UK-RAS White Papers

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UK-RAS NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

UK Cross-Sector RAS Development Task Force
National Collaboration Transforming the Route to Market

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FOREWORD

Welcome to the UK-RAS White Paper Series on Robotics and Autonomous Systems (RAS). This is one of the core activities of the UK-RAS Network, funded by the Engineering and Physical Sciences Research Council (EPSRC). By bringing together academic centres of excellence, industry, government, funding bodies and charities, the Network provides academic leadership, expands collaboration with industry while integrating and coordinating activities at EPSRC funded RAS capital facilities, Centres for Doctoral Training and partner universities.

Public and private organisations in the United Kingdom (UK) are investing in Robotics and Autonomous Systems (RAS) fuelling a rich vein of both academic and industrial research and development. These cover capital and operational investments across transportation networks, airports, and ports, advancements in modern methods of construction, environmental protection, and innovations in horticulture and agriculture, healthcare, nuclear, space and much more. Such investments continue to push the science, demonstrating the art of the possible with increasing levels of autonomy, dexterity, and mobility, capacity for interpreting the surrounding environment, and fast-advancing machine-learning and artificial intelligence capabilities that make the most of such functionality.

The work reported in this White Paper assesses the deployment experience taken from these investments and, for the first time, captures valuable knowledge that is emerging across disparate areas of economic activity and more specifically in public sector organisations responsible for the UK's national infrastructure. It's an exercise that creates foundations for collaboration on RAS development between sectors as it develops collective recognition for a need to share knowledge and good practice, and opportunities to reduce costs, address common risks, and accelerate their journey toward added value from RAS. The recommendations offer a way forward for supporting adoption of smart machines in the UK— which we note ranks well below its G7 counterparts and other industrialised countries— and thereby enhance the impact from automation and AI right across the UK economy. They also inherently underpin development of the UK RAS supply chain and its potential contribution to global markets for smart machines, forecasted to be less than 1% by the Manufacturing Technologies Association. The impact of this work lies in the range and scale of the organisations that have been actively engaged and in the intensity of the consensus these organisations have reached.

The UK-RAS white papers are intended to serve as a basis for discussing the future technological roadmaps, engaging the wider community and stakeholders, as well as policy makers in assessing the potential social, economic and ethical/legal impact of RAS. It is our plan to provide future updates for these white papers, so your feedback is essential whether it be pointing out inadvertent omission of specific areas of development that need to be covered, or major future trends that deserve further debate and in-depth analysis. Please direct all your feedback to info@ukras.org.uk. We look forward to hearing from you!

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Department for Science, Innovation, & Technology

This report was prepared partly under the auspices of the Robotics Growth Partnership, which is mandated by the Department for Science, Innovation and Technology to support robotics procurement and supply chain activities.

EXECUTIVE SUMMARY

This White Paper describes the work undertaken to form a UK Cross-Sector RAS Development Task Force and the key lessons learned in the first stages of collaboration between the different public and private sector stakeholders engaged within it. The unique value of this enterprise lies in the significance of these stakeholders in a national context and in the resulting recognition from them that collaboration at a national level will be essential in driving the UK to maximise the benefits of Robotics and Autonomous Systems (RAS)[1] within its national infrastructure and in the associated supply chains.

The Task Force created through this work brings together an unprecedented range of public sector and infrastructure stakeholders who have recognised that they may be better served by working in collaboration. Each has assessed that RAS can play a key role in their achievement of core objectives, both economic and societal, while also appreciating that RAS is complex and must be adapted to their own circumstances and applications. In coming together, varied common interests emerged that would both add value to stakeholders' individual objectives and progress more effectively with a joint approach to development. In taking stock of their work, it is possible to begin to understand the emerging business cases for RAS, the underlying cross-sector technologies, and the corresponding opportunities for development within the supply chains. This White Paper provides an overview of this context through the insights of the organisations that are driving development, and shares selected use cases, sector influences and initiatives that illustrate varied contributions to the emergence of this joint approach.

The work has the potential to kick-start a process for enabling the articulation of a "whole economy" approach to RAS development supported by a vibrant UK innovation ecosystem. It also contributes to fundamental national discussions echoing the remit of the Government's newly created Department for Science Innovation and Technology to align technology innovation across government, exemplifying its approach through the range of government departments its members are associated with.

The cohesion of understanding expressed within the Task Force creates an urgent need to establish national capability to accelerate their knowledge exchange, drive regulatory reform, enhance skills, and share best practice that can ensure lessons are shared and used cross-sector to benefit the national agenda.

To this end, a set of recommendations are made to:

1. Provide continued support for engagement between the emerging cross-sector community by formalising the inception of the Task Force.
2. Assemble a national cross-sector regulations, standards and ethics committee to develop joint approaches and lower supply chain barriers.
3. Carry out a cross-government requirements analysis to define procurement-based innovation, drive uptake across use cases and sectors, and enable the government as an intelligent customer.
4. Formulate and deploy tools that assist in bringing RAS, including within the context of other technologies, into the development cycle of projects at an early stage.
5. Define and deliver a portfolio-based innovation programme that enables best practice and knowledge transfer and highlights national exemplars of RAS deployment.

Success built on these recommendations will be seen when sectors are able to approach the deployment of RAS through an examination of how others have achieved it: The outcome being a shared understanding of; where and how RAS applies, of the key use cases, of the regulation and skills needed and of how RAS fits technically. Ultimately, this would identify innovation opportunities for a pipeline of cross-sector technologies within the UK for rapid development and uptake of RAS technology that will positively transform productivity across the economy. This requires a strategic view that can be developed by acting on knowledge that is currently buried in the lived experience at the point of adoption. It requires the ability to test scenarios, not just focussed applications, and to arm supply chains with an understanding of the requirements and innovation opportunities that can deliver significant value at lower cost. Progress today is reliant on early adopters with the resources to shoulder the complexity, significant costs, and associated risks. As solutions advance toward readiness for deployment, these organisations look for the levels of sustainability and support that exists with more established technologies as they consider embedding them within their programmes or operations, adding to the risks that slow development.

The ambitions for a national capability have been identified to underpin dependencies across the economy, growth and productivity, as well as societal wellbeing. The cost of not taking the opportunity to accelerate the maturing of these technologies by strategically enabling the sharing of this growing body of experience would be significant.

