by ACFR are in four core areas (1) sensors, fusion and perception (2) movement, control and decisions (3) modelling, learning and adapting and (4) architectures, systems and cooperation of robotics and intelligent systems [130]. The ACFR is housed within the Faculty of Engineering and Information Technologies at the University of Sydney.

CSIRO, Australia's national science agency, has a long history of developing autonomous systems to improve the safety and efficiency of all aspects of mining and minerals discovery. For example, the majority of new underground coal mines in Australia use the longwall automation technology developed by CSIRO's Data61 which improves safety and productivity. This world leading technology has been licenced by five global mining companies. Other AI related mining technologies developed by CSIRO include tracking systems for underground mines, wearable technology to give remote mineworkers expert/visual guidance on complex tasks and continuous miner navigation systems.

Large Australian based mining companies such as Rio Tinto, BHP, Fortescue Metals and others are already at the forefront globally in developing and applying automated minesite technology.

Mining operations in the Pilbara region of Western Australia are amongst the world's most automated. Within this region Fortescue operates 112 driverless trucks with a reported 30% productivity gain [131]. Australian mining company BHP has 50 autonomous trucks at its Jimblebar site and 20 autonomous drills in Western Australia [131]. Launched in 2008 Rio Tinto's mine-of-the-future has 140 automated trucks, over 11 automated drills and 60% of train kilometres are in autonomous mode [132].

Case Study – Orefox

Emerging companies in Australia are at the forefront of global efforts to use machine learning and related AI technologies to bring down the costs of minerals exploration. Orefox is a Brisbane-based technology company using machine learning and artificial intelligence to analyse large amounts of geophysical data and discover mineral deposits [4].

Orefox have gone to market with their proprietary AI-enabled mineral exploration system that has been trained on economic gold deposits. The Queensland University of Technology, ESRI and Unearthed are shareholders, sponsors and supporters of Orefox.

8.3.3 Opportunities to Export

Across the world and especially within the Asia-Pacific region agricultural production is expanding to meet demand. The global food system will be expected to increase production by as much as 35% by 2030 from a 2015 baseline [133]. Furthermore, the global food production system is challenged with climate variability, water availability, land availability, crop disease, livestock disease and herbicide/pesticide resistance. AI-enabled systems will play a critical role in allowing the world to produce more food and fibre within tighter environmental constraints. This means a growth in demand for agricultural robotics, precision agriculture systems, data driven farming methods and a wide range of AI-enabled agricultural technologies. Australian companies developing these technologies are likely to find large marketplaces.

The global food system will be expected to increase production by as much as 35% by 2030 from a 2015 baseline.

Australia's mining engineering technology and services (METS) sector has already grown substantially. This sector is increasingly developing AI-related mining industry products. According to industry body Austmine, the Australian METS sector generates $90 billion in revenue, employs 400,000 people, and exports to more than 200 countries [134]. The coming decade is likely to see the continued development of high quality mineral ore deposits in Africa, Asia and South America. The new mining operations are likely to use AI in mineral exploration and operational phases of development. There will be vast opportunities to grow exports of Australian mining AI to the world.

Biodiversity loss, climate change and other environmental problems are escalating across the globe. As the newly industrialised countries (particularly in Asia), become wealthy they are actively looking for ways to manage the environmental impacts of rapid industrialisation. China, for example, has a commitment to improving air quality in cities and regions. China's air pollution action plan is targeting a 33% improvement in air quality in Beijing by 2020 [135]. Right across the Asia-Pacific we are seeing a rapid and sizeable introduction of biodiversity and environmental conservation programs. The implementation of these programs will be aided by AI technology. Australia is well placed to develop these AI technologies and sell the solutions into global markets.

9 Foundations for the Future

For Australia to take full advantage of the potential benefits of AI technologies it will be critical to build the right environment for effective adoption, adaptation and development. Actions are required to remove barriers and capture opportunities for growth. These actions are relevant for government, industry and community organisations.

9.1 Developing an AI Specialist Workforce

In preparing this report, we analysed over 4 million Australian job advertisements since 2014 of which 5,200 were classified as being closely related to AI. We crossed referenced this data with other datasets to forecast trends in Australia's emerging AI workforce. We found that Australia currently has 6,600 AI specialist workers. This is up from 650 AI workers in 2014 and future growth is expected. We estimate that by 2030 Australian industry will require a workforce of between 32,000 to 161,000 employees in computer vision, robotics, human language technologies, data science and other areas of AI expertise. There is a wide range of future possibilities due to uncertainty about the extent of scientific advances and the extent of technology adoption by industry.

In addition to overall growth Australia's AI workforce is likely to become more geographically dispersed. In 2015 we estimate that 89% of AI jobs were in Sydney and Melbourne. However, by 2018 the share of Sydney and Melbourne AI jobs had fallen to 75% of the total as Brisbane, Canberra, Adelaide and Perth grew their relative shares. Some regional areas such as Ballarat, outback South Australia and the NSW Central Coast also saw strong growth in AI Workers. This is likely to continue. There will be substantial job opportunities for Australian AI workers in both capital cities and regional areas by the year 2030.

