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2050 vision for automation and robotics in UK manufacturing

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Established and supported by Innovate UK, the High Value Manufacturing Catapult bridges the gap between business and academia, helping to turn great ideas into commercial realities by providing access to world-class research, development facilities and expertise that would otherwise be out of reach for many businesses in the UK. The HVM Catapult prides itself onhelping businesses to transform the products they sell, the way they make them and the skills of their workforce to remain competitive in a global marketplace.

Foreword

Automation and robotics (A&R) technologies have rapidly evolved over recent years and are transforming industries across the world. The UK has been no exception to this technological revolution, but has not taken advantage.

In the UK, the adoption of A&R has lagged other countries without any significant growth in the past decades, particularly in the manufacturing sector. Some policymakers and industrial organisations have been recently acknowledging the potential of A&R and promoting its integration into manufacturing processes but with very limited success in terms of implementation. A&R adoption is recognised to significantly improve productivity and reduce operational costs, whilst improving product quality in the manufacturing industry (Economics, 2018). UK Research and Innovation (UKRI) and Innovate UK have outlined a clear roadmap for the development and integration of advanced materials and technologies, including robotics, in the UK manufacturing sector. This vision emphasises sustainability, efficiency and competitiveness in the UK manufacturing and A&R plays a key role in achieving these goals (Innovate UK, 2023).

A&R adoption is having a remarkable impact on the UK manufacturing industry, not only by significantly improving efficiency and quality but also improving safety in industrial processes. Robots are extensively used for tasks such as welding, assembly and where they enhance precision and considerably reduce the risk of workplace accidents. Furthermore, A&R has enabled manufacturers to flexibly respond to the fluctuating market demands, leading to a competitive edge in the global market. A&R is also playing a pivotal role in achieving sustainability goals by optimising resource utilisation and reducing waste.

However, A&R adoption comes with several risks and challenges related to concerns about displacement of workers. To date, evidence suggests that a proportion of labour will be re-deployed to perform other tasks, and overall, A&R adoption leads to larger employment, in different job roles. Relevant upskilling and reskilling programmes need to be put in place to prepare and adapt the current workforce to the new roles that will be created and ensure the incoming pipeline of workers also have the right skills.

In the UK, A&R adoption varies significantly across different sectors. The manufacturing sector has been at the forefront through adopting some advanced manufacturing processes and robotic assembly lines to revolutionise production especially in automotive. According to International Federation of Robotics (IFR), the UK saw an increase of 7% in robot installations in manufacturing in 2020 (International Federation of Robotics, 2023). The logistics and warehousing sector have driven significant adoption of A&R through the E-commerce growth and the need for efficient supply chain operations, while automated guided vehicles (AGVs), robotic pickers and automated sorting systems have become extensively used in distribution centres. On the other hand, the construction industry has been much slower in adopting A&R due to complex site environments and regulatory challenges, although advances are being made in 3D printing of building components and autonomous construction equipment. Similarly, the agriculture sector has faced challenges related to the diverse and variable nature of agricultural tasks along with concerns over initial investment costs, all of which have delayed A&R adoption.

Overall, the UK has historically lagged other countries in robot uptake, being the only G7 country with a robot density below the world's average. Although it has seen comparatively low levels of uptake of industrial robots, the UK is in a strong position to take advantage of A&R. The UK is a world leader in robotics research and hosts highly innovative robotics companies, several collaborative research centres, and institutes as well as a strong AI ecosystem.

Even though the UK's position as a leading manufacturing nation is unquestionable, its productivity levels could be significantly improved through A&R adoption. The UK will not be able to keep competing on the international stage unless it significantly increases the level of automation and prioritises the development of a skilled pipeline of people who can design, build, programme, integrate, operate and maintain manufacturing technologies.

Unlocking the potential of A&R is not straightforward with a significant gap between UK companies' ambitions for A&R and actual adoption. Despite the UK's strengths in advanced robotics research and AI, the UK needs to ensure that it is not left behind other nations when it comes to implementation. Compared to the global landscape, the UK is making slow progress in A&R adoption, but its emergence within more traditional-based manufacturers is encouraging. This progress is driven by a strong commitment to research and innovation, and collaboration between academia and the industry. It is crucial to continue investing in research and development, fostering collaboration, but also ensuring the responsible adoption of A&R technologies to maximise their benefits across the UK and the global manufacturing industry.

The Made Smarter review, published in October 2017, was originally intended to "drive UK manufacturing growth, productivity and transformation". It found that faster adoption of technology will positively impact the scale of investment and manufacturing in the UK and that most developed countries including Germany, China and the USA already had coherent government strategies and were already seeing the associated benefits (Maier, 2017). According to a report published in 2019, the take-up of this pilot programme was impressive but given that there was little else the Government was doing to increase automation adoption in UK businesses, it suggested the progress was too slow. It recommended that the government should evaluate the pilot quickly and commit to a fully funded roll out scheme across the UK (House of Commons Business, Energy and Industrial Strategy Committee, 2019). These reports highlight the need for a coherent government-led strategy to secure the future of the manufacturing sector in the UK.

In November 2023 the government announced a plan of support, the Advanced Manufacturing Plan, for manufacturing with £4.5 billion in targeted funding for automotive, aerospace, clean energy and life sciences over five years from 2025 (Department for Business and Trade, 2023). This included a national roll out for Made Smarter. The plan states, "Advanced Manufacturing is critical to UK prosperity" and defines advanced manufacturing "to be production processes that integrate advanced science and technology, including digital and automation, to manufacturing". The greater use of A&R technologies within manufacturing is a key contributor to future UK prosperity.

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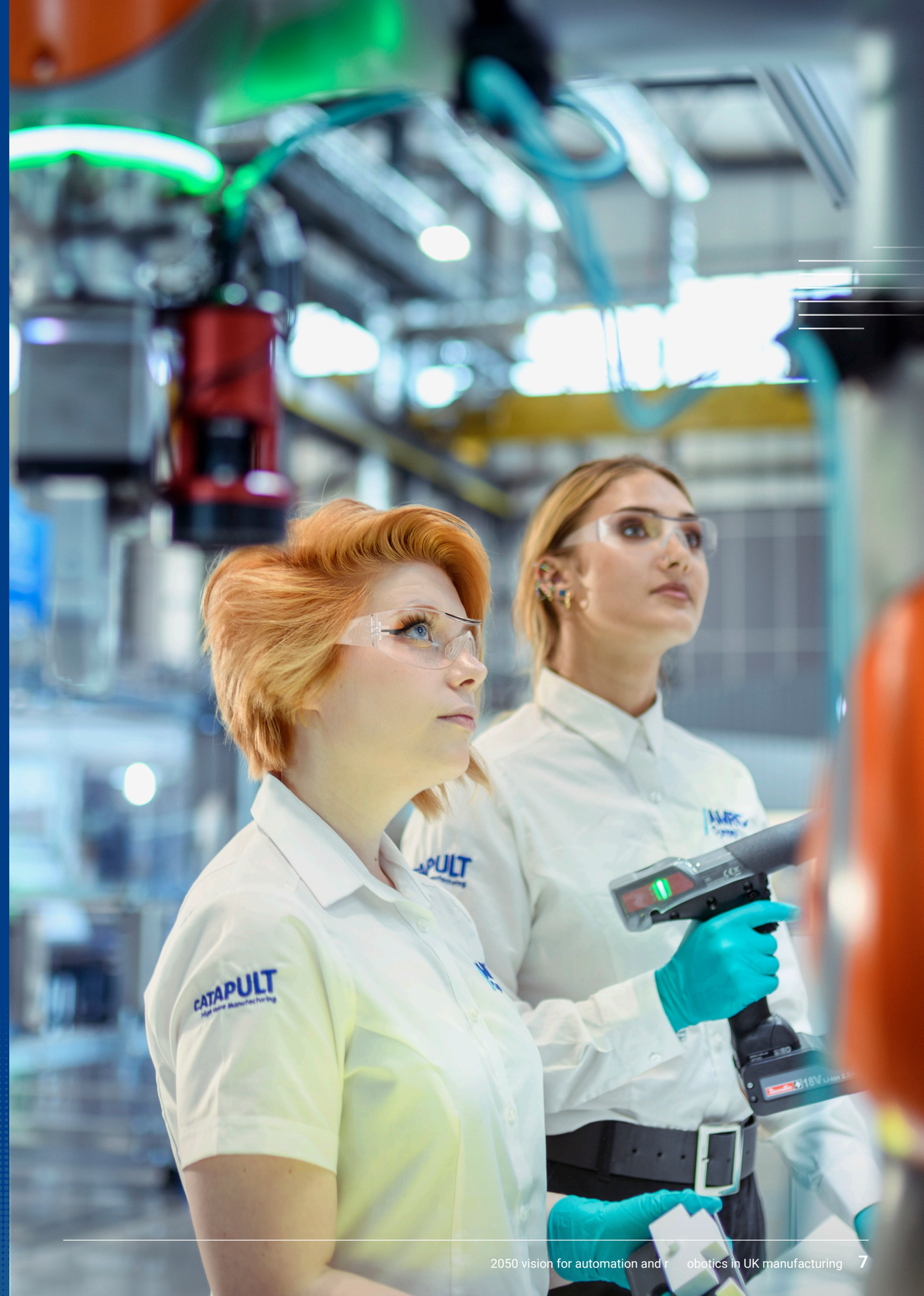


1. What is A&R?

In today's rapidly advancing technological landscape, automation and robotics (A&R) plays a pivotal role in enhancing efficiency and productivity across numerous industries. This section aims to provide a comprehensive understanding of the definition of A&R and how it relates to other technical terms such as Artificial Intelligence (AI), Embodied Intelligence, Robotics and Autonomous Systems (RAS), Service Robotics and Robotic Process Automation (RPA). A&R term is formed by the integration of two technology concepts: Automation and Robotics:

Automation refers to the process of using technology and machines to perform tasks or processes with minimal human intervention. It involves the integration of controls systems, sensors and machines to streamline operations, increase efficiency and reduce human error. Automation focuses on the execution of predefined tasks in a systematic and repetitive manner, ranging from simple processes like assembly lines in manufacturing to complex operations in industries such as logistics and healthcare.