[1] Definition- Robotics and Autonomous Systems (RAS) : Robotics and autonomous systems (RAS) include machinery and physical systems that can act independently of human control, by sensing, reasoning and adapting to a given situation or environment. In contrast to more traditional machines that have a single, pre-determined purpose, RAS applications are able to understand what is happening in their sphere of operation and tailor their behaviour to particular circumstances with varying degrees of decision-making autonomy. Source: BEIS 2021, THE ECONOMIC IMPACT OF ROBOTICS & AUTONOMOUS SYSTEMS ACROSS UK SECTORS, prepared by London Economics

"Success will be seen when sectors are able to approach the deployment of RAS through an examination of how others have achieved it.....This requires a strategic view that can be developed by acting on knowledge currently buried in the lived experience at the point of adoption."

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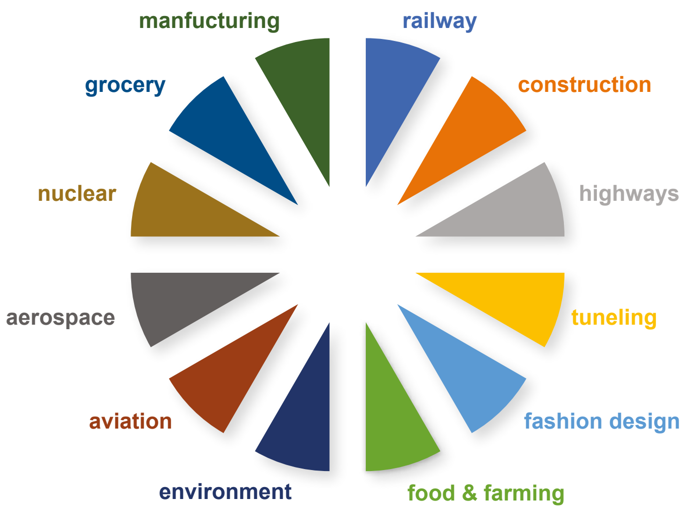
1. INTRODUCTION

The UK Cross-Sector RAS Development Task Force first came together in September 2022 to explore opportunities for collaboration on RAS solutions for their development roadmaps, and to share knowledge for addressing the challenges they face on the road to adoption.

The Task Force has developed a broad community of interest of over 100 public and private stakeholder organisations covering 12 sectors of economic activity (see chart) that participated in a series of structured discussions and an interactive symposium hosted on behalf of the Task Force by the UK Government's Department for Science, Innovation & Technology, and the Department for Business & Trade. The programme of work also included one-to-one problem-book sessions with public sector challenge holders, including the Department of Transport, National Highways, the UK Space Agency, Network Rail, Lower Thames Crossing, Sellafield Sites and National Nuclear Laboratory, Heathrow Airport and the Department for Environment, Food and Rural Affairs, creating a unique



opportunity to collate challenge statements underlying the value cases, targets, and developing practices for existing public-sector investment programmes. While not meant to be an inclusive overview of all RAS development, the work summarised here provides perspective from the people that are driving development, and representatives of their supply chains, capturing both high-level observations and direct recommendations shared across the community of interest.

Established with initial project funding from the EPSRC UK-RAS Network, the Task Force is led by Professor Samia Nefti-Meziani OBE, Chair in Robotics and AI and Director of the Birmingham Robotics Institute, with the support of UK-RAS member Universities: University of Surrey, University of Warwick and University of Leeds. It is chaired by Tobias Lin, National Space Capability Lead, Department for Science Innovation and Technology, deputy-chaired by Dan Jones, Future Markets Lead, UK Space Agency, and includes participation from: The Department for Science, Innovation & Technology, Department for Business & Trade, UK Space Agency, UK Research and Innovation (UKRI) (including Engineering Physical Sciences Research Council (EPSRC), Innovate UK KTN, Science and Technology Facilities Council (STFC)), High Value Manufacturing Catapult representatives (including Manufacturing Technology Centre (MTC), Construction Innovation Hub, Nuclear Advanced Manufacturing Research Centre (NAMRC)), Department for Transport, Department for Environment Food and Rural Affairs, Lean Construction Institute, National Highways, Lower Thames Crossing, Heathrow Airport, Network Rail, Sellafield Sites, National Nuclear Laboratory, Robotics Growth Partnership, National Robotics Network (NRN), The Lincoln Institute for Agri-Food Technology; Health and Safety Executive; Arcadis, MDA, Jacobs, and a growing community of interest.

Their observations, with reference to relevant underlying contexts, are detailed within Part One: Insights Elevating Opportunity and Part Two: Lessons Learned of this Paper. Part Three: Sector Influences & Use Cases, features select contributions from individual Task Force contributors who have taken the time to detail their current initiatives and the developing strengths driving emergent understanding of the overall opportunity.

The range of organisations involved offers the opportunity to kick-start a process for enabling the articulation of a "whole economy" approach to RAS development, backed by their weight of influence. These observations evidence a prevalence of common interests and strategic imperatives for underpinning stated ambitions targeted at advancing economic and societal wellbeing.

The Task Force programme of work contributes to fundamental national discussions currently in motion, particularly within the remit of the Government's newly created Department for Science Innovation and Technology. In her opening speech at the May International Conference on Robotics and Automation in London[4] Chloe Smith,then Secretary of State for Science, Innovation and Technology emphasised many opportunities to address significant challenges from the transition to net zero, interacting with dangerous environments, and improvements in the quality, safety, and productivity of the work people can do. Declaring "regulation is right at the heart of my agenda," she said her government was unafraid to work together with industry and academia to get it right and make "Britain the best place in the world to start and scale a safe and successful robotics business." These are words that speak to the ambitions and priorities shared by the Task Force's community of interest, including proposals that directly align with her Department's mandate to drive innovation that changes lives, sustains economic growth, and creates better paid jobs, by positioning the UK at the forefront of global technological advancement.

[4] https://www.gov.uk/government/speeches/secretary-of-states-opening-speech-at-robotics-and-automation-conference

PART ONE

1. INSIGHTS ELEVATING OPPORTUNITY

1.1 BREAKING DOWN SECTOR SILOES

The work to create a cross-sector stakeholder community of Interest for RAS is driven by the recognition that early deployment of RAS is complex: complex because of the technology, complex because it is untried, and complex because it changes modes of working that, in some cases, have been in place for many decades. Such complexity is amplified by a bespoke development culture typical of any early-stage technology advances, and the resulting sector-siloed multitude of approaches to advancing solutions for RAS. Choices between alternative handling, sensing, and mobility components, and their associated software and interaction components, shape the specific machine to be applied to each sector challenge. This situation relies on early adopters to shoulder the complexity, significant costs and associated risks. As solutions advance toward readiness for deployment, user organisations look to understand levels of sustainability and support that exists with more established technologies as they consider embedding them within their programmes or operations, adding to the risks associated with adopting such fast-evolving innovations. Normally modularity standards emerge from dominant members of developing supply chains, but with RAS the current level of bespoke development of application-specific machines coupled with the new skills and technology needed has created slow and costly development of such standards, calling for a different approach.