The new AI workforce is needed to meet the operational requirements of industry. Already supply is failing to meet demand. For example, Australia had an estimated 301,000 data scientists in 2017 and that figure is expected to grow by 2.4% each year until 2022. This contrasts with average annual job growth for the entire labour force of 1.5%. Data science workers with postgraduate IT qualifications are expected to see average annual salaries rise from approximately $111,634 to $130,176 in this period [136].

Australia had an estimated 301,000 data scientists in 2017 and that figure is expected to grow by 2.4% each year until 2022.

Advanced mathematics and computational logic are core skills required within AI. The evidence from education research suggests we need to build these skills early. For example, a longitudinal study [137] of 1,364 children in the United States by Researchers at the University of California–Irvine found that mathematical skills at age 4.5 years accurately predicts mathematics achievement at age 15 years. The study also found improvement in mathematical skills from kindergarten to first-year was an even better predictor of adolescent mathematics capability. This and other similar studies [138] provide strong evidence for improving the quality of mathematics knowledge and skills in kindergarten, prep and junior school in Australia.

Of importance are skills in advanced mathematics which are needed for AI development and application. However, data from the Programme for International Student Assessment (PISA) published by the Australian Council for Educational Research (ACER) shows that Australia's relative ranking in mathematics skills, compared to other countries, has been declining since the year 2003. According to ACER the PISA survey is an assessment of the ability of 15 year-olds to use mathematics skills to meet real life challenges [139]. Given that mathematics is a foundational skill for AI, this trend is of concern.

Overall, Australia needs to train and educate an entire new AI specialist workforce to meet the current and future operational needs of industry. Schools, universities, technical colleges and private training providers will all play a role in developing these skills. The training imperative relates to young and old workers at all stages of learning. This will require a mix of strategies catering to the unique needs of individuals.

Australia's ICT Workforce

According to a recent study by Deloitte Access Economics and the Australian Computer Society [3] the entire information, communications and technology (ICT) sector workforce – which is closely aligned to the AI workforce – contained 663,100 workers in year 2018. This is up 3.5% or an additional 22,300 workers from the previous year.

Demand for ICT workers is forecast to grow to a total of 758,700 workers by 2023 at a rate of 20,000 additional workers per year. This represents a challenge for Australia.

Australia produces only 5,000 domestic ICT university graduates per year. Whilst not the full supply of ICT skilled workers this falls well short of industry demand.

However, the prospects for developing AI specialist skills are good. Our analysis found that within Australia's ICT workforce there are approximately 500,000 workers who have the right foundational skills and aptitudes to specialise in AI.
This includes around 470,000 people already working in the top ten AI-relevant occupations such as software programming, computer networking, web development and ICT management [10], prime candidates for upskilling in AI.

9.2 Career Transitions and Skills Upgrades

Most Australian workers won't need to develop AI specialist skills; however, their jobs are likely to be impacted in some way by AI and related digital technologies. According to a recent report from the World Economic Forum [140] AI will displace 75 million jobs and create 133 million new jobs leading to a net increase of 58 million new jobs by the year 2022 in the world economy.

This is creating a career retraining and transition imperative. A recent study by Google and consulting firm AlphaBeta [141] found Australian workers will, on average, need to increase time spent learning new skills by 33% over their lifetime and that job tasks will change 18% per decade. The need to upskill is primarily because digital technology (including AI) will shift the workforce skills demand profile. Some of the new skills needed will be of a technical nature. However, as AI uptake increases there will be considerable emphasis on human skills such as creativity, judgement, reasoning, communication and emotional intelligence.

Australian workers will, on average, need to increase time spent learning new skills by 33% over their lifetime and that job tasks will change 18% per decade.

Whilst previous generations needed literacy and numeracy to get practically any type of job, future workers will also need digital literacy. Digital literacy implies an ability to interact with, and effectively use, advanced information and communication technologies. However, these three capabilities of literacy, numeracy and digital literacy won't be enough for most workers. To get the right job in the right place with the right salary and good career prospects people will need
well-rounded skills and well-rounded knowledge.

For example, a study by researchers at Harvard University [142] found that between 1980 to 2012 jobs involving high levels of social interaction increased by 12%. In contrast they found that math-intensive but less social jobs shrank by 3.3%. Although relating to a dataset over seven years old this study does show the importance of softer skills alongside pure mathematics and/or technical skills. Another study by researchers at Indiana University in the United States found that "in an increasingly data-driven economy, the demand for soft social skills, like teamwork and communication, increase with greater demand for hard technical skills and tools" [143].

Overall digitisation and automation of tasks will require workers to transition their careers from lower-demand areas to higher-demand areas. Individual workers, governments and companies can take actions – such as retraining, upskilling and reskilling – to make earlier (and better) career transitions. There will be a mix of technical and human/social skills and knowledge needed by employers. Technical skills on their own may not be enough to get a desired job.

Workforce upskilling – Micro-credentialing

One of the strategies helping existing workers acquire critical skills for the future is micro-credentialing. A growing number of Australian universities are offering micro-credentials to provide workers with digital skills via short, sharp and highly targeted training programs.