Robotics is a specialised branch of engineering that deals with the design, development and application of robots capable of performing tasks autonomously or semi-autonomously. Robots can be equipped with sensors and actuators to interact with their environment and develop specific functions.

Considering these two concepts' definitions, the term A&R refers to a multidisciplinary field that combines principles of engineering and computer science to design, create and use automated systems and machines, including robots, which can perform tasks with minimal or no human intervention. These systems can incorporate sensors, actuators and control algorithms to achieve various levels of autonomy (PPMA-BARA, 2023).

AI, on the other hand, refers to the development of algorithms and systems that can perform tasks that usually require human intelligence. While A&R can leverage AI techniques for tasks like perception, decision-making and learning, AI itself is a broader field applicable in various domains beyond just robotics. Embodied intelligence emphasises designing robots and systems that interact with their environment using physical bodies, sensors and actuators. It promotes the integration of sensing and acting to achieve intelligent behaviour. Standard automation and robots can use embodied intelligence principles to create solutions capable of adaptive and context-aware behaviour – a RAS application. RAS involves the deployment of machines equipped with advanced algorithms, allowing them to perceive and adapt to their environment autonomously.

Unlike standard automation and robots, which rely on pre-programmed instructions, RAS possesses the capacity for real-time decision making and navigation (Department for Business, 2020).

While standard A&R solutions are indispensable in sectors like manufacturing, where they enhance productivity and precision, leading cost savings and improved quality, RAS technologies are key in fields such as transportation, healthcare and agriculture, enabling machines to perform tasks that require contextual awareness and decision-making capabilities.

On these fields, service robots are extensively utilised. Service robotics is a branch of robotics focused on creating robots that assist humans in various service-oriented tasks. These tasks can range from healthcare and education to entertainment and customer service. A&R, in this context, encompasses service robots, especially those designed for tasks requiring physical interaction with humans or the environment.

Other activities exist that do not require this physical interaction such as back-office operations for tasks like data entry, data extraction and data processing. This is when the RPA comes into play. RPA involves the automation of business processes using software robots or bots. In contrast from A&R, RPA does not involve physical machines but rather software-driven automation.

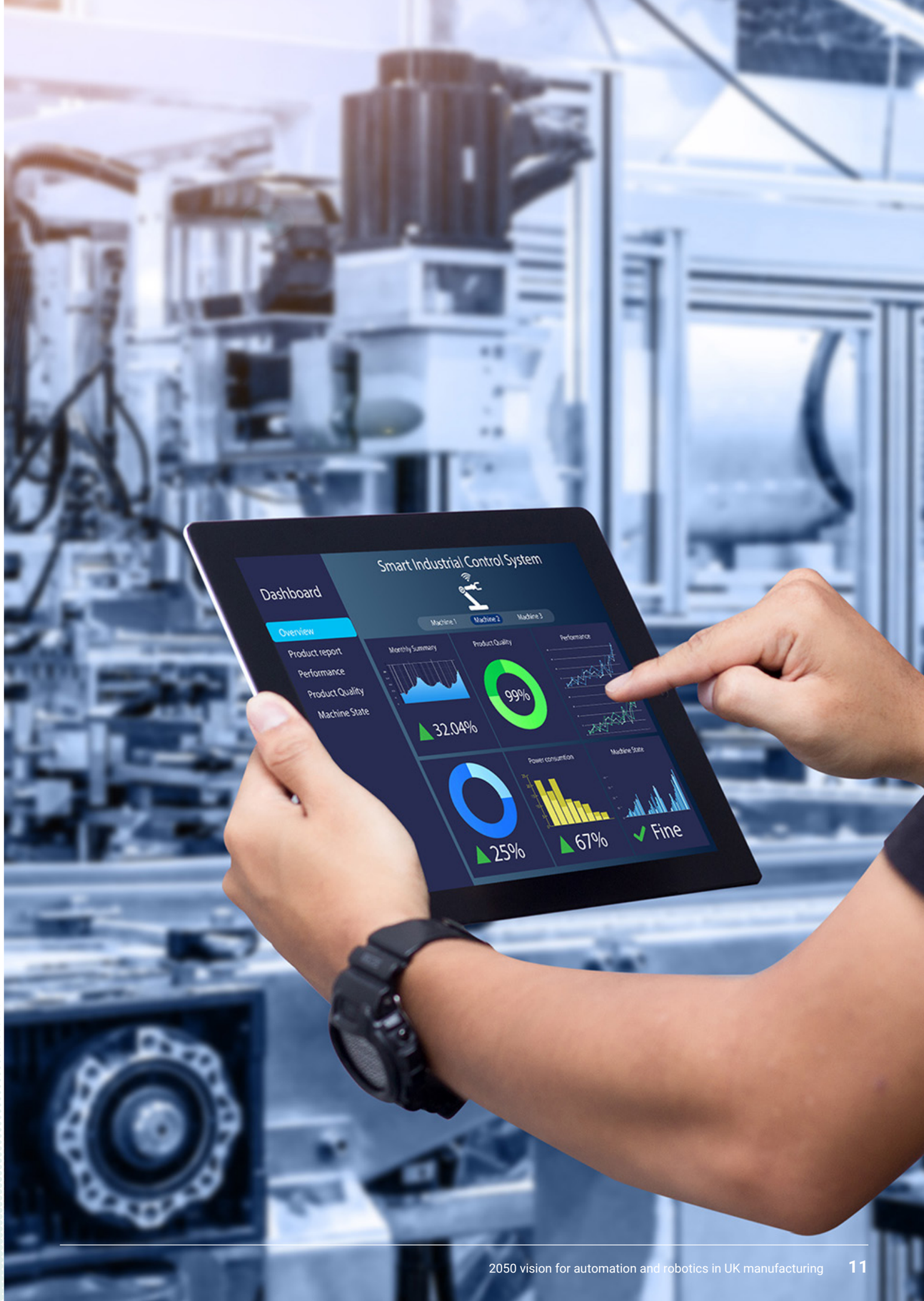
A&R forms the backbone of modern technological advancements, encompassing the automation of tasks and the development of autonomous machines. They coexist with related concepts like artificial and embodied intelligence, RAS, RPA and service robotics, each contributing unique capabilities and perspectives to the broader landscape of A&R technologies. Understanding these definitions and relationships is crucial for harnessing the full potential of these technologies across various industries and applications. In this report we will focus on A&R defined as a grouping of automation, robotics, autonomous systems and service robotics.

1.1 Introduction

This paper brings together the thoughts and ideas of various leaders in the UK R&D sector focusing on robotics and automation. It has been produced with two purposes. Firstly, to review the UK's current position on A&R, utilising research from state-of-the-art industry reports as has been presented in the prior sections, and secondly to present a collective vision for the landscape of A&R in 2050. This is based on the strengths, weaknesses, opportunities and threats highlighted from the research conducted by the MTC along with the valuable contributions from other centres, partners and members.

Section one and two has been produced at the Manufacturing Technology Centre (MTC). Multiple industry published reports have been extensively reviewed to ensure a balanced understanding of the outlook for UK robotics and automation. This paper has utilised information published about not only the future of robotics but also the associated challenges and advancements in manufacturing, the workplace and the landscape of future skills. These reports have included UKRI produced papers, UK government funded initiatives, EU funded projects and others research groups. The topics of many of these papers have covered a vision for 2050 of other sources across areas adjacent to robotics and automation. This included the "UKRI Materials and Manufacturing Vision 2050", published in 2023, which sets out Innovate UK strategies for industry to make the UK a leader in manufacturing (Innovate UK, 2023). Another example of the work forming a core research piece for this report is the market research conducted by Made Smarter looking at the opportunities of the fourth industrial revolution and digitisation (Made Smarter, 2022).

Sections three and four have been created through valuable insight and contributions from experts in the A&R sectors across the HVM Catapult centres. This collaboration is valuable for bringing a dimension of impartiality to the paper. The aim of incorporating the perspectives of these experts and organisations was to give a more comprehensive and objective analysis of the challenges, potential solutions and outlook for the A&R sector. Following this, section three brings about a summary of the key challenges we perceive which are barriers to this vision as described in section two which are the priorities to achieve the future of A&R for 2050.



2. Current state

The UK's manufacturing sector has long been a cornerstone of its economic landscape, playing a pivotal role in driving innovation, trade and employment. Since the first industrial revolution of mechanisation, each new technological "era" has been intrinsically linked to manufacturing.

From mechanisation, through mass production, digitisation and cyber-physical connectivity the ability to manufacture larger quantities, at faster speeds, with high quality and at lower costs has driven forward technological advancements. Remaining at the forefront of manufacturing technology is key to remaining competitive in the manufacturing sector worldwide and, in turn, important for a country which relies on its productivity and output. Globally, the UK is still one of the largest manufacturing nations. In 2021 around £200 billion was contributed to the UK economy from manufacturing and it is estimated that around 45% of UK exports come from this sector (Innovate UK, 2023).

However, the UK's current trajectory is not enough to keep up with other nations and remain a manufacturing sector leader. From a productivity perspective, according to the Made Smarter review, the productivity gap between UK and leading economies shows the UK productivity being 16% below the G7 average (Made Smarter, 2022). In fact, the UK experienced a fall in GDP growth and hours worked in 2020, with the UK and France being the only G7 countries to face negative output per hour growth rates within the G7 across 2020-2021 (National Office for Statistics, 2021).

Automation plays a large part in productivity and is a key factor in ensuring a country has world-class production. Research shows that increasing a country's robot density can positively impact GDP growth (Atkinson, 2019). Some of the biggest changes in manufacturing have been directly caused by, or at least enabled by, A&R. There are no signs of this trend changing as manufacturing is expected to have flexible capability to handle dynamic demand while still maintaining a zero-defect and high-precision environment; an environment in which A&R is well suited to in large-scale production.