Turning this dynamic on its head, The UK Cross-Sector RAS Development Task Force came together to identify if common approaches and requirements exist. Early discussions identify opportunity to collaborate more deeply and triggered a process for articulating a cross-sector problem book with focussed sessions for challenge holders to discuss specific design criteria and implementation experiences that are currently influencing innovations for RAS and related technologies. Many challenge holders are engaged in requirements gathering, development or implementations addressing immediate needs, as well as the longer-term prospects for RAS technologies to support the decades-long operating expectancy of many projects currently in planning. One contributed insight from the National Highways CAP Roadmap (more detail on CAP in Part Three) confirms that significant segments of the building trade, including more than 60% of the organisations in housing and commercial segments, are already deploying connected or autonomous construction equipment [1].

Five high-level observations emerged from across the sectors outlining that:

1. The deployment of RAS is already being built into the profile of capital investment and improvement schemes across the economy based on existing assessment of its impact and on an expectation of future capability. Some future planned investments would be impossible without using RAS.
2. The navigation of standards, regulations and ethics presents significant hurdles to adoption of RAS solutions, while a lack of harmony across these factors limits supply-chain ability to scale across sectors.
3. The values inspiring the evaluation and adoption of RAS reflect key challenges in an increasingly socially conscious economic climate, where workplace health and safety, ethical considerations, net zero, and circular economy targets sit alongside more direct financial impact.
4. A growing repository of experience, lessons learned and developing practices is emerging within sectors. Making it available cross-sector will accelerate the transference of technology, methods, learning and practice, that can quicken uptake in new areas ripe for the adoption of RAS.
5. The skill transformations needed to both understand, procure, deploy and operate RAS within complex infrastructure can be shared between sectors, creating opportunity for cross-sector approaches to establish an economy of scale for skill development.

Such observations are testament to how robotics and autonomous systems are working their way into a growing number of real-world applications, and inspiring challenge holders to not just think about how they may evolve their organisations with them, but also set targets that begin a process of adaptation that responds to their impact. More importantly, it provides context that informs emerging business cases, the underlying cross-sector technologies, and the corresponding opportunities for development within the supply chain. In addition, the opportunity ahead is dependent on allied areas of technology and fast-emerging conditions across the technical fabric driving societal change; from the IoT and network foundations of a cyber physical infrastructure, to the Government's efforts to ensure sovereign capabilities and broad adoption of safe and reliable foundation models in Artificial Intelligence (AI).

A common outcome from the considerations discussed is the need for national coherence around RAS technology and infrastructure. A need was identified for a focal point for access to cross-sector RAS resources both at a technology level and at a process level. This is seen as an opportunity to create alignment between sectors in terms of a range of technical domains, including autonomy, AI for systems, digital twins; processes from regulatory systems; procurement and skills development. Such a national focal point can accelerate uptake and propagate RAS best practice and knowledge transfer between key end users in sectors, across critical infrastructure as well as within government services.

1.2 THE VALUES INFLUENCING CHANGE

1.2.1 Productivity & Infrastructure Optimisation

A 2021 study commissioned by the UK Government estimates the total economic impact of RAS uptake in the UK to be in the region of £6.4 billion by 2035, placing £4.4 billion within a single sector, warehouse and logistics. Prepared by London Economics, The Economic Impact of Robotics & Autonomous Systems Across UK Sectors[5] also estimates an economic impact of £149.9 billion if all sectors in the study were to achieve their potential rates of automation. Evaluating opportunities for enhancing productivity, the report acknowledges that UK productivity is lower than in many peer economies such as the United States, France and Germany as reported by international body The Organisation for Economic Co-operation and Development (OECD) and that growth in the UK, as monitored by the Office of National Statistics, has been sluggish since the 2008/09 recession.

Significant programmes of work supported by the UK Government, such as those guided by the Transforming Infrastructure Performance Roadmap [2] and industrial strategies address the optimisation of national infrastructure delivering energy, utilities and transport by creating the knowledge and capability to transform services and maintain a balance between the natural and built environment with new technology. RAS is emerging as an integral part of this transformation.

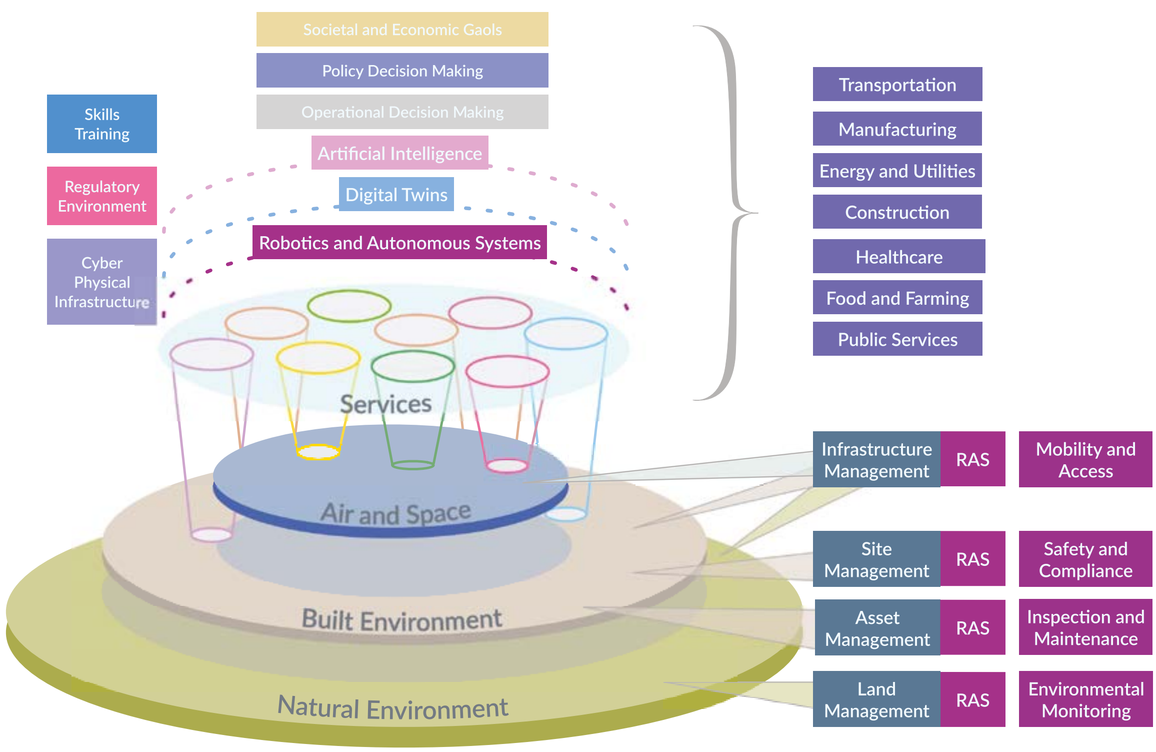


Figure 1: Illustrates the breadth of application of emerging roles for RAS and associated technologies within the context of the transforming public infrastructure performance roadmap, the Government's vision for innovation and reform in infrastructure delivery.