For example, with campuses in Sydney, Brisbane, Melbourne, the Blue Mountains, Adelaide and Auckland, Torrens University is partnering with IBM to deliver both degree programs and micro-credentials in cloud computing, big data and AI [5].

In another example the University of New England in Armidale is offering bespoke courses which allow students to choose specific subjects they need to acquire specific skills and knowledge relevant to their career trajectories. Many of the bespoke courses are in areas relevant to data science and AI [8].

9.3 Data Governance and Access

In most applications, AI depends on large, detailed and diverse datasets. Machine learning applications often need a "training dataset" which allows the algorithm to be designed, tested and improved before being applied in the real world. Access to training datasets has become one of the most critical and complex stages of AI development.

For example, Google company DeepMind started working with the United Kingdom Royal Free Hospital in 2016 to detect and diagnose acute kidney injuries (AKI) with machine learning techniques [144]. The main challenge for this life-saving technology was not designing the machine learning algorithms; the main challenge was handling 1.6 million detailed patient medical records with sufficient levels of privacy protection. The United Kingdom Information Commission (ICO) identified some concerns relating to patient awareness and consent about how their private data was being used [145]. Development of these technologies will depend on all parties involved resolving the legal, ethical and practical challenges of data access. A large number of highly beneficial, and life-saving, AI applications in health, transport, law enforcement and other sectors hinge upon data governance.

Better access to high quality, labelled datasets will improve the training ground for AI systems. There are already substantial open data and related initiatives happening in Australia, examples include data.gov.au and the Australian National Data Service, but more can be done. AI developers also need certainty and guidance around what represents ethical and acceptable use of private data. This requires attention to "data creep"; the gradual increase in the comprehensiveness and granularity of data held by organisations about people which, when cross-referenced to other data, provides even more detailed personal insights. Organisations will increasingly be challenged with achieving data integrity whereby people's private and confidential information is properly protected and managed. Issues related to the ethical handling of data within the context of AI are covered in more detail in the AI ethics framework [146].

9.4 Building Trust in AI

Trust will be essential to achieve widespread adoption of AI and this has been the focus of the Australian Government's AI Ethics Framework released in 2019 for public consultation.

Three main issues have been identified which make trust important for AI adoption. Firstly, an AI system typically involves the surrender of some level of human control to a machine. The user needs to trust that the AI will do the task at least as well as, if not better than, a human in terms of safety, efficiency and overall quality. Secondly, many AI systems acquire, analyse, transmit and store private and confidential data. The user needs to trust the AI system won't inappropriately divulge or delete personal information. Thirdly, due to the complexity of its internal workings AI is often a black-box to users; people can't easily know how advanced AI is working. The user will need to trust that the AI product is doing what it is supposed to do; they won't be able to see or verify its operations. These three factors mean that AI developers have a significant trust hurdle to clear, including perceived risk, before consumers use (and buy) their products.

For example, the driver of an automated vehicle needs considerable trust before surrendering control to the machine. So too do the traffic authorities. People are likely to insist upon higher standards of comfort and safety performance for automated cars compared to human driven cars. A survey conducted by the American Automobile Association [147] shortly after the fatal Uber automated car incident in March 2018 found that trust in automated cars is declining (not increasing).
The survey found that 64 percent of millennials would not ride in a self-driving car; up from 49 percent previously. Older generations are even more distrustful with 71 percent of baby-boomers and 68 percent of generation-x indicating they did not feel safe in an automated car. Widespread adoption of automated vehicles won't happen until people trust the products.

Researchers from Zeppelin University in Germany studied how people develop trust in AI within transport and healthcare settings [148]. They used a case study approach which examined the Daimler Future Trucks 2025 project, BMW automated cars, the use of IBM's Watson in healthcare settings, the Care-O-bot robotic device developed by the Fraunhoffer Institute to care for the elderly in their homes and several other AI products. The researchers find that trust needs to be achieved by the AI developer in two ways: (a) trust in the technology and (b) trust in the company. Trust in the technology comes from building effective user interfaces, product manuals, scientific data, technical explanations, scientific reviews and visible trials. Trust in the company comes from the company's track record of prior success and failure with AI products which builds a reputation over time. Trust in the company also comes from their overall level of transparency.

9.5 Science, Research and Technology Development

As a new and emerging field of science and technology both pure and applied R&D is needed to unlock the benefits of AI for Australia. Many proposed AI systems represent early stage ideas or theories about what may be possible. However, they cannot be safely or effectively applied in the real world because we lack sufficient knowledge to make them work properly. For example, if we are to achieve level five automated cars (i.e. fully automated in all conditions) we need scientific breakthroughs in computer vision and machine learning which have not yet happened. Such breakthroughs depend on pure theoretical research in mathematics, physics and other scientific fields.

We will also need applied R&D to identify how to implement many off-the-shelf AI products within the context of existing supply chains or business processes. That's because a novel AI system may involve a very different way of doing business. For many companies AI is an unknown quantity offering substantial opportunity but also risk. Implementation of AI systems typically requires an intensive process of trial and error involving applied R&D to determine what works and what does not work. In all areas of application R&D will allow us to conceive, design, build and test experimental AI systems in novel contexts.