The UK's investment in automation systems has not matched that of other countries and despite economically relying on the manufacturing sector it currently ranks outside the top 20 countries worldwide for number of robots per 10,000 workers (Atkinson, 2019). Increasing the investment and uptake of A&R presents an opportunity for the UK to increase productivity, foster economic growth and upskill the workforce which further compounds these increases and the benefits they bring to the economy and the individual. An example of this compounding and domino effect would be upskilling. This idea alone could deliver 3.2% GDP growth through productivity by 2030 and allow filling of 42% of the current vacancies that are due to skills shortages which in turn could contribute a further £7 billion to UK GDP annually (Department for Business and Trade, 2023).

This report, produced by the MTC with contributions from other High Value Manufacturing Catapult centres, looks to present the current state of A&R in the UK, focusing on the adoption of these technologies across multiple industrial sectors and the strategies currently being carried out. It will highlight the strengths, weaknesses, opportunities and threats present for A&R in UK before outlining a vision for automation and robotics in the UK for the future. This vision for widescale adoption by 2050 targets multiple challenges facing the UK and discusses a varied set of key technologies and trends which will address these, being not an exhaustive list but one of ideas and suggestions to strengthen UK manufacturing and bring the UK back to the forefront of the global stage.

2.1 UK strengths, weaknesses, opportunities and threats

Strengths	Weaknesses
■ World-class academic research ■ Strong aerospace, automotive and defence sectors ■ Catapult centres focused on applied research and adoption of technology ■ Growing number of startups and several established large systems integrators ■ Finance sector and banks	■ Lack of adoption and investment ■ Skills and supply chain deficiencies ■ Limited support and lack of strategy ■ Unrealistic expectations ■ Market and social constraints ■ Lack of coherent and coordinated robotics landscape
Opportunities	**Threats**
■ Large-scale adoption and emerging markets ■ Economic and manufacturing revival ■ Demographic changes ■ Drive for sustainability and responsibility for products ■ Growing investment into new technologies	■ Economic downturn and cultural challenges ■ Lack of government prioritisation ■ Regulatory and competitive disadvantages ■ Skills shortage ■ Overseas A&R competitors as a threat to local developers/businesses due to greater support, larger home markets, allowing them to come to market faster ■ Public backlash against greater use of robotics

2.1.1 Strengths

The UK's strengths in the automation and robotics landscape are multifaceted, combining exceptional academic research with strong industrial sectors such as automotive, aerospace and defence. This is complemented by the applied research and technological adoption driven by Catapult centres. The landscape is further enriched by a growing startup scene and the expertise of several large systems integrators, ensuring continual innovation and growth. Additionally, financial backing and AI developments support the expansion and the enhancement of technological capabilities, consolidating the UK's position as a prominent player in the global automation and robotics landscape.

2.1.2 Weaknesses

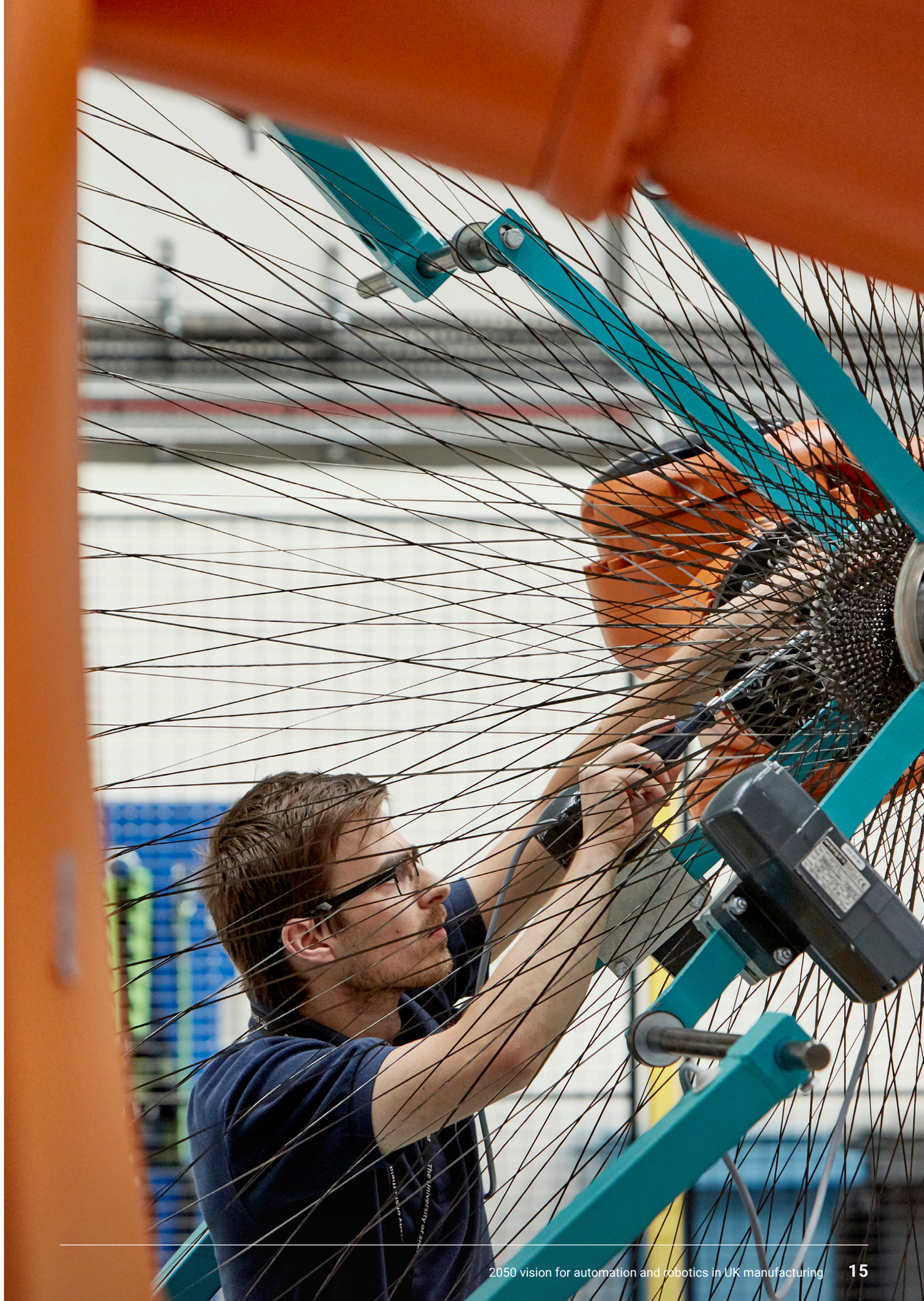
The UK automation and robotics landscape faces several weaknesses that hinder its development and growth. Key issues include low levels of technology adoption, inadequate capital investment and significant skills shortages. Supply chain problems and insufficient support for startups increases these challenges, alongside businesses' focus on short-term goals. The lack of a strategic, government-led approach to adoption and the setting of unrealistic investment return targets by manufacturers further discourages innovation and adoption of novel technologies. Additionally, societal and market constraints, such as a small local market, a declining economy and a general reluctance to embrace risk and domestic products, stifle the sector's potential. Addressing these weaknesses is crucial for the UK to fully leverage its strengths and capitalise on the opportunities in robotics and automation.

2.1.3 Opportunities

Automation and robotics in the UK is presented with substantial opportunities amid changing economic, demographic and regulatory landscapes. There is potential for widespread adoption across traditional and new sectors, fostering innovation and positioning the UK as a leader in automation. The shift towards onshoring manufacturing due to recent global challenges, combined with an increasing private investment landscape, offers a fertile ground for the expanded adoption. Labour shortages and an aging population further drive the demand for automation, presenting a solution to current and future workforce challenges. Additionally, the growing emphasis on sustainability, the right to repair and product traceability opens new avenues for the development and application of robotic and automation technologies, aligning with global trends towards more responsible and efficient manufacturing practices. This combination of factors creates a unique opportunity for the UK to enhance its manufacturing capabilities and economic resilience through the strategic adoption and development of robotics and automation technologies.

2.1.4 Threats

There are several threats that could impede adoption and development of automation and robotics for UK manufacturing. Economic downturns could restrict necessary investments, while cultural opposition could slow down or even halt the adoption of new technologies. Additionally, the sector may suffer from insufficient governmental focus and inadequate financial support for emerging companies, stifling innovation and scale-up efforts. Safety regulations for new technologies such as collaborative robots or AI-driven autonomous systems need to be addressed to ensure widespread and safe adoption. The UK also faces intense competition from abroad, where companies might have access to more resources and larger markets. Finally, the lack of a skilled workforce to support the sector's growth is a significant concern, as it is essential for both the development and implementation of these technologies. Addressing these threats is crucial for the UK to maintain and enhance its position in the global robotics and automation landscape.



3. 2050 vision for automation and robotics

3.1 Introduction

Our vision for 2050 is the widescale adoption of A&R across UK manufacturing. By embracing this technology across the industry, the UK will benefit from increased productivity and competitiveness across manufacturing which will improve living standards and create more jobs with improved salaries. The adoption of this technology will create strong supply chains, with businesses able to re-shore operations efficiently and effectively within the UK. The UK will be an increasingly popular place for organisations to manufacture their goods, with businesses who embrace A&R benefiting through:

- **Enabling neszero and circular economy:** using technology to achieve sustainable practices.
- **Creating agile and resilient supply chains:** with an ability to respond to changes in customer demands and manage global supply chain challenges through utilising localised support.
- **Improving productivity:** through implementation of A&R to improve speed and quality whilst reducing errors and waste.