5 https://www.gov.uk/government/publications/robotics-and-autonomous-systems-the-economic-impact-across-uk-sectors-2021

1.2.2 Workplace Health & Safety

Alongside these national programmes, there is a context for RAS being advanced more broadly to progress better working conditions. For example, technology adoption rates in the construction sector, one of the largest sectors of the British economy, have significantly lagged behind others, with processes remaining unchanged for many decades. It is recognised, as outlined in Part Three – Sector Influences & Use Cases, that this must change in the face of significant challenges that include an operative fatality rate reported in 2020 to be around four times higher than the all-industry rate by the UK Health and Safety Executive [3] and an ageing workforce. Our challenge holders universally identified that their assessment of RAS potential is deeply rooted in the need to take people out of harm's way and improve working conditions, as these concerns become a key criterion for innovation across development programmes.

In some cases, such as the featured case study from the Port of Felixstowe (also in Part Three), improved health and safety is the leading value driver for innovation. Many also highlight ambitions to make their sector or workplace attractive for the next generation citing both the modernisation of roles and the opportunities to manage workload pressures as smart machines reduce the need for time-consuming manual or on-site tasks, by for example using remote inspection capabilities.

1.2.3 Net Zero Impact

Targets to achieve net zero and improved environmental conditions (net zero plus), that are being embedded into public infrastructure capital investment and operational management, are also cited by our challenge holders as having a significant influence on the current value proposition driving RAS investment. The manufacturing sector, which employs 2.7 million people in the UK, identifies potential for automation to produce goods as energy efficiently as possible, including enabling more local manufacture as a key contribution to the nation's commitment to a carbon net zero economy by 2050. [4] A grand challenge for the construction sector as a whole, targets reducing greenhouse emissions in the built environment by 50%. [5]

Task Force challenge holder Heathrow Airport points to a focussed carbon and sustainability plan as one of six areas in its H7 5-year £3.6 billion capital improvement programme. Another challenge holder, Lower Thames Crossing, a project to relieve congestion at the Dartford Crossing by creating a 14.3-mile link under the Thames River aims to increase biodiversity in the area, limit the footprint of construction activity to mitigate habitat loss, and cut the amount of carbon expected during construction by one third. The project, due to break ground in 2024/25 will create the longest road tunnel in the UK. Engineering for the tunnelling is to use automation, virtual and augmented reality tools to minimise the exposure of humans to dangers in the operation and maintenance of the heavy machinery; AI and intelligent data within the built asset to improve asset life; and offsite construction to optimise logistics, scheduling and other measures that determine levels of waste, carbon footprint and quality.

1.2.4 Procurement Support for Innovation

Challenge holders recognise that ambitions are evolving beyond the low skill, repetitive tasks that are often assessed for robotics adoption, and that a high level of collaboration with their suppliers must be established from the early design stages of programmes and their built assets. Successful consideration of new technology, of how it can be utilised and how best to approach and adopt it requires open discussion and market engagement prior to the commencement of procurement exercises. Delivering innovation therefore is being considered prior to the design stage when project outcomes are being defined and as part of the specification when engaging firms in the supply chain. Examples of good practice include clear targets being written into requests for proposals and later contracts that become the basis of discussion, not just submission for how they may be achieved; budgets for training and skills development that become part of the programme or project ethos, along with support for shared learning. Heathrow, for example, manages a large number of diverse infrastructure assets, including the largest privately-owned water and high-voltage electric networks in Europe, 125 km of roads, 4 million square metres of paved runway and multiple building-control systems supported by many and varied service providers and suppliers. This complexity of interdependent assets has inspired Heathrow to instigate an innovation community where its supplier companies look beyond competitive boundaries to discuss responses to daily challenges and incidents and inspire proposals for solutions. Such insights reveal developing approaches for managing emerging challenges with the introduction of new technologies such as RAS that can significantly alter current practice, and even challenge regulatory norms within complex asset structures.

1.3 THE STRATEGIC IMPERATIVE

1.3.1 International Leadership

The UK has set out global ambitions for Science and Technology in The UK's International Technology Strategy published in March 2023[6]. This new international strategy places the UK Science and Technology Framework [6] in an international context and sets out the ambition to champion the UK as a global leader in science and technology aligned with an "open, responsible, secure and resilient" approach. While robotics is not currently one of the five technology areas the framework focuses on, it is advancing with and supporting development of several of them, particularly AI (see Enabling Frameworks below), while the overall value drivers discussed within this White Paper are strongly in line with the priorities and ambitions expressed within Task Force sessions and events.

In particular, the framework details ambition around public procurement, skills, regulatory reform, innovation infrastructure and funding. It also sets out the need for inter-departmental engagement in the use of advanced technologies in delivering public services and sets a remit for DSIT in "bringing together core science and technology functions across government". This aligns with the demand side needs of the challenge holder organisations engaged in this work and their supply chains.

The Task Force sessions reveal clear ambitions for leadership by evolving ways of doing things, from building bridges, schools and hospitals, farming and producing food to engineering one of the world's largest tunnels. Contributors advocate that emergent knowledge and evolving business models, where for example buildings move from being projects to products, and food production sits within the farm gate, have a contribution to make beyond national ambitions with opportunity to create exportable intellectual property.

These sessions also offered insights into developing international agreements that assume a dependency on robotics as they seek to establish the UK's contribution to global initiatives, such as the building of a lunar gateway, developments in space-based solar power, nuclear fusion and hydrogen energy.

The UK is not alone in considering these opportunities. Other influential nations and organisations have updated strategies that align with ambitions either focused on societal concerns, for example the European Missions or the United Nations Sustainable Development Goals (SDGs) or on national technology sovereignty and industrial strength as in the strategies of Korea or China. Notably, Canada's approach of focusing on end users and engagement with small and medium enterprises rather than technical progress aligns well with this White Paper and perhaps indicates that an international dimension to this work could be explored.