R&D can be viewed as a pipeline of future opportunity for the Australian economy.

The most recent OECD data shows Australia spent 1.9% of GDP on all types of R&D compared to the OECD average at 2.4% and China at 2.1% [149]. In the fiscal year ending June 2016 all of Australia's businesses combined spent $16.7 billion on all types of R&D [150]. However, companies such as Amazon ($31 billion/yr), Alphabet (Google) ($22 billion/yr), Intel ($17 billion/yr) and Microsoft ($17 billion/yr) [151] are spending heavily on R&D; much of which is AI related. Alibaba, Tencent and Baidu from China are also making large AI R&D investments as are many companies worldwide.

The investments being made by these companies fund deep, blue-sky and discovery science in addition to applied research. These, and other such, companies will use their advanced AI technologies to compete with Australian companies at home and abroad. Many sectors of the Australian economy will need to put more into the research and development pipeline today to stay competitive by the year 2030. We'll need R&D to unlock the value of this highly complex, novel and uncertain technological capability.

9.6 Digital Infrastructure and Cybersecurity

Digital infrastructure is needed for the acquisition, transmission, storage and analysis of data. AI won't work, and can't be developed, where there's insufficient digital infrastructure. This includes a requirement for access to secure high performance computing and the development of sensory systems in addition to fast internet connectivity. For example, the development and application of agricultural robotics will be limited in rural areas without sufficient connectivity. Due to the vast areas of remote land with low population density Australia is challenged with ensuring cost effective high speed internet across the entire continent. As part of AI enablement, we will need to target digital infrastructure upgrades to geographic regions and industry sectors where needed.

The Australian Government Department of Communication and the Arts administers the Mobile Black Spot Program and the Regional Connectivity Program which provide funding to improve telecommunications across Australia. The Mobile Black Spot Program is investing in mobile telecommunications infrastructure to improve mobile coverage; especially along major regional transport routes and in small communities. The Regional Connectivity Program is being developed to target investment in a range of technologies to maximise economic opportunities and region-wide benefits for regional, rural and remote Australians. These and other such programs will help develop digital infrastructure vital for the AI enablement of the Australian economy.

Another critical requirement for AI enablement relates to cybersecurity. The shift from human controlled to AI systems is associated with an increased cybersecurity hazard. AI will also be used by cybercriminals to create new forms of risk and vulnerability. Achieving higher levels of cybersecurity, and developing entirely new systems of cybersecurity, will be vital for achieving AI enablement of the Australian economy.

9.7 Standards, Interoperability and Ethics

The rise of AI will require new standards relating to AI system performance, safety, levels of transparency and explainability, autonomy, privacy, interoperability, data security, data acquisition, data ownership, data quality, data formats and data storage. The International Standards Organisation (ISO), the American National Standards Institute (ANSI) and Standards Australia (SA) are actively working in this area. Standards and system validation will be important ways for developing improved trust which will be vital for achieving widespread adoption of AI. In addition to standards is the issue of ethical application. AI represents an opportunity for improved fairness, transparency, equality of opportunity and overall ethical outcomes. However, it is a powerful technology and comes with risks for negative outcomes. An AI Ethics discussion paper [146] accompanies this document. It provides a set of principles and tools for ethical AI supported by numerous case studies.

10 Conclusion

Humanity is in the process of building machines which have the ability to learn themselves without explicit human guidance.
AI is already coding its own AI. We are witnessing the convergence of powerful technologies with unknown future possibilities. That's why the world is waking up to AI and that's why this document has been written. The ability of the machine to learn represents a new way to solve our most challenging problems. This can boost the productivity of Australian industry and improve the quality of life enjoyed by current and future generations of Australians.

11 References

1. Eggleton, M. 2019. The megatrends shaping our future (28 May). The Australian Financial Review. Sydney.

2. Pope, N. 2018. Technology improves independence for people with disability. Disability Support Guide. Adelaide.

3. Deloitte Access Economics. 2018. Australia's digital pulse: Driving Australia's international ICT competitiveness and digital growth. Australian Computer Society. Sydney, Australia.

4. OreFox. OreFox Company Website accessed on 1 Feb 2019. Orefox Pty Ltd. Brisbane, Australia.

5. Torrens University. 2019. Partnership with IBM. Torrens University Australia (Website https://www.torrens.edu.au/about/partnerships/ibm). Sydney.

6. RMIT. 2018. Computers use social media data to predict crime. RMIT University. Melbourne.

7. Garnsey, E. and P. Heffernan. 2005. High-technology clustering through spin-out and attraction: The Cambridge case. Regional Studies 39(8):1127-1144.

8. UNE. 2019. Study just the parts of a degree you need - UNE New Bespoke Courses. University of New England (Website: www.une.edu.au/bespokecourses). Armidale, New South Wales.

9. Naughton, J. 2013. They call it Silicon Fen. So what is the special draw of Cambridge? (1 December). The Gaurdian Newspaper. Sydney.