This section explores some of the key technology, market and social trends that will impact and influence this future vision:

- **Democratisation of A&R** – allowing wider access to technologies through affordable and easy-to-use practices.
- **Distributed manufacturing and robotic micro-factories** – a decentralised and scalable approach to the production of goods.
- **Embodied intelligence and digitalisation** – using AI `mc digital developments to enable more intelligent and adaptable robotics and automation systems.
- **Design for automation** – optimising product design to enable efficiency manufacture and assembly of products, maximising the use of A&R.
- **Personalisation and new market demands** – addressing the current and future changes to market demand for personalised products (high mix, low batch) requiring adaptable and reconfigurable systems.
- **Circular economy** – utilising A&R to enable higher production rates and productivity, more efficient use of materials and higher quality of parts and hence lower scrap rates.
- **Skills and generational changes** – how aspirations and attitudes will impact the use of A&R as well as the impact of and requirements for changing skills provision.

3.2 Democratisation of automation and robotics

In the past, adoption of traditional A&R technologies has been restricted to those in 'privileged' positions with the ability to make significant investment in hardware, software and skills due to the perceived high investment costs and extensive programming knowledge required to successfully adopt them. In 2050, we expect the emergence of the democratisation of A&R to be fully embedded in the supply and use of A&R technologies, with wider access to A&R through the wide-scale development and adoption of more affordable and easier to use technologies, a multitude of financial options for using and purchasing equipment and an abundance of opportunities to purchase out-of-the-box A&R solutions.

Whilst many larger companies have adopted significant A&R technologies, small and medium-sized enterprises (SMEs) lag. In 2021, Make UK stated that SMEs accounted for 99% of UK manufacturing firms and contributed 58% to manufacturing employment (Make UK, 2021). Manufacturers investing in A&R technologies are proven to experience improved productivity, efficiency and resilience, which is critical for SMEs looking to scale and grow (Atkinson, 2019) (Make UK, 2021). The democratisation of A&R will open this technology to all UK manufacturing businesses, allowing wide-scale adoption across industry through reduced investment costs and enhanced ease-of-use.

UK-RAS Network has highlighted the lack of skills as a key challenge to the adoption of A&R in the UK (UK-RAS Network, 2016). The emergence of low code/no code intuitive programming allows users to program A&R technologies without the need for specific programming expertise, utilising specialist tools and frameworks. This addresses the UK's skills shortage from a different angle: rather than aiming to increase the skills of the workforce, it reduces the skills needed to adopt the technology effectively which in turn reduces the level of training required for operators to be skilled to use these technologies.

This often involves using graphical representations with drag and drop or visual modelling interfaces to program robotic tasks, with complex programming mechanisms hidden underneath (Leonida, 2022). Recently, robot manufacturers have taken significant steps to introduce low code/no-code options as part of their product offerings, with new robot manufacturers entering the market with these principles at the forefront. Traditional robot manufacturers are also adapting to offer low code/no code options. In addition, there has been an emergence of third-party software, enabling robot agnostic programming functionality through similar graphical interfaces. Technologies like these are removing the need for an end user to learn in-depth programming knowledge for every type of robot they encounter. By 2050, wide-scale adoption of low-code/no-code robotics through non-traditional methods of programming such as gesture control, voice commands or programming through demonstration with all prominent robot manufacturers offering non-teach pendant style programming options is expected. This will enable non-experienced robot users to program more capable robots and open up access to a skills pool of individuals who were not previously able to use robotics (for example, those with physical disabilities). This is expected to be complemented by wide-scale adoption of low-code/no-code robotics using third party software, removing vendor-dependency for users, encouraging multi-vendor solutions where relevant and enabling guman qbot bollaboration (HRC) where possible, to increase application flexibility.

Safety is a big concern for those adopting automation. Traditionally, the infrastructure required to install was often costly, including physical guarding/fencing, interlock systems and additional sensors. More recently, there has been a rise in the demand for HRC, allowing humans and robots to share workspaces. A particular technology trend addressing safety as well as the skills shortage is the emergence of collaborative robots. Collaborative robots, also known as cobots, are specific robots

designed to work with or alongside humans to complete tasks, enabling HRC (RNA, 2023). These robots have additional safety features such as force/torque sensors to detect impact and design considerations such as reduced pinch points and no sharp edges. These robots are often paired with a low‚code or no‚code programming interface making them simpler to use. Additionally, their enhanced safety features potentially enable them to be used with reduced infrastructure (depending on the application), reducing the integration and implementation costs.

The skills shortage or requirement for expertise extends to the initial build of A&R systems. With on-demand, out-of-the-box solutions,companies can purchase simple systems as and when they need them, without going through the lengthy process of working with an external party to design and build a custom solution and without needing the expertise to purchase all the individual components themselves and build it safely in house. Most A&R systems consist of a variety of different components and parts, often supplied by different manufacturers. For example, a robot on a portable platform doing a pick and place routine would need a robot, the platform, gripping mechanism and possibly an air supply. This means a customer must either source of these parts themselves, or rely on a third-party integrator to source, build and commission the system. For new A&R users, this can be confusing and overwhelming. An emerging offering from some manufacturers is concept of a 'out‚of‚the‚box' solution. This allows users to purchase a complete system from one supplier which is delivered to them ready to go. Whilst this may not be fit for all required solutions, this is particularly useful for companies looking for a one-off simple system and who do not have existing relationships with integrators. An out‚of‚the‚box solution means users do not need the expert skills to build an automated system and can access on-demand solutions, as opposed to the long lead times often associated with custom solutions.

In 2050, we envision robot manufacturers and traditional integrators offering out-of-the-box robotic and automation solutions for on-demand adoption.

Traditional A&R solutions are known for high capital investment costs. Despite the global industrial robot market growing last year, there has been some caution amongst SMEs. In the current climate, survival is the priority for SMEs, meaning capital investment is scrutinised. Affordability is key to the democratisation of A&R, to address the perception of extremely high investment costs associated with these technologies. The development and emergence of low-cost technologies and other affordability mechanisms allows businesses to benefit from lower cost investment opportunities which will reduce the payback period of these technologies, providing stronger justification of adoption of these technologies into their businesses. In addition to the emergence of lower‚cost robots being offered by manufacturers, the market has seen other financial models emerging. Many companies now offer leasing or renting options for A&R, allowing users to pay a reduced amount to use equipment for a shorter period, increasing flexibility. Others have opened to the opportunity of second-hand robotics, selling used robotic equipment at lower prices. In addition to reducing the initial investment costs, A&R technologies that are flexible and easy to redeploy, as opposed to fixed, specialised technologies, provide companies with a larger return on investment by maximising use of each piece of equipment. By 2050, a reduced average price point for A&R equipment is expected and multiple financial options for renting and buying new and second-hand systems offered wide scale across all prominent robot manufacturers.

3.3 Distributed manufacturing and robotic micro-factories

Distributed manufacturing refers to a decentralised approach to the production of goods, where manufacturing processes are dispersed across multiple locations or facilities rather than being concentrated in a single central location. By 2050 this approach will be supporting manufacturing facilities across the UK to enable more efficient and flexible manufacturing.

This concept is enabled and enhanced by advanced technologies, especially A&R, as well as digital communication and information systems. In traditional manufacturing models, large factories or facilities are responsible for the entire production process, from raw material sourcing or basic components to final product assembly. However, distributed manufacturing takes a more fragmented and networked approach, breaking down the production process into smaller, specialised tasks that can be performed in different locations. This decentralisation offers several advantages in terms of efficiency, flexibility and responsiveness to market demands (Jagjit Singh Srai, 2020).

Robotic micro-factories will utilise small-scale automated manufacturing units that operate with minimal human intervention. These facilities, characterised by their compact size and high level of automation, are integral components of the decentralised manufacturing paradigm. These units leverage advanced robotic systems and technologies to perform specific tasks within the production process, aligning with the overarching principles of decentralised manufacturing. In the context of localisation, robotic micro-factories bring manufacturing capabilities closer to end-users or specific markets. This decentralisation reduces dependence on centralised facilities, which minimise the impacts of disruptions in the supply chain and minimise transportation costs, enabling supply chain resilience adhering to the fundamental concept of distributing production closer to consumption points. The agility and flexibility inherent in robotic micro-factories facilitate rapid adaptation to changes in product design or market demands. These market demands include mass customisation of products as well us circular economy operations that are additional to traditional manufacturing, i.e. servicing or remanufacturing operations including, inspection, disassembly, replacement part manufacture with 3D printing, reassembly and validation. This responsiveness is crucial in the decentralised manufacturing approach, emphasising the need for quick adjustments to meet dynamic and evolving requirements (Autodesk, 2023).

The adoption of distributed manufacturing holds profound implications for the UK manufacturing sector with its potential to boost productivity, operational efficiency and responsiveness. Fragmenting the production process into specialised tasks distributed across various locations allows the manufacturing sector to optimise resource utilisation including the creation of more advanced employment locally and improving resilience of the local supply chain.

The integration of distributed manufacturing aligns with the global trend towards automation, positioning the UK at the forefront of technological advancements in manufacturing. The localisation aspect of this model is particularly significant for UK manufacturing, bringing production capabilities closer to end-users and specific markets. This not only minimises transportation costs but also aligns with environmental sustainability goals, ultimately reducing the overall carbon footprint of the manufactured product, as direct manufacturing process impacts could be considered equivalent. The agility and flexibility inherent in robotic micro-factories enable swift adaptation to change in product design or market demands. This responsiveness is crucial in a dynamic and competitive global market, allowing the UK manufacturing sector to stay innovative and efficiently meet evolving customer preferences (e.g. mass customisation). This has the potential to bring manufacturing back to the UK from abroad. The reshoring initiative can create more advanced and better-paid jobs locally, contributing to UK productivity and growth of the domestic workforce. By fostering a resilient, sustainable and innovative manufacturing ecosystem, the UK can solidify its position as a leader in the global manufacturing landscape, simultaneously addressing economic and employment considerations.