The UK needs to keep pace with these international contexts. RAS is being advanced as a dominant factor in achieving productivity gains in the next decade and there is a risk of long-term disadvantage for the UK if it falls behind innovation and adoption curves whilst influential economies, including China, the United States, Japan and Australia ramp up investment in RAS capabilities in support of their national strategic development goals.

1.3.2 Enabling Framework

In the main, these national and transnational strategies focus on both innovation in robotics technology and on how these innovations are translated to market. The overwhelming evidence from the UK Task-Force sessions underlines that the enabling of adoption, rather than the advancement of technical capabilities per se, is the current core requirement, and that this requires collective action both in government, with end users and through supply chains, by addressing the socio-technical, organisational and cultural barriers to greater deployment.

This aligns with the national perspective for RAS development that is driven by the need to improve resilience, productivity, and security, as outlined in The Cyber Physical Infrastructure Vision [7] published by the Robotics Growth Partnership and a subsequent government consultation exercise [8] which set out how AI, Digital Twins and Robotics can be used together to bolster resilience, productivity and security, stating:

"Working through the CPI makes a step change in our productivity. It enhances resilience by providing the means to adapt and repurpose at pace. It levels-up through greater accessibility and remote working. And it prepares us to face the major challenges ahead in sustainability, security and prosperity."

At its core is the establishment of a national initiative to create, through a "digital commons" approach, cyber physical infrastructures that join robotics to synthetic environments driven by AI. For example, autonomous transport systems able to schedule against demand fluctuations and environmental conditions; or a hospital able to integrate all relevant data to drive supply logistics. Clearly such an approach also applies to large infrastructure projects where a real-time digital twin, being updated by sensing assets can be used to schedule and optimise construction and planning, both in the immediate term and in forward projection.

[6] Derived from the Integrated Review 2023, a refresh of the Integrated Review 2021

Robotics serves a dual role in such complex structures, acting both as the actuator to carry out physical tasks as well as one of a range of sensing assets. Robots can, in addition to the visual sensing ability needed to navigate, be augmented with additional sensor types to provide rich multi-spectral sensing of an environment. This real-time feed of up-to-date data keeps the digital twin in sync with the site in a way that is currently impossible. Such an approach requires a national infrastructure of interlinked information to be shared, open and available. For example, information about the wider transport network might be used to impact on delivery predictions at site, or real-time information from a national water authority on the impact of works.

These developments lay the ground for a significant opportunity in the UK to advance prospects for smart machines, the related developments in AI, the digital twins that these machines will catalyse and the critical sectors looking to these technologies: the UK space sector contributions to the emerging maintenance market of in-orbit infrastructure that supports business and society around the globe, for example and pioneering processes in nuclear decommissioning, employing robotics, for compacting and storing low, intermediate and high-level nuclear waste from the UK and overseas at Sellafield. (More detail in Part Three)

Collectively, the UK is advancing the necessary technical expertise to support adoption of RAS at scale, presenting a clear opportunity for informing a well-focused strategic vision that highlights RAS in a broader technical, national, and international context and is tuned to UK strengths and needs.

1.4 ARTICULATING A PROBLEM BOOK

1.4.1 The Emergence of Shared Understanding

Success built on the recommendations in this White Paper will be seen when sectors are able to approach the deployment of RAS through an examination of how others have achieved it. The outcome will be a shared understanding; of where and how RAS applies, of the key use cases, of the regulation and skills needed and of how RAS fits technically, ultimately identifying innovation opportunities for a pipeline of cross-sector technologies.

Opportunities that challenge holders are exploring are varied, with examples that cover inspecting track networks, surveying site conditions, the environment and flood defences, clearing litter, managing cargo or changing parts without having to get in the way of heavy equipment, fast-moving vehicles or enter dangerous spaces.

Common challenges, use cases and the experiences along the journey toward automation and adoption of robotics in such scenarios are highly apparent across multiple sectors. This includes characteristics of the environments in which robotics are being deployed and other varied requirements such as security or integration with data platforms that are informing systems design. Our challenge holders are at different stages of adoption, from assessing the opportunities to testing specific innovations or in some cases such as space or nuclear decommissioning, developing underlying capacity to advance levels of autonomy. Almost all are working to embed capabilities within mission-critical operations, and therefore looking for assurances of sustainability and quality, testing for very low tolerances in failure rates, and seeking verification of systems resilience. In doing so, they are identifying current gaps in the availability of data and support that could provide such assurances as a key barrier to progress and, inherently, an imperative for collaboration.

A significant first wave of implementation experience is emerging with off-road use of connected autonomous vehicles and aerial drones presenting a clear opportunity for initial knowledge sharing and documenting lessons learned and developing practices.

1.4.2 Operational Challenges

Inspection and assessment of environments from underground mines to coastal cliffs or construction sites was universally identified as an area of interest, if not current activity. Many are assessing new approaches to the monitoring and maintenance of built assets and machinery, and eventually associated systems that can facilitate automated repairs, changing of worn tool heads, or initiation of upgrades. There is significant interest fuelling the capacity to identify, sort and manage different types and sizes of materials. Tunnelling and excavation are also commonly identified operational challenges; as are module assembly, whether they be within a manufacturing, on-site construction, or an extra-terrestrial environment.

While each sector has its specific requirements, they share many high-level considerations associated with deploying RAS solutions including:

- Physical hardening: From high radiation and extreme temperatures within space and nuclear to construction operations in underground spaces, hazardous environments and extreme weather within terrestrial environments, robots are being subject to harsh physical conditions.
- Navigating unstructured spaces: Many delegates are actively exploring opportunities to enhance robotic mobility to negotiate unstructured and uneven and variable (muddy) terrains.

- **Dynamic operating environments with limited or incomplete information:** Live construction sites, for example, are rapidly changing, dynamic risk-prone and unmapped work environments subject to changing weather patterns or operational conditions) resulting in uncertainty and risks of failure.
- **Human-in-loop operation:** Almost all active operations currently use human-in-loop command and control systems to minimise error, maximise user comfort and/or increase productivity and efficiency in human-robot cooperative systems.
- **Trustworthy by design:** The overarching need to provide safety certification, assurances of reliability and resilience and for systems to meet formal regulatory and internal procurement regimes have challenge holders documenting processes for embedding such criteria within the design cycle.