10. ABS. 2018. Labour force, Australia (Catalogue Number 6202.0). Australian Bureau of Statistics. Canberra.

11. PwC. 2019. Sizing the prize: PwC's Global Artificial Intelligence Study: Exploiting the AI Revolution. Price Waterhouse Coopers. London.

12. Vision2020. 2019. A snapshot of blindness and low vision services in Australia. Vision 2020 - The Right to Sight Australia. Melbourne.

13. AIHW. 2018. Older Australia at a glance. Australian Institute of Health and Welfare. Canberra.

14. QUT. 2019. AgBot II Robotic Site-specific Crop and Weed Management Tool. Queensland University of Technology (Website accessed 10 Sept 2019). Brisbane.

15. Robinson, J. and P. Thorn. 2018. Do chatbots have a role to play in suicide prevention? The Conversation (24 October). Australia.

16. AIHW. 2016. Skin Cancer in Australia. Australian Institute of Health and Welfare. Canberra.

17. Esteva, A., B. Kuprel, R.A. Novoa, J. Ko, S.M. Swetter, H.M. Blau, and S. Thrun. 2017. Dermatologist-level classification of skin cancer with deep neural networks. Nature 542:115.

18. AlphaBeta. 2018. Digital innovation: Australia's $315B opportunity. AlphaBeta. Sydney.

19. Sentance, R. 2018. The future of voice search: 2020 and beyond. Econsultancy. London, United Kingdom.

20. Olson, C. 2016. Just say it: The future of search is voice and personal digital assistants. Campaign. London, United Kingdom.

21. Ballard, D. and C. Brown. 1982. Computer Vision. Prentice-Hall. Edgewood Cliffs, New Jersey.

22. Goodfellow, I.J., J. Pouget-Abadie, M. Mirza, B. Xu, D. Warde-Farley, S. Ozair, A.C. Courville, and Y. Bengio. 2014. Generative adversarial nets. Advances in Neural Information Processing Systems:2672-2680.

23. Kubota, T. 2017. Stanford algorithm can diagnose pneumonia better than radiologists. Stanford News. United States.

24. Nau, D., M. Ghallab, and P. Traverso. 2004. Automated planning: Theory and practice. Cambridge University Press. United Kingdom.

25. Jiménez, S., T.D.L. Rosa, S. Fernández, F. Fernández, and D. Borrajo. 2012. Review: A review of machine learning for automated planning. The Knowledge Engineering Review 27(4):433-467.

26. Walker, M.A., D.J. Litman, C.A. Kamm, and A. Abella. 1997. Evaluating interactive dialogue systems: Extending component evaluation to integrated system evaluation. Interactive Spoken Dialog Systems on Bringing Speech and NLP Together in Real Applications:1-8.

27. Martins, R. and F. Meneguzzi. 2014. A smart home model using JaCaMo framework. 12th IEEE International Conference on Industrial Informatics:94-99.

28. Tyran, C.K. and J.F. George. 1993. The implementation of expert systems: a survey of successful implementations. ACM SIGMIS Database: The DATABASE for Advances in Information Systems 24(1):5-15.

29. Neelakantan, A. 2017. Knowledge representation and reasoning with deep neural networks. Doctoral Dissertation. University of Massachusetts Amherst.

30. Schmidt, E. and J. Rosenberg. 2014. How Google Works. Grand Central Publishing. New York City.

31. Treasury. 2015. Intergenerational Report: Australia 2055. Commonwealth of Australia. Canberra.

32. DIIS. 2018. Industry insights: Future productivity. Office of the Chief Economist, Department of Industry, Innovation and Science, Australian Government. Canberra.

33. Organisation for Economic Co-operation and Development. 2018. Main science and technology indicators, Volume 2018 Issue 1. Paris.

34. Gurría, A. 2016. Launch of the OECD economic outlook, June 2016. Organisation for Economic Cooperation and Development. Paris.

35. Jones, C.I., P. Aghion, and B.F. Jones. 2017. Artificial intelligence and economic growth. Stanford Insititute for Economic Policy Research. U.S.A.

36. Purdy, M. and P. Daugherty. 2016. Country spotlights: Why artificial intelligence is the future of growth. Accenture. Dublin, Ireland.

37. McKinsey. 2017. Digital Australia: Seizing the opportunity from the Fourth Industrial Revolution. McKinsey and Company. Sydney.

38. AlphaBeta. 2019. Australia's digital opportunity - Growing a $122 billion a year tech industry. Consulting report prepared for DIGI (www.digi.org.au) by AlphaBeta. Sydney.

39. OECD. 2019. Recommendation of the Council on Artificial Intelligence (5 May). Organisation for Economic Cooperation and Development Legal Instruments. Paris.

40. Treasury. 2018. Budget Strategy and Outlook 2018/19. Budget Paper Number #1. Australian Government. Canberra.

41. CSIRO. 2018. CSIRO invests $35M in future of space and AI for Australia. Media Release 19 November. CSIRO. Canberra.

42. UoA. 2017. New research institute for machine learning (9 December, Media Release on Website). University of Adelaide. Australia.