The vision for distributed manufacturing through micro-factories represents a transformative paradigm in the realm of robotics and manufacturing. The layout of a traditional manufacturing assembly line is abandoned in favour or multipurpose or specific (e.g. welding) cells, with flexible, autonomous intralogistics routes. Leveraging the prowess of automation, robotics and machine learning, micro-factories stand as beacons of improved efficiency, offering a streamlined production process that minimises costs and overheads. A&R is also applied to logistics for work in progress (WIP) transfer between stations, routes are dynamically flexible and responsive, not only to complete the operations in an optimal route but respond to maintenance or resource shortages. Routine, critical non-value add operations (such as scheduled quality inspections and maintenance) are facilitated by autonomous robotic systems. This efficiency is complemented by a smaller yet highly skilled workforce, fostering engagement and investment in outcomes.

In this landscape, innovation becomes paramount, as micromanufacturing being a lean process, enables rapid prototyping, testing and iteration. The small-scale nature of production facilitates generative design without imposing significant financial burdens, ushering in an era of greater personalisation and customised solutions for end products. The footprint of micro-factories is inherently smaller, often integrating seamlessly into existing spaces and reducing the need for new constructions. This not only lowers overhead costs but also promotes sustainability by utilising resources more judiciously. These micro-factories operate on a demand-driven model, minimising raw material usage and waste, contributing to a more environmentally conscious manufacturing approach. Moreover, the customisation capabilities of micro-factories break away from the traditional high-volume, mass-production model, catering to specific consumer needs that may not be economically viable for larger enterprises. This tailored approach not only enhances material efficiency but also enables on-demand production, eliminating the inefficiencies associated with large, unbought inventories. The distribution process is streamlined in micro-factories, eliminating the need for extensive networks. The one-on-one engagement with customers allows for direct delivery, enhancing the overall efficiency of the supply chain. Customer responsiveness is heightened in this model, fostering closer relationships and customer loyalty through a highly personalised manufacturing process. As micro-factories redefine manufacturing landscapes, their integration into existing engineering and design firms offers comprehensive end-to-end solutions. This value-addition contributes to a holistic approach that combines design, engineering and manufacturing within a single framework (World Economic Forum, 2023).

For the widespread adoption of this distributed manufacturing paradigm based on micro-factories, collaboration and support are essential. Academic researchers and innovation centres can contribute by advancing technologies in automation, robotics and machine learning, ensuring continuous improvements in efficiency and innovation. Together, with concerted efforts from automation supply chain, researchers, investors and government, the era of distributed manufacturing through micro-factories can usher in a new chapter in the evolution of the manufacturing industry.

3.4 Embodied intelligence and digitalisation – intelligent manufacturing

The manufacturing sector in 2050 will showcase intelligent systems, adapting to changing environments and maximising performance through widespread introduction of sensors, advanced algorithms and digitalisation for dynamically changing environments.

Embodied Intelligence in A&R enables intelligence where it is needed, so that manufacturing operations can be understood and optimised. This is delivered using data sensors, processors and communication technology. A robot with embodied intelligence may be equipped with a vision camera, force-sensitive feedback control and the ability to plan new paths in dynamically changing environments. These applications have emerged onto the market with the availability of collaborative robots (cobots) and mobile robots such as automated guided vehicles (AGV) and autonomous mobile robots (AMR). As their adoption grows, this presents opportunities for manufacturers to co-ordinate and maximise their assets with digital transformation of operations (Xiao, 2021) (Grand View Research, n.d.).

Digitalisation is a trend that is affecting all areas of life and can be considered as the improvement or replacement of hardware with software. Examples include the additional functionality of smart watches and smart bulbs, or calculator and timer apps installed onto smart phones. In manufacturing, digitalisation exploits the use of data to monitor, contextualise and improve operations, and can be applied to A&R systems in uses such as KPI dashboards, augmented reality work instructions, and supply chain scheduling. Similar terms referring to digitalisation of manufacturing include Industry 4.0 and smart manufacturing.

Within A&R, digitalisation can enable data captured from the assets to be processed and communicated in real time, using Edge devices and IIoT, to inform a digital twin model. This data is transformed into information that can be actioned to optimise the operational performance or maintenance health of A&R assets. Without the application of digitalisation, automated processes may become a “black box” where performance and utilisation are misunderstood and assets are operated in a sub-optimal way.

Presently, digitalisation of A&R is not limited to new installations and solutions exist that can be fitted retrospectively to legacy equipment. The benefits of digitalisation can be unlocked in the short term for low cost, such as identifying key energy inefficiencies in the production line and offer energy-saving suggestions; providing data that can build a stronger market position on sustainability (Oulton, 2023).

Smart automation can be adopted without a business’ operations being digitally transformed, however combining the two fields together in a coherent strategy amplifies the benefits of each. The digital thread running through design, manufacturing and use of product life can be informed by smart automation for the manufacturing phases, providing data and context of the processes. Further to this, dynamic changes (such as part shortages, breakdowns, robot collisions) can be sensed by the distributed intelligent systems, communicated to a central holistic decision-making system, and optimised reaction instructions can be automatically enacted. Leading to increased responsiveness, productivity and resilience.

The introduction of low-cost smart A&R means it becomes more competitive with more tradition A&R, and the barriers to adoption are reduced. Force sensing and visions systems integrated into the solutions means less infrastructure is required to install the assets, this reduces costs for peripheral equipment such as guarding and enables A&R to be installed into smaller footprints. A&R with the embodied intelligence to understand what it is making means the A&R can be responsive. This removes the need for bespoke fixturing and tooling per product, reducing related investment costs. The greater flexibility of smart A&R allows it to be reconfigured more quickly, reducing the time to market for new products. Additionally, automatic diagnostics, reporting and features to enable remote support means that assets can run more effectively and be more productive. These benefits can combine to reduce the return on investment (ROI) time for adoption of A&R. Whilst doing this, A&R can also support new business challenges such as monitoring and contextualising energy consumption of manufacturing processes for carbon accounting or net-zero initiatives.

HVM Catapult's vision for digitalised A&R with embodied intelligence aligns with the "lights off" manufacturing concept; automation solutions that are productive, predictive and diagnosable to a level that they need no direct human intervention to operate or maintain, even as their capability and complexity grows. The concept of digital twin for manufacturing assets is firmly established in industry; A&R will reliably report in real time against a range of standard KPIs that are relevant to bespoke audiences, generate optimised recommendations for future actions that benefit the holistic manufacturing systems, and respond as expected to tactical and strategic prompts.

The cost of additional sensors, processing and communication devices has become so competitive and the insights so valuable that they become the standard offering of A&R solutions. Legacy equipment has been retired, but the previous application of IIoT sensors and the appropriate contextualisation of their operation has built a solid knowledge foundation of assets performance and reliability that informs the application and use of future A&R.

The role of A&R grows from completing value-add manufacturing operations to also become responsible for executing critical non-value add activities such as quality inspections and predictive maintenance. Furthermore, robotic applications are mobile, safe and collaborative enough to seamlessly support humans in non-routine activities prompted by verbal and physical cues.

3.5 Design for automation

In 2050 products will be designed with automation and circular economy in mind, creating resource efficient economy of products and improving the efficiency and quality of production. Design for automation is a process that considers the way a product is designed so that it can be assembled automatically with little to no human intervention. It is similar to design for manufacturing or design for assembly that are considered under the design for excellence (DfX) umbrella. Design for automation goes further than design for assembly, the rules of an assembly-oriented design are also found in design for automation. If something is easy to automate, then it is also easy to manually assemble (Fraunhofer IPA, 2021).

It is important to consider design for automation as separate and distinct from automated design (related to creating, updating and documenting product designs with automated processes and workflow) and automation design (design of an automation system based on assembly requirements); though these activities are considered complementary and good practice when determining how a product can be manufactured. Additionally, while some DfX practices include quantitative assessments (such as Boothroyd's methodology for design for assembly), design for automation is implemented with the use of "Golden Rules", ***these rules typically include considering:***

- **Standardising parts** and registering them in component libraries, where compatible automation tooling can also be referenced
- **Part identification**, by including product traceability or variant information in machine readable formats (i.e. barcode, QR, etc) ensuring they are applied to surfaces with limited distortion
- **Loading direction**, as assembly parts are mated together, which in most cases is vertically from above. Additionally, it is important to consider the number of times a part or subassembly must be reorientated to achieve optimal loading as this may incur additional non-value add automation operations
- **Locating datums** and constraining degrees of freedom, so that parts can be consistently positioned in fixtures or mated together during assembly operations
- **Access for tooling**, and the limits on working ranges for force and dimensions. Tool reach within A&R may be limited by "bed size" or working volume; tool approach and placement needs to fall within these ranges to be viable
- **Packaging optimisation**, so that parts are consistently presented to automation in an orientation compatible with part grippers to approved locations on the part. This can be considered for both incoming and outgoing parts. It should be noted that this requirement can be bypassed with the use of vision systems and embodied intelligence but is particularly difficult for parts that are flexible or vulnerable to entanglement
- **Working environment**, where A&R can be more advantageous, such as mitigating contamination risk in clean environments, or need additional servicing in the case of excess waste material build up.

There are a range of barriers to A&R adoption including technical risk, payback period and floor space required (The Institution of Engineering and Technology, 2018). Optimising products and packaging for automated assembly is an enabler for automation adoption, allowing them to be manufactured more repeatably, faster and at a lower cost. When these practices are applied to variety of products then lower volume products also become compatible with A&R, increasing the application, flexibility and utilisation of A&R assets. As well as increasing manufacturing productivity, the application of design for automation rules makes products more suitable for a circular economy; the A&R used to assemble products can be used to disassemble and reassemble them, enabling them to be refurbished, remanufactured or recycled at higher volumes. This justifies the use of A&R in manufacturing a wider range of products and in more applications related to manufacturing.

The design of products is undertaken simultaneously with the design or reconfiguration of A&R solutions as part of a rapid, iterative process. This (re)design phase is undertaken in compatible digital engineering environments, using libraries of standard multipurpose tools, and applied to all aspects of the life cycle for both product and A&R.