1.4.3 Strengths in Existing Initiative

Many existing initiatives within individual sectors spoke to others' requirements or expressed ambitions that resonated across the group, including the mentioned use of drones, the hardening of underwater systems to monitor oceans or manage nuclear waste; the digital mapping of underground services, the integration of fleet and asset management systems and the development of human-robot interfaces for arms-length and remote teleoperation. These technical capabilities are influencing an emerging domestic innovation ecosystem, enriching the development of test beds and data platforms, and focus ambition for digital twinning to improve knowledge capture and ultimately management of complex assets.

A collective view of the articulated requirements is informing significant interest in common design criteria for component and system elements, including underlying data structures that could advance lower cost, easy-to-use, reconfigurable, modular, and adaptable systems that can be well-specified for cross-sectoral applications. Current investments into AI and sensing in unstructured environments, built asset design and levels of autonomy in particular, inspired interest in the advancement of common use cases, technical specifications and taxonomies for modular technology, along with supporting guidance based on collaboration around: common criteria for facilitating interoperability, configurability and reuse; platformed plug-and-play services built on common data platforms; common technology and task-specific building blocks that respond to broad and growing demand.

Challenge holders and symposium delegates put a specific emphasis on enabling ways for humans to work differently, extend their capacities, accuracy, or efficiency in addressing challenges as well as eventual transitions to autonomy where relevant. This prompted discussion around the desired human-robot ecosystem that could emerge with common understanding of human safety measures, reliability and robustness, and compliance implications that could eventually lead to certification of systems and solutions addressing desired standards in communication, dependability, security and sustainability, for example.

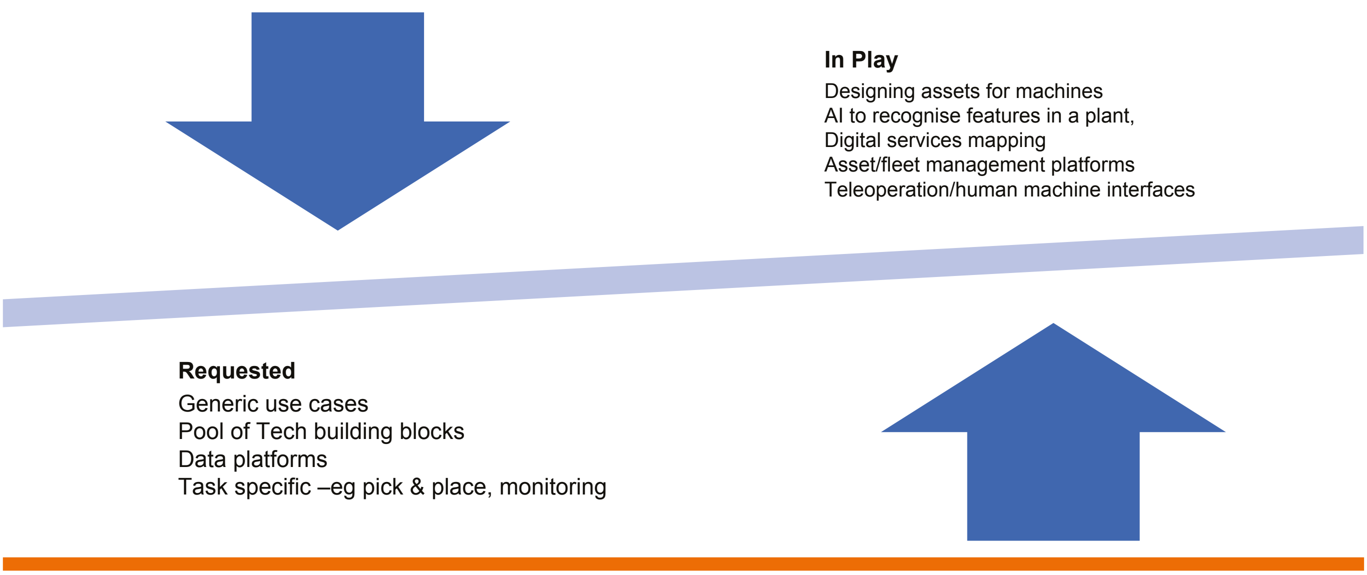


Figure 2: Details of a selection of the current initiatives that are already in play and the requested common resources they could be deployed to support.

1.4.4 Advancing on Collective Experience

To move beyond the "show" and use RAS to advantage will only be achieved slowly, if at all, when done on a sector by sector or project by project basis. Various Task Force contributors highlighted limitations in their experience and/or their sector capacity to generate enough demand to interest system integrators and developers in their needs alone. They also acknowledge complex and comprehensive supply chains delivering their capital works and the risks involved for them to follow on the innovation journey, citing barriers that include a lack of clarity around liabilities, ownership, and regulatory concerns, alongside the constraints of annualised budgets that limit longer-term visioning.

The growing repository of experience, while reflecting a mix of different approaches to development and engagement, is inspiring significant interest in advancing the shared understanding. With discussions highlighting common operational challenges, an exchange of knowledge could inform all levels of innovation planning from the definition of value and design considerations to the transfer into operational management, maintenance and anticipation of future, if as yet unknown innovations. Notable opportunities include:

- the best approaches to engaging, collaborating and educating supply chains who may have little experience of RAS working;