43. ARC. 2019. Grant Outcomes dataset. Australian Research Council (Website). Canberra.

44. QUT. 2014. New centre will give robots the gift of sight (Media Release 18 March). Queensland University of Technology. Brisbane.

45. DIIS. 2019. Stocktake of Australian Innovation Precincts – Including collaboration networks, university precincts and industry clusters. Australian Government Department of Innovation Industry and Science. Canberra.

46. DIIS. 2018. Statement of Principles for Australian Innovation Precincts: Place-Based Partnerships Building on Competitive Strengths. Australian Government Department of Industry Innovation and Science. Canberra.

47. Startup Muster. 2018. Startup Muster 2018 annual report. Sydney.

48. Startup Muster. 2017. Startup Muster 2017 annual report. Sydney.

49. Business. 2019. Grants, assistance & other support - Small and Medium Enterprises (SME) Export Hubs. Australian Government (business.gov.au). Canberra.

50. Pianta, M. and V. Meliciani. 1996. Technological specialization and economic performance in oecd countries. Technology Analysis & Strategic Management 8(2):157-174.

51. Jungmittag, A. 2004. Innovations, technological specialisation and economic growth in the EU. International Economics and Economic Policy 1(2):247-273.

52. Archibugi, D. and M. Pianta. 1992. The technological specialisation of advanced countries: A Report to the EEC on international science and technology activities. Springer Science and Business Media. London.

53. Evangelista, R., V. Meliciani, and A. Vezzani. 2018. Specialisation in key enabling technologies and regional growth in Europe. Economics of Innovation and New Technology 27(3):273-289.

54. OECD. 2013. Innovation-driven growth in regions: The role of smart specialisation.

55. ISA. 2017. Australia 2030: Prosperity through Innovation. Innovation and Science Australia (ISA), Australian Government. Canberra, Australia.

56. Mazzucato, M. 2018. Mission-oriented innovation policies: challenges and opportunities. Industrial and Corporate Change 27(5):803-815.

57. IIPP. 2019. A Mission-Oriented UK Industrial Strategy: UCL Commission for Mission-Oriented Innovation and Industrial Strategy. Institute for Innovation and Public Purpose. London.

58. Paulus-Rohmer, D., H. Schatton, and T. Bauernhansl. 2016. Ecosystems, Strategy and Business Models in the age of Digitization - How the Manufacturing Industry is Going to Change its Logic. Procedia CIRP 57:8-13.

59. Clarysse, B., M. Wright, J. Bruneel, and A. Mahajan. 2014. Creating value in ecosystems: Crossing the chasm between knowledge and business ecosystems. Research Policy 43(7):1164-1176.

60. Tsujimoto, M., Y. Kajikawa, J. Tomita, and Y. Matsumoto. 2018. A review of the ecosystem concept — Towards coherent ecosystem design. Technological Forecasting and Social Change 136:49-58.

61. Moore, J. 1993. Predators and Prey: A New Ecology of Competition. Harvard Business Review (May-June Issue). United States.

62. AIHW. 2017. Health expenditure australia. Australian Government - Institute of Health and Welfare. Canberra, Australia.

63. CSIRO. 2018. Future of Health: Shifting Australia’s focus from illness treatment to health and wellbeing management. CSIRO. Australia.

64. AIHW. 2018. Waiting times for emergency department and elective surgery on the risse. Australian Government Institute of Health and Welfare. Canberra.

65. Banger, M. 2019. Residential aged care wait time increases (22 January). The Australian Newspaper. Sydney.

66. AIHW. 2018. Australia’s health 2018 - rural and remote population. Australian Government - Institute of Health and Welfare.

67. AIHW. 2017. Rural and remote health. Australian Government Institute of Health and Welfare. Canberra.

68. Department of Health. 218. Ageing and aged care. Australian Government Department of Health.

69. AIHW. 2018. Australia’s health 2018: in brief. Australian Institute of Health and Welfare.

70. Alpha Beta. 2018. Digital Innovation - Australia’s $315b Opportunity. AlphaBeta. Sydney.

71. AIHW. 2018. Australia’s health 2018 in brief. Australian Government - Australian Institute of Health and Welfare. Canberra.

72. AIHW. 2018. Deaths in Australia. Australian Government - Institute of Health and Welfare.

73. Ong, J.M. and L. da Cruz. 2012. The bionic eye: a review. Clinical & Experimental Ophthalmology 40(1):6-17.

74. Johnston, M. 2018. Melbourne uni to lead medical AI research centre (10 October). IT News. Australia.

75. Deakin University. 2018. Applied Artificial Intelligence Institute. Deakin University.

76. Monash University. 2018. Multi Modal Medical AI. Monash University.

77. Palmer-Derrien, S. 2018. Medical AI startup secures $1.1 million government grant, to develop Alzheimer’s diagnosis tool with CSIRO. SmartCompany. Australia.

78. WHO. 2018. New Perspectives on Global Health Spending for Universal Health Coverage: Global report. World Health Organization. Geneva.

79. GMI. 2018. Digital health market size to exceed $379bn by 2024. Global Market Insights.

80. UN. 2017. The global guardian of public health. United Nations. New York.

81. BITRE. 2019. Road deaths Australia: December 2018. Australian Government Bureau of Infrastructure Transport and Regional Economies. Canberra.