Product designs are dynamically evaluated for impacts to automation, informed by existing or proposed automation solutions. Solutions for operations are standardised and specific equipment, such as tooling and fixturing, is minimised; this reduces the cost of implementing A&R even further.

As A&R technologies continue to evolve, providing more flexibility and applicability, common challenges across industries and sectors products are solved and design for automation frameworks can identify challenges and pair them with applicable solutions. Similarly, components that are typically more difficult to automate (such as flexible, non-rigid parts) are quantified; the impacts of advanced A&R solutions for those complex components are considered to steer the overall product design.

Engineering environments that support design for assembly assessment and could be complimented by other technologies such as AI, can consider ranges of manufacturing processes. This range of manufacturing solutions can be simultaneously evaluated and the optimal process can be selected. Additional constraints can be applied to identify opportunities that enable more elegant design: higher functional ability, assembled in optimal sequence, consuming less resources and generating less waste. Business cases for automation adoption can be automatically evaluated and justified, even when geographical variables (e.g. manual labour costs) are considered.

3.6 Personalisation and new market demands

In 2050, we can expect to see wide reaching A&R solutions that enable fast and efficient manufacture of personalised products to meet customer demands. From use in pharmaceuticals to textiles, agile automation will support this manufacturing sector to meet the increased demand.

A 2013 report on the Future of (UK) Manufacturing (Foresight, 2013) outlined that "more responsive and closer to customers"

would be one of four key future characteristics of manufacturing by 2050. In recent years the demand for personalised and customised products has certainly increased. Consumers now more than ever, seek products that resonate with their individuality and match their unique tastes and needs. For the manufacturer, this offers a significant opportunity to meet customer demand and increase competitiveness. However, delivering a high variety of products (high mix) at low volume (HMLV) has traditionally been very challenging for implementation of A&R, from both a technological and economic perspective.

The nature of many of the products manufactured in the UK lend themselves to HMLV manufacturing of high-value components, hence a larger contribution to this type of manufacturing than the rest of Europe. Many traditionally high-volume sectors, such as automotive have become progressively customised (SMMT, 2021). The pharmaceutical industry is increasingly moving towards personalised medicines (such as gene therapies) and devices that are unique to the patient and require a batch of one to be manufactured in a heavily regulated environment.

The personalisation and new market demand sector encompasses a large portion of UK manufacturing making it critical for the economy. The sector contains varied areas and levels of personalisation for both individual and business customers. Some types of personalisation are easier to achieve as they form part of the standard process and require a small amount of input, such as a name printed on a bottle or a different ratio of components in a formulated product. More complex processes are required where the personalisation covers a full product, for example a medicine or a specialised machine which currently are made by hand to allow the business to meet customers requirement. All of these are highly driven by demand and impossible to predict making the manufacturing process complicated and required to rapidly adapt.

Use of A&R for manufacturing of personalised and customised products will ensure increased responsiveness to both variable customer demand and supply chain pressures. With correct implementation and product design, A&R will enable reduced inventory and waste, delivering high-quality products quickly and at an attractive price point, irrespective of sector. The ability to manufacture small or individual batches where and when they are required will also reduce transport costs.

Widespread adoption of A&R for personalised products will require and build on many of the concepts and technologies detailed in this report. For a small number of products, the automation technology to support customisation is well established, for example store based colour-matching for paints which match customer need to the nearest available product. The adoption of A&R is critical to the development of this market, from the design of products through manufacture and assembly to end-of-life concepts. Within the design stage, design for automation is essential, products and assembly processes are designed with automation in mind. Where possible, products use libraries of components appropriate for the area considering relevant standards and requirements. Additive manufacturing can support rapid prototyping for development, but throughput is typically low, making it uneconomical for production. Unique products often require specialised tooling and changes to automation workflows, which can bring high capital costs.

New approaches to support the manufacture and assembly processes are required. Development of improved autonomous grasping to handle flexible and variable components, such as those found in the fashion industry, will decrease the production costs. Typically, the manufacture of many lower-value customised products, especially textiles, is outsourced to developing countries. Introducing the technology will support the manufacturers to reshore their production while the societal impact of implementation of A&R to these sectors should be also considered.

The assembly processes will be based on continued adoption of collaborative robotics – allowing humans and robots to work side by side increasing the productivity and efficiency while keeping the quality high. The processes will be based on a blend of expertise of skilled operators or craftsmen with robotics, keeping with traditional values where needed but with improved outputs. Introducing collaborative robots, especially as a mobile solution will increase the flexibility by being able to move where needed filling in the process gaps to keep the production performing.

The technologies introduced will allow for rapid changeover between products, further increasing the efficiency of the manufacturing and assembly process. Additionally, use of offline simulation to enable robot programming before introducing to manufacture will reduce downtime for equipment. The assembly process will have to be based on specific scenarios – multiple products in same work cell vs continuous production, depending on the needs of the process.

There are both high and low TRL solutions that are required to increase the adoption of A&R in the personalisation market. As the products can vary significantly between themselves, the processes need to have increased adaptability compared to traditional manufacture to meet demand and minimise capital costs. Continued adoption of available solutions will support the market in the short term but continued work on future technologies and skills is needed for the long-term prospects.

Mix of automation, semi automation and manual production will be a fixture for the foreseeable future within the personalisation and new markets area. Increased use of human robot collaboration will increase productivity, with judicious choice of tasks where automation can add value. Improving the accessibility to A&R through low-code and no-code automation with use of AI to support task scheduling and data processing will allow for wider adoption. Many of the companies within the area are SMEs who, in general, struggle to adopt A&R technologies due to financial constraints, lack of awareness and lack of national support. Lowering the barrier of entry for A&R will be critical to the success of the market.

3.7 Circular economy

There has been an increased focus on circular economy and achieving net-zero goals over the last decade, including the reduction in greenhouse gas emissions by 100% from 1990 levels by 2050 (HM Govermnment, 2021). This strategy involves all industrial sectors of the UK, with a focus on transformation in terms of switching to cleaner fuels and focussing on resource efficiency. A truly circular economy has become an industry wide initiative from electrification of vehicles to recycling and remanufacturing. This has created many opportunities for use of A&R to achieve sustainability goals and improve the outlook of the economy.

In 2050, circular economy will become a reality with products designed to be easily remanufactured and reused, maximising the efficient use of resources. Automated solutions will be widely used to support the processes within circular economy, from automated manufacturing processes, repair and remanufacturing, to recycling and recovery of high-value materials.

Circular economy is a concept based on three main principles, which are all driven by design – eliminate waste and pollution; circulate products and materials (at their highest value) and regenerate nature (Ellen MacArthur Foundation, 2023). This approach allows for creation of a system where materials are reused, remanufactured or, in the worst case, recycled allowing for a high resource efficiency and less waste being generated. It has created many areas of interest where A&R can generate impact by using improved processes (eliminate waste and pollution) as well as improved quality (circulate products and materials).

Strating with a generally low proportion of robots in industry – IFR data puts UK in 25th place globally in 2023 (International Federation of Robotics, 2023), with Italy (14th) and France

(18th) significantly ahead; increasing the levels of automation could improve the productivity by about 22.3% (Lene Kromann, 2021). There are challenges relating to adoption of A&R in manufacturing and greater industry: lack of knowledge – especially in SMEs, lack of funding and expectations for short ROI as well as the perceived unavailability of solutions, make it difficult for companies to adopt automation.

This transformation would not only support the economy and net-zero transition, it will also reduce waste – due to increased quality of parts as well as better utilised resources through an optimised product design. Additionally, the business itself will benefit with improved and more efficient processes, decreased impact on the environment and higher resilience.

There is a significant role A&R can play in several areas of enabling circular economy, both in terms of adoption of solutions which already exist and a focus on solutions that need to be developed. Many benefits of adopting automation resonate with the challenges of creating a circular economy model – higher production rates and productivity, more efficient use of materials and higher quality of parts and therefore a lower scrap rate, all have a part to play. Improving the safety of operators and decreasing the hours they work has also a positive societal impact (Britannica, 2023). It is understood up to 35% of jobs in the UK are capable of being fully computerised by robotics, AI or similar technologies (Barbosa, 2022). This indicates the scale of impact automation could have in terms of number of opportunities to improve processes and introduce circular economy.

Increasing the quality of products manufactured has a clear impact on the longevity of products and the ability for them to be reused but there are challenges associated with the approach when the products are machines or other types of equipment. Currently there is no standardised approach to documenting the journey equipment has taken, this includes white goods from an individual user's perspective but more importantly machines used in the manufacturing sectors. Creation of such a standard would allow for a simpler and streamlined exchange and circulation of equipment allowing for a second or third life. Possessing traceability data for each piece of machinery could also follow with added sensors and continuous monitoring to decrease levels of downtime by implementing preventative maintenance more widely. A similar approach can be taken with reuse of materials as well, where scrap or waste materials can be reused especially where high-value materials are used.

It is worth remembering that as much as A&R supports circular economy, they are also part of it – solutions need to be created to allow for repair, retrofit, remanufacture and refurbishment of the devices so they can get a second or even third life (ABB, 2023). A standardised approach to traceability of equipment would allow for a wider adoption of circular economy principles for A&R. A different approach but with similar positive impact might be a Product-as-a-Service (PaaS) model, where rather than buy to own, equipment is allowed to be reused and better utilised.

Adopting current technologies and circulating more equipment is only one part of the puzzle, there are advances required to develop new technology for the manufacturing sector but also new ways of supporting elimination of waste. Novel approaches are being developed to sort recycling and other similar applications removing operators from the dull, dirty and dangerous tasks. These technologies have a level of impact now, with much more that could be realised when more systems are introduced across household recycling and related fields. In time, these technologies will become more efficient, reliable and keep increasing their impact on the recycling industry across Europe.