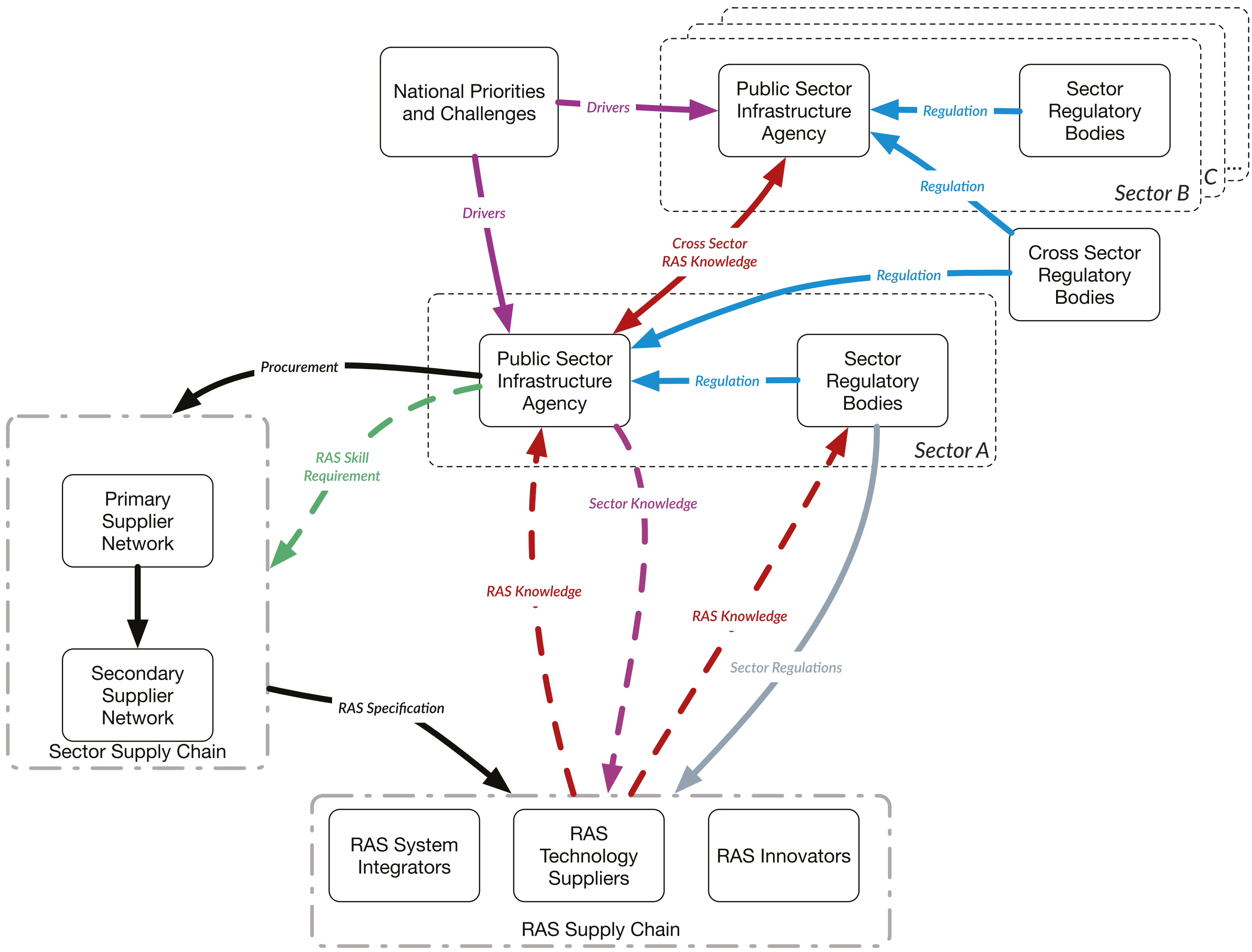


Figure 3: Outline of the knowledge flows across multiple agencies and regulatory bodies, both sector-specific and general, needed to enable RAS adoption. Each flow needs intervention to prevent it becoming a barrier to adoption.

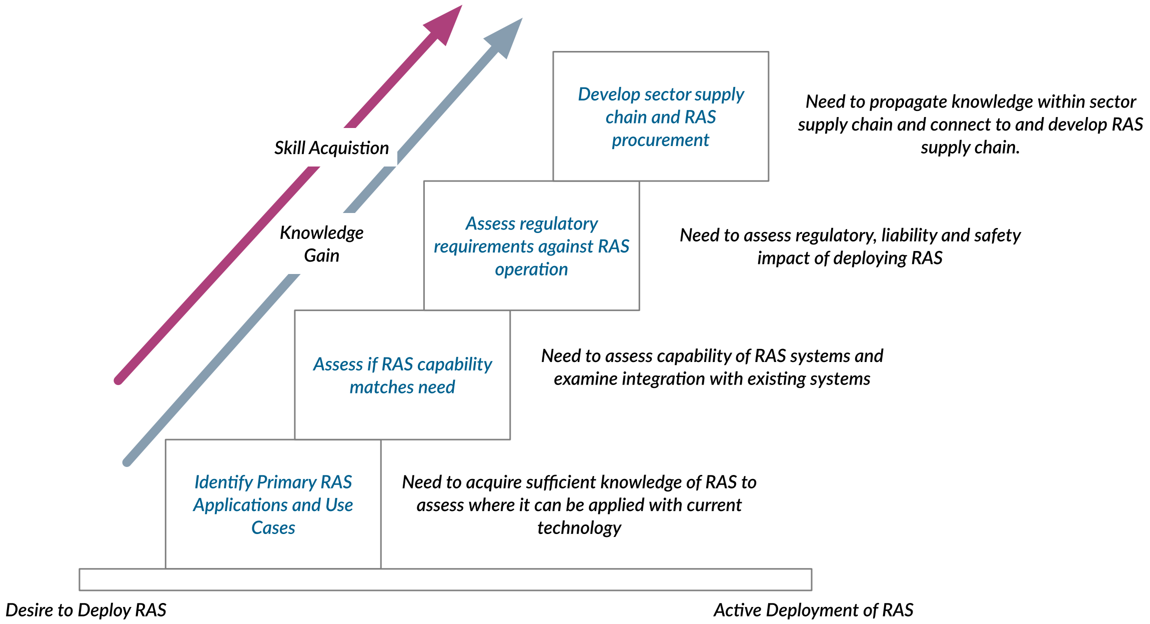


Figure 4: Illustration of knowledge steps needed to achieve deployment of RAS and therefore the knowledge barriers that need to be overcome.

- the deployment of the technology itself to best effect, its integration into both existing technical systems and its integration with other systems such as AI driven data analysis and digital twins;
- the performance of RAS in addressing structural issues such as labour shortages or low carbon delivery; and
- the need for regulatory collaboration around liability and the construction of safety cases.

In each of these areas, there was acknowledgement both of the need to understand them in context and to understand where shared context might be used as an advantage for all. Examples cited cover the potential development of common approaches to safety that could be regulated across sectors, or the generation of a larger market for RAS equipment by aligning needs and standards, or the common championing of the skills needed in the workforce through shared educational programmes. Recognition of these collaborative strengths also drives the imperative to engage government in the process, to use its convening power to champion on a wider scale than a single project or sector.

1.4.5 Cross-Sector Dependencies

Further, sectors recognised cross-sector dependencies driven by modernisation agendas were an incentive for collaboration on initiatives that can bring down costs and reduce risks in meeting stated aims. For example, Defra's Horticulture Automation review highlights the advantages of collaboration and knowledge sharing "as a more effective use of limited development resources, accelerating technologies to market and increasing the chance of success". It identifies the impact of fragmentation between technology developers, across the private, research technology organisations (RTO) and academic communities, and reports of duplication "where many stakeholders work on the same common problem." [9]

Significant risks associated with applying autonomy in space, in particular, which may cause issues with regulation and qualification of technology for missions, is prompting assessment of solutions that can be demonstrated terrestrially before they are applied in space. With declared missions working toward the building of space infrastructure such as the lunar gateway and solar power noted above, Space is also looking to advances in modern methods of construction that are in turn benefitting from advanced manufacturing processes to meet declared aims. Sellafield, the largest site of the Nuclear Decommissioning Authority (NDA) estate, points to imperatives for cross-industry collaboration on many key enabling activities for their robotics development roadmap (to be published later this year), including the advancement of functional and intelligent client capability, standardised systems, cybersecurity, regulatory frameworks and sustainability.