82. AIHW. 2018. Injury – hospitalised injury due to land transport crashes. Australian Government Institute of Health and Welfare. Canberra.

83. DIRDC. 2018. Road Safety. Australian Government Department of Infrastructure, Regional Development and Cities. Canberra, Australia.

84. AAA. 2018. Road congestion in Australia. Australian Automobile Association (AAA). Canberra.

85. BITRE. 2015. Traffic and congestion cost trends for Australian capital cities. Bureau of Infrastructure, Transport and Regional Economies, Australian Government, Canberra. Australian Government – Department of Infrastructure, Regional Development and Cities.

86. Hubele, N. and K. Kennedy. 2018. Forward collision warning system impact. Traffic Injury Prevention:1-6.

87. Cicchino, J.B. 2017. Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. Accident Analysis & Prevention 99(1):142-152.

88. Patel, P. 2016. Pittsburgh's AI traffic signals will make driving less boring. IEEE Spectrum.

89. Blowers, D. 2018. Energy policy failure behind 10 year story of spiralling electricity bills. ABC

90. Finkel, A. 2017. Independent review into the future security of the National Electricity Market. Chief Scientist.

91. Zia, T. 2017. Australia's car industry needs cybersecurity rules to deal with the hacking threat. The Conversation.

92. Centre, A.C.S. 2017. 2017 threat report. Australian Government - Australian Cyber Security Centre.

93. Accenture Security. 2018. Gaining ground on the cyber attacker: 2018 state of cyber resilience.

94. ACIC. 2016. From state to federal to global crime issues. Australian Criminal Intelligence Commission.

95. Terrill, M. 2018. Cost overruns in transport infrastructure.

96. PC. 2014. Public Infrastructure Inquiry (Report Number 71) Volumes 1 and 2. Australian Government Productivity Commission. Canberra.

97. Bowditch, G. 2017. Re-establishing Australia's global infrastructure leadership. University of Sydney. Sydney, Australia.

98. ATIC. 2018. Connected and Automated Vehicles. Australian Trade and Investment Commission, Australian Government. Canberra.

99. Smith, J. 2018. Australia moves another step closer to driverless vehicles. Telstra Exchange. Sydney.

100. Cohda. 2019. Cohda chosen for new US connected car trial. Cohda Wireless Website (cohdawireless.com) Accessed on 17 April 2019. Adelaide.

101. Austrade. 2019. Case Study - Cohda Wireless beats GPS blackspots in New York City. Austrade Website (https://www.austrade.gov.au/future-transport/case-studies/cohda-wireless/). Canberra.

102. SCATS. 2019. Why choose the Sydney Coordinated Adaptive Traffic System? Sydney Coordinated Adaptive Traffic System Company Website and NSW Government Department of Transport Roads and Maratime Services. Sydney.

103. Arash Jalalian, S.C., Michael Ostwald. 2014. Simulating pedestrian flow dynamics for evaluating the design of urban and architectural space. University of Newcastle.

104. PSMA. 2017. Annual Report. PSMA Australia. Canberra.

105. Carmody, J. 2017. Uber-style driverless cars set for Perth as part of international trial (29 November). ABC News. Sydney.

106. Rio Tinto. 2018. How did the world's biggest robot end up here? Rio Tinto Website. Sydney.

107. CSIRO. 2016. Hovermap. CSIRO Website. Canberra.

108. FAO. 2017. The future of food and agriculture - trends and challenges. Food and Agriculture Organisation of the United Nations.

109. Roberts, A. 2014. Predicting the future of global water stress. Massachusetts Institute of Technology. Boston.

110. EIA. 2016. EIA projects 48% increase in world energy consumption by 2040. US Energy Information Administration.

111. UN. 2018. World Urbanisation Prospects. United Nations Development Program. New York, United States.

112. DFAT. 2017. Foreign policy white paper. Australian Government, Department of Foreign Affairs and Trade. Canberra, Australia.

113. Heathcote, C. 2017. Forecasting infrastructure investment needs for 50 countries, 7 sectors through 2040. The World Bank. Washington DC.

114. FS. 2018. Global Autonomous Driving Market Outlook. Frost and Sullivan. San Antonio, Texas, the United States.

115. Vidot, A. 2017. Farmers getting older as latest survey reveals average age is 56 (7 July). ABC Rural News. Sydney.

116. ABS. 2017. Australian Industry Catalogue Number 8155.0. Australian Bureau of Statistics. Canberra.

117. ABARES. 2017. Productivity matters for farm profit (ABARES website). Australian Government Department of Agriculture and Water Resources. Canberra.

118. Doyle, K. 2019. BOM declares 2018 Australia's third-hottest year on record (10 Jan). ABC News. Sydney.

119. Owen, M., C. Preston, and S. Walker. 2013. Resistance Rising Across Australia. GroundCover 104(1).

120. DIIS. 2018. Resources 2030 Taskforce Australian resources - providing prosperity for future generations. Department of Industry, Innovation and Science, Australian Government. Canberra.