Further new technologies and approaches need to be developed for the incoming challenges – EV battery disassembly, electronics products, sorting and containing nuclear waste, decommissioning of vessels, power plants and others to allow for the highest amount possible of materials and parts recovered for reuse.

Most of these tasks are currently completed in a manual way with operators sometimes being in harm's way, automating these tasks could have a significant impact on circular economy as well as safety and welfare. These challenges are particularly difficult due to the product's design not having considered disassembly.

Developing technologies to address these challenges is a critical element of preparing the industries for a circular economy approach, allowing the businesses to create new capability fit for the future. Once new solutions are established, the technologies contributing can be used across industries making for an expedited developmental timescale. Between the developments being made at universities, research and technology organisations, supported by industry, the future looks bright, with new advances being developed.

However, there is a journey of adoption which needs to take place to fully realise the benefits of circular economy enabling technologies. Government support, both financial and regulatory is needed to develop the space and increase the chances of creating a high-performing industry and a prosperous and sustainable society. Without introducing A&R technologies, the manufacturing sector will suffer with other countries taking over supplying products as with automation they will be able to keep the costs down and produce a more sustainable product. A circular economy depends on having tools and a method to reuse, remanufacture and in the worst case recycle products and materials, without a strong, automated industry this will not be possible in the UK.

3.8 Skills and generational change

The development of robot technologies and increased and more widespread use by 2050 will have impacts on both skills requirements and general acceptance of robotics. This will manifest in several different ways.

Firstly, advances in sensory capabilities and intelligence, largely driven by AI, will make robot use throughout industry much simpler. It will no longer be necessary to have specialised skills to apply these machines. There will be little, or no, customisation required for specific tasks. Robots will have become the ubiquitous tool with the capability to undertake a wide range of activities. They will have the intelligence to understand and undertake the tasks required of them. Operators will also no longer require any training or particular skill sets. The use of these machines will become as natural as the use of a mobile phone.

Robots will also have taken over skilled manual tasks such as painting and welding. They will have learnt how to successfully undertake these types of operations with the sensors and intelligence to monitor the outcomes of their work and modify their performance or other equipment and tools they might be using to ensure the output meets the standards required. As a result, we will still be able to undertake these manual skilled roles using robot automation replacing the skilled workforces we are struggling to provide at present.

They will be undertaking all tasks that we would consider to be menial or arduous, particularly the 3Ds: dull, dirty and dangerous. There will be an expectation that robots will be performing many tasks that people no longer wish to perform, but still need to be undertaken. Robots will be in widespread use not only in manufacturing but also many other sectors including construction, agriculture and healthcare. It is expected there will be increased leisure time as robots will be undertaking most of the production, maintenance and service roles which are currently manual.

In addition to robots in widespread use in industry, we will also have seen them widely used throughout society in general as well as robotic technologies also being used in driverless transport systems and similar. This will lead to much greater acceptance of robots throughout work, leisure and the home. The younger generations will have been brought up with robots alongside and helping them and will not see them as alien technologies. Robots and

robot technologies will be utilised in schools and throughout the service sectors, including retail and entertainment. As a result, there will be an expectation they are there in our lives as a tool to provide support to our activities.

The one area, in relation to robots, where there will be a need for skills will be in the development of these machines. This will encompass many software and hardware skills including AI, perception including vision and sensors, electronics and mechanics including biological devices, muscles and similar. It is also likely these skills will be largely at a graduate and postgraduate level.

Robots and robot technologies will be providing support to humans throughout all areas of human activity, not just work but also leisure and the service and support sectors. There will be general acceptance of robots working alongside humans or providing support by undertaking tasks which humans do not want to do. This interaction will not require any specific skills or training with the robots having the sensory capabilities and intelligence to navigate their environments and also understand and respond to the needs of humans. The machines will be available cost effectively or via business models that enable widespread use throughout industry, service sectors and society.

The achievement of these capabilities will require significant advances in technology, both hardware and software, including cost reduction, as well as much greater availability, particularly with younger generations. The drive to provide these robots will require significant resources in pools of skilled personnel as well as funding to support the development of the technologies and the future robots. This is an opportunity and a threat. To enable these developments in the UK will require investment, both financial and skills as well as the building of appropriate RAS ecosystems to encourage and drive technological development. If developments and solutions are not achieved in the UK, there will be a need to buy in solutions from overseas which is much less attractive from a financial and security perspective.

3.9 Roadmap

The roadmap shown below in Figure 1 illustrates the path towards achieving the vision set out in this report for A&R in manufacturing by 2050. In the short term, expected transformation is mostly related to increasing capabilities of pre-existing technology deployments such as autonomous grasping, advanced sensing and increased intelligence. In addition, changes to business models and introduction of standardisation practices will help adoption of some A&R. In the mid-term HVM Catapult expects adoption of A&R across society to enhance trust amongst users, propelling adoption within the manufacturing industry, also enabling enhanced human robot collaboration as opposed to traditional A&R approaches. Here, we start to see the manufacturing industry committing to the long-term use of A&R through adjusting their product designs to enable A&R and beginning to adopt and deploy systems such as distributed manufacturing systems. Finally, by 2050, the manufacturing industry will have fully embraced non-traditional approaches to A&R, with AI and digital technologies embedded throughout their systems to enable lights-off automation where needed and enhance task scheduling and data processing. To complement this, a full curriculum dedicated to the development and growth of skills in A&R is expected to be embedded at all levels of primary and secondary education, with clear pathways for career development.

Democratisation of A&R

Distributed manufacturing and robotic microfactories

Embodied inteligence and digitalisation

Design for automation

Personalisation and new market demands

Circular economy

Skills and generation change

Emergence of business models for robot rental, costed by manufacturing time / asset utilisation

Digital twin (process) fameworks understood

Virtual build of products in A&R design models are common-place

Standardisation of traceability of equipment journey

First UK commercial deployments of distibuted micro-factories

Improved approaches to autonomous grasping and handling

Improved sensing capabilities and intelligence enabling simpler use of A&R

Vendor agnostic robot-to-robot collaboration

Automatic recovery of automation systems established

Increased efficient use of human-robot colaboration to enable semi-automation for personalised products

UK leading in deployment of distibuted manufacturing systems supporting reshoring of the production

Products designed for traceability and handling in A&R

Wide-scale adoption of technologies for recycling sorting

Wider adoption of A&R within society (eg: driverless cars) to increase acceptance

Enhanced agility of A&R systems through non-traditional programming enabling quick changes

Wide-scale adoption of distibuted manufacturing and highly automated micro-factories

AI orchestrated operation, holistically optimised at systems level, enabling lights off operations with interative digital twins. Human intervention by exception

Enhanced adoption of AI to support task scheduling and data processing

Factory configurators with optimised flow and throughput

Widescale adoption of A&R for battery disassembly and re-processing of electronics waste

Fully developed A&R education programmes embedded in curriculum at all levels

2030

2040

2050

Figure 1: Roadmap for 2050 Vision for UK A&R in manufacturing

4. **Key challenges and recommendations**

The following recommendations have been gathered from the specific sections in this report and encompass a range of recommendation to ensure **the** 2050 vision for UK automation and robotics becomes a reality. The challenges apply to any of the topics discussed in this report: democratisation of A&R, distributed manufacturing and robotic micro-factories, embodied intelligence, design for automation, personalisation and new market demands, circular economy and skills and generational changes.

The challenges are separated into five groupings following the Robotics and Automation: A New Perspective report: skills and education, finance, national support, awareness and additionally technology development (IPRC, 2022).

4.1 Skills and education

- A commitment to addressing the full skills pipeline, from different levels of apprenticeship and education programmes, including early curriculum in coding, AI and robotics and automation
- Focus on skills both required to develop new and innovative technologies and the skills required to operate and maintain these technologies within the industrial environment
- In-career (upskilling) training focussed on digital technologies, A&R and their benefits, as well as circular economy to develop a competitive edge.

4.2 Finance

- Financial support for adoption of A&R technologies within the UK manufacturing in particular for SMEs
- Commitment and support to enable second use/second-hand and new business model – such as Robotics as a Service (RaaS) rental service models – retaining the value of equipment for longer and supporting circular economy of robotics
- Access to finance for robotic start-ups need continued investment and funding opportunities to ensure they can develop their product/service to a high quality. This includes giving them access to funding routes such as venture capitalists and angel investors. Build awareness amongst the investor community on the size of the prize for robotics companies in the UK.