121. Prior, T., D. Giurco, G. Mudd, L. Mason, and J. Behrisch. 2012. Resource depletion, peak minerals and the implications for sustainable resource management. Global Environmental Change 22(3):577-587.

122. Schodde, R. 2017. Long term trends in global exploration – are we finding enough metal? 11th Fennoscandian Exploration and Mining Conference 31st October, Levi, Finland. MinEx Consulting. Australia.

123. Rodriguez-Galiano, V., M. Sanchez-Castillo, M. Chica-Olmo, and M. Chica-Rivas. 2015. Machine learning predictive models for mineral prospectivity: An evaluation of neural networks, random forest, regression trees and support vector machines. Ore Geology Reviews 71:804-818.

124. SWA. 2016. Fatality statistics by industry. Safe Work Australia. Canberra.

125. Sydney Environmental Institute. 2018. Australia's biodiversity and climate change. University of Sydney. Sydney, Australia.

126. State of the Environment. 2016. Regional and landscape-scale pressures: Land clearing. Commonwealth of Australia. Canberra, Australia.

127. AIMS. 2018. Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18. Australian Institute of Marine Science. Townsville.

128. Bogue, R. 2016. Robots poised to revolutionise agriculture. Industrial Robot: the international journal of robotics research and application 43(5):450-456.

129. Hall, D., F. Dayoub, T. Perez, and C. McCool. 2018. A rapidly deployable classification system using visual data for the application of precision weed management. Computers and Electronics in Agriculture 148:107-120.

130. ACFR. 2019. Australian Centre for Field Robotics (Website Accessed 1 Feb 2019). University of Sydney. Sydney, Australia.

131. Gray, D. 2019. No one behind the wheel: The new workforce driving Australia's mines. Sydney Morning Herald (27 April). Sydney.

132. RioTinto. 2019. Mine of the future. Rio Tinto (Company Website Accessed on 13 Sept 2019). Australia.

133. Kray, H. 2015. Farming for the future: The environmental sustainabililty of agriculture in a changing world. World Bank Group. Washington, United States.

134. Austmine. 2019. Austmine company website accessed 1 Feb 2019. Austmine. Woolloomooloo, New South Wales, Australia.

135. Hao, F. 2018. China releases 2020 action plan for air pollution (6 July). China Dialogue. China.

136. Deloitte. 2018. The future of work: Occupational and education trends in data science in Australia. Deloitte. Sydney.

137. Watts, T.W., G.J. Duncan, R.S. Siegler, and P.E. Davis-Kean. 2014. What's Past Is Prologue: Relations Between Early Mathematics Knowledge and High School Achievement. Educational Researcher 43(7):352-360.

138. Ritchie, S.J. and T.C. Bates. 2013. Enduring Links From Childhood Mathematics and Reading Achievement to Adult Socioeconomic Status. Psychological Science 24(7):1301-1308.

139. ACER. 2019. The Programme for International Student Assessment (PISA): Australia versus the world. Australian Council for Educational Research (Website Accessed 13 August 2019). Sydney.

140. WEF. 2018. The future of jobs report. World Economic Forum. Geneva.

141. AlphaBeta. 2019. Future Skills - To adapt to the future of work, Australians will undertake a third more education and training and change what, when and how we learn. Prepared by AlphaBeta for Google Australia. Sydney.

142. Deming, D. 2017. The Growing Importance of Social Skills in the Labor Market. Quarterly Journal of Economics 132(4):1593-1640.

143. Börner, K., O. Scrivner, M. Gallant, S. Ma, X. Liu, K. Chewning, L. Wu, and J.A. Evans. 2018. Skill discrepancies between research, education, and jobs reveal the critical need to supply soft skills for the data economy. Proceedings of the National Academy of Sciences of the United States of America 115(50):12630-12637.

144. BBC. 2017. Google DeepMind NHS app test broke UK privacy law (3 July). British Broadcasting Corporation. United Kingdom.

145. ICO. 2017. Royal Free - Google DeepMind trial failed to comply with data protection law. Information Commissioner's Office. London.

146. Dawson, D., E. Schleiger, J. Horton, J. McLaughlin, C. Robinson, G. Quezada, J. Scowcroft, and S. Hajkowicz. 2019. Artificial Intelligence: Australia's Ethics Framework. Data61 CSIRO. Australia.

147. AAA. 2018. American Trust in Autonomous Vehicles Slips. American Automobile Association. Orlando.

148. Hengstler, M., E. Enkel, and S. Duelli. 2016. Applied artificial intelligence and trust—The case of autonomous vehicles and medical

assistance devices. Technological Forecasting and Social Change 105:105-120.

149. OECD. 2018. OECD Statistics. Organisation for Economic Development and Cooperation. Paris.

150. ABS. 2016. Research and Experimental Development, Businesses, Australia, 2015-16. Catalogue Number 8104 Australian Bureau of Statistics. Canberra.

151. PWC. 2018. The 2018 Global Innovation 1000 study: Investigating trends at the world's 1000 largest corporate R&D spenders. PWC Strategy&. London.

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