4.3 National support

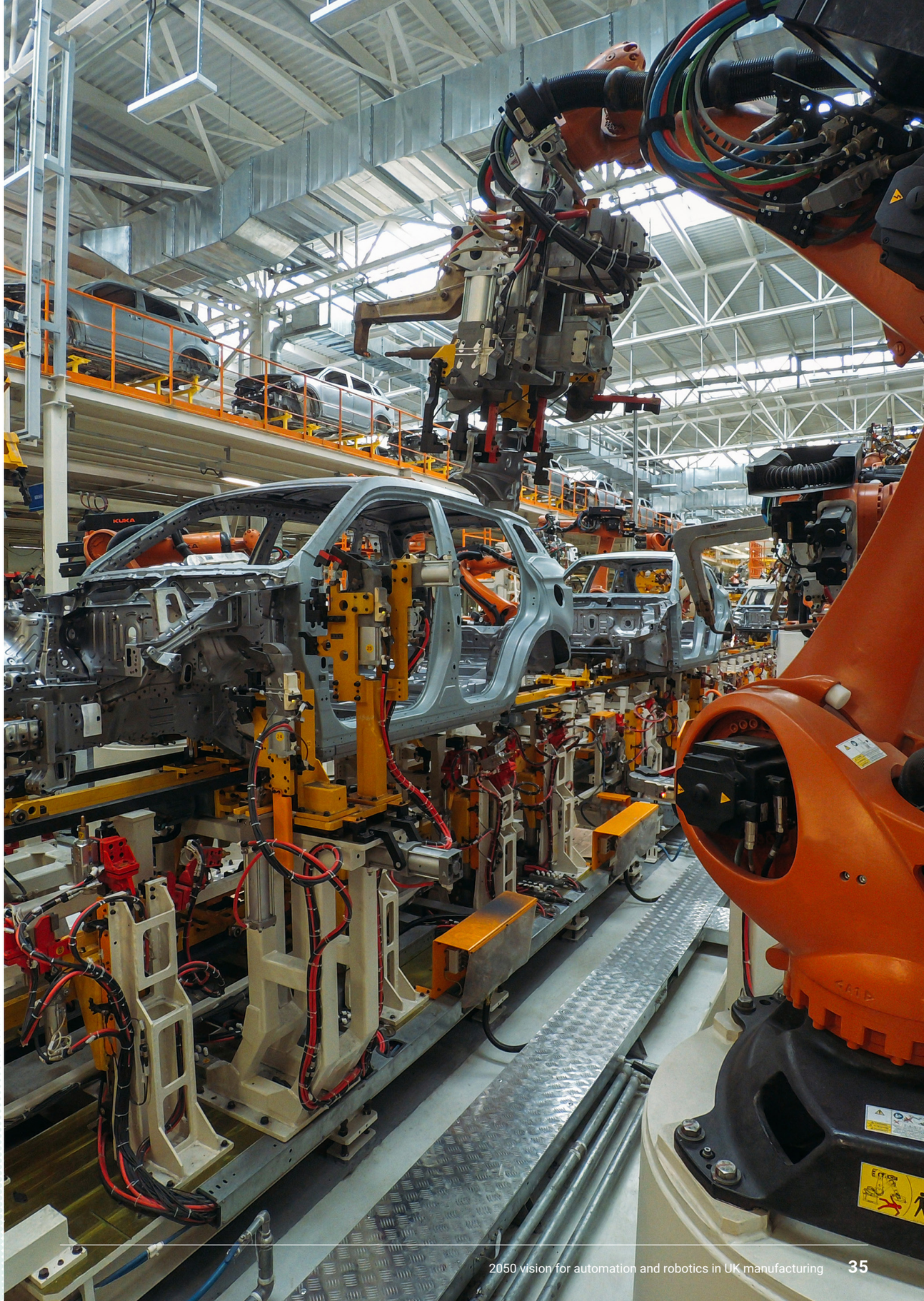
- Startups and scaling up of UK R&A – creation of regional accelerators/incubator facilities focussed on A&R supporting their access to customers through showcasing events as well as access to technical expertise and test facilities focussing on A&R
- Adoption of technology in the UK – a big challenge in the UK, is the resistance to change when it comes to new technology adoption. A government-backed, nationwide campaign, focussed on changing the perception of A&R through awareness activities would start the required cultural change for adoption of automation
- Government initiatives and policies that promote sustainable manufacturing practices, incentivise research and development, and provide regulatory frameworks for the seamless integration of technology, including use of collaborative robots, AI and autonomous systems.

4.4 Awareness

- To achieve a successful industry wide adoption of A&R technologies a joint approach encompassing all industrial sectors, supply chain, academia and RTOs would create a critical mass to move the dial on robotics adoption, improving the outcomes and availability of solutions
- Create opportunities for collaboration and knowledge sharing between the industry, academia and government bodies that would allow for a conjoined approach to delivering the vision and recommendations with a focus on widespread adoption of digital and automation technologies.

4.5 Technology development

- Planned development of A&R solutions focussing on a range of novel areas such as AI and no code/low code robotics enabling wider adoption and development of robotics and automation solutions.
- Introduction of product design for circular economy focussing on design for automation for assembly, repair and disassembly evaluating assembly complexity during a product's design phase.
- Continued technology development of solutions that allow for interchangeability and modularity increasing adoption and continued use of A&R.



5. **Conclusions**

This report recognises the importance of manufacturing to the future prosperity of the UK economy and the need for the manufacturing sector to adapt to the current challenges whilst applying appropriate technologies to ensure it is competitive. A&R is clearly identified as a key technology to help manufacturing develop and grow by meeting the challenges of today and the future.

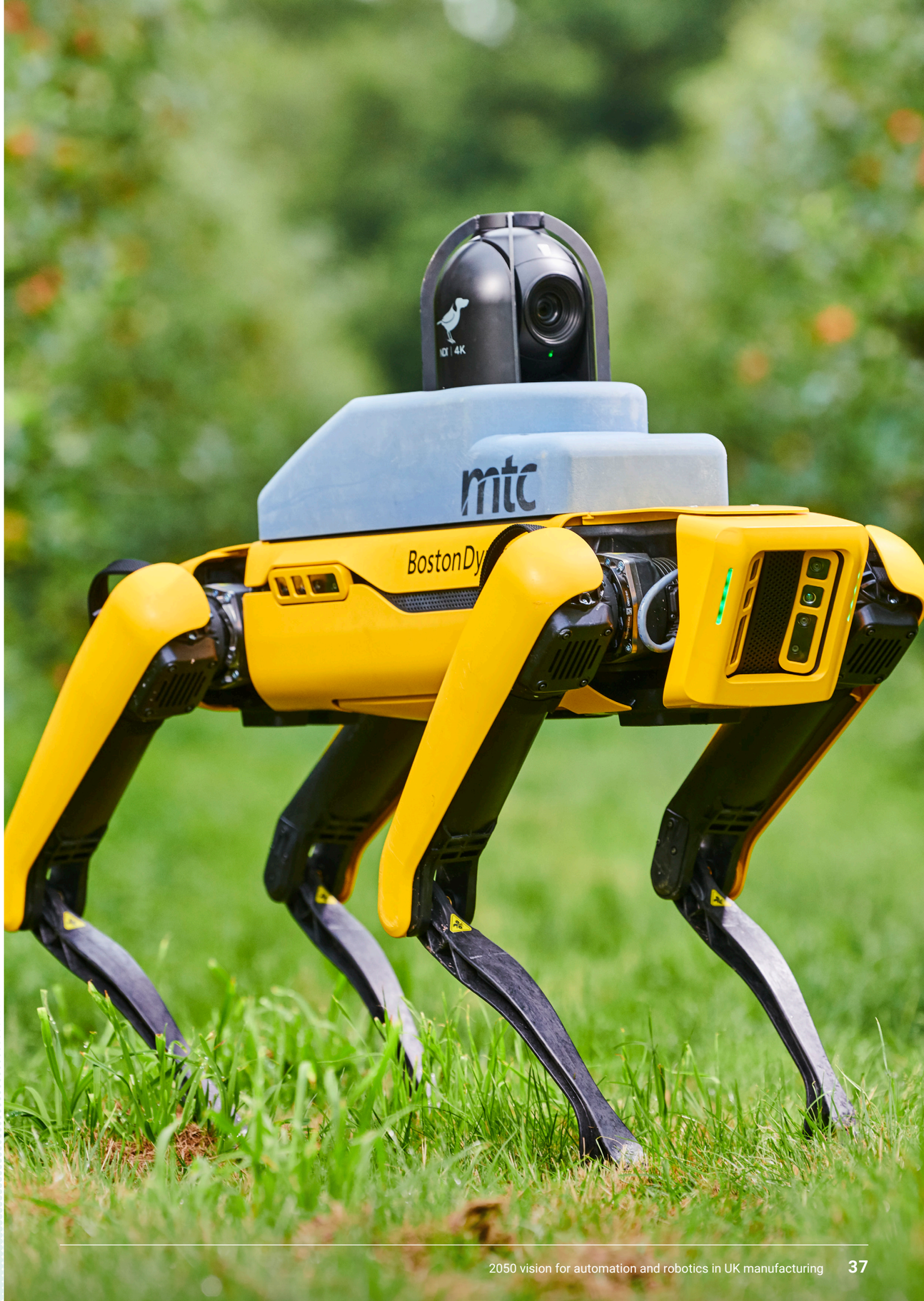
The current situation in the UK has been assessed with a SWOT analysis that demonstrates that despite a number of current weakness and threats, there are significant opportunities and strengths from which to build. It must be noted that the rest of the world is moving at pace with both the development and exploitation of A&R technologies. The UK is clearly behind in terms of adoption which must be addressed or the opportunity to develop a thriving manufacturing sector will be missed.

A potential rationale for the low adoption rate in the UK is the nature of our manufacturing businesses. There is a high percentage of SMEs with a general tendency towards high-mix, low-volume manufacture. There is therefore a requirement for highly agile robot automation solutions to meet the needs of the UK sector. The technologies, such as vision and AI, are now becoming viable and therefore these agile solutions will be realised. This provides the UK with the opportunity to leapfrog our major competitors by installing the latest technologies and, as a result, provide a significant boost to the manufacturing sector in the UK.

The themes and technologies reviewed within this report all point towards this trend. Increasing ease of use, the move towards micro-factories, meeting local market demands and the use of digitalisation to achieve smart factories will all support a much more agile manufacturing sector. The utilisation of design for assembly processes will enable the delivery of efficient and effective automated manufacturing whilst also achieving true circularity. The drivers from generational changes, provided we meet the skills requirements, will provide the opportunity to develop technological leadership.

The drive towards sustainability through achievement of net zero and a truly circular economy will provide more opportunities for A&R solutions. Improved design to enable disassembly will also provide for much easier automation of assembly operations. The need to undertake disassembly tasks will result in many new businesses performing these tasks with the consequent need for automation and labour. The need for more local, agile manufacturing facilities to increase efficiencies and reduce carbon footprint will also drive towards much greater use of A&R systems to enable the implementation of cost-effective manufacturing systems.

The UK must recognise the importance of A&R technologies and build a strong foundation, based on this underpinning technology, for our future manufacturing sector. All the constituents in the sector, from academics, RTOs, equipment and solutions providers, educational establishments and end users must work together to ensure we develop the appropriate solutions that can be easily installed, the support services to provide assistance and the skills pipeline to meet the needs of UK manufacturing businesses. Done right, the UK can build a successful manufacturing sector that drives the country's future prosperity.



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