1.5 THE CALL FOR CLARITY: REGULATIONS, STANDARDS AND ETHICS

Discussions were steeped in a universal desire across regulators, challenge holders and all participating stakeholders to address the fact that current standards, regulatory, funding and therefore procurement landscapes have not anticipated the journeys currently in play, leaving many hurdles to overcome. Identifying the navigation and interpretation of standards and regulations as a first priority for advancing their shared understanding, these discussions elevated clear opportunity in collating experience and documenting provenance around changing risk profiles, product safety cases, validation and reliability data to speed progress through technology readiness assessments and deployment. Some sectors have documented approaches, while many are hampered by complexity, recognition of whether existing regulations are known or applicable to a given scenario. All are concerns that especially impact engagement with the small and medium (SME) organisations, many within a supply chain, that may have little resources to address them.

1.5.1 Navigating Requirements

All organisations routinely navigate their way through a range of regulatory requirements relating to, for example, health and safety, employment law, data protection, and environmental protection. The development and deployment of RAS, like any other undertaking, imposes a range of statutory obligations. For example, the occupational use of drones requires employers to understand and meet their obligations under health and safety regulations, the General Data Protection Regulation and aviation safety regulations.

Organisations may demonstrate reluctance to invest in or adopt new RAS technologies if there is uncertainty over which regulations apply to its use and/or how to adequately meet those requirements in a cost-effective manner. Delegates perceive that RAS funding or research may be directed to countries with regulatory regimes that offer greater clarity, or quicker regulatory processes than the UK, contributing to a risk of falling behind in the development and deployment of RAS. Beyond legal compliance, organisations may have ethical concerns about using new technologies that may present unfamiliar risks to employees, the public and the planet.

1.5.2 Guidance & Standards

There are already numerous examples of guidance and standards being developed to help organisations develop and deploy new technologies, including RAS. Professional networks such as the UK Safety Critical Systems Club (which has an Autonomous Systems working group) and the Engineering and Physical Science Research Council's EMERGENCE network, which is working on healthcare robotics to support people living in the community with frailty, are actively researching and producing guidance, such as a publication addressing safety assurance objectives for autonomous systems. Regulators are often involved in the development of standards and guidance relating to new technologies, which can help to achieve a proportionate approach to both compliance with and enforcement of Regulations. Some useful examples include:

- **The Specific Operating Risk Assessment (SORA)** is currently being developed to provide recommendations and guidelines for conducting a risk assessment and achieving required target levels of safety for the use of unmanned aircraft. SORA will offer an Acceptable Means of Compliance (AMC) to the European Union Regulation on the operation of unmanned aircraft [10].
- **Building Information Modelling (BIM)** is a process for enabling a team to collaboratively create, manage, and utilise rich, digital information through the whole life cycle of a building, highway or other asset. When first introduced, BIM was met with initial reluctance to invest (potentially considerable) resources in new ways of working which were 'unproven', queries over ownership of data and intellectual property rights, and other concerns amidst general confusion about what it is and how to deploy it. A suite of Publicly Available Specifications (PAS 1192) followed to provide clarity and guidance for teams using BIM, and as part of a wider construction strategy for the UK, the Government mandated the use of BIM on centrally procured public sector projects from April 2016. [11] This incentivised organisations to invest in enhancing their BIM capabilities.
- **National Highways** has set out a vision for digital roads which, like BIM, fundamentally influences the design, planning and construction processes. The use of automated plant is one part of that strategy. The Department of Transport's sponsored development of PAS 1892 (which is ongoing), relating to the use of Connected and Automated Plant in construction sets out performance requirements for automated systems (More detail in Part Three).
- **Self-driving buses** started operating in Edinburgh in May 2023. This is part of Project CAVForth[7], which was funded by the UK Government. The project serves as a case study for collaboration with numerous stakeholders, including Transport Scotland (the National Transport Agency) and numerous local roads authorities to establish and approve the safety case for operating these vehicles.

[7] https://www.cavforth.com/

1.5.3 Existing Approaches

2024 marks the 50th anniversary of the Health and Safety at Work etc. Act 1974. The Act, and the secondary legislation which followed, is based on the principle of "goal setting." Employers must assess risks, then devise and implement reasonably practicable means of managing those risks rather than following a prescriptive set of rules. When the Provision and Use of Work Equipment Regulations (PUWER) first came into force in 1992, for example, it would not have been possible to predict many of the technological advancements that have occurred in the 30 years that followed (for example, it infers that all self-propelled work equipment requires a driver). Nonetheless, PUWER is broad in its scope, and can be applied to RAS, with particular regulations being more or less applicable depending on the specific characteristics of, and hazards presented by, an item of equipment, or the environment in which it is being used.

While PUWER does not address (or even mention) software, it is a subject which receives particular attention in relation to Major Accident Hazard (COMAH) sites. There are also ongoing and well-publicised discussions regarding the opportunities and risks presented by AI. The UK Prime Minister has declared an intention to regulate AI and it would be prudent to understand the proposed scope of those regulations and the extent to which they could influence or limit the software used to control RAS.

The power and process industries, including the Nuclear Sector, use a range of methods for assessing and managing risks that other sectors may be unfamiliar with, such as Hazard and Operability (HAZOP) studies, Fault Tree analysis, Event Trees and Failure Modes and Effects Analysis. A clear link of how the assessment will be implemented is known as the 'Golden Thread' [12]. This can be achieved through a Claims Arguments Evidence (CAE) approach[8] as outlined in Figure 5 to ensure all hazards can be safely managed in a proportionate manner following a hierarchical approach to safety, with the risks being reduced to As Low As Reasonably Practicable (ALARP) to ensure compliance with all necessary Regulatory requirements.

These are robust examples of methodologies which could, following adaptation, or are already being used to assess and manage the risks posed by RAS. They present opportunity for common and scalable approaches for assessing risks (the greater the complexity and risk posed by a RAS, the more effort would be invested in the assessment process). Taken further, there could be baseline or generic risk assessments for different types of RAS (akin to the model risk assessments on the Health and Safety Executive website) that organisations could adapt to suit their particular equipment, environment and tasks. SORA is an example of this approach.

Various standards already exist in relation to safety requirements for industrial robotics, such as ISO 10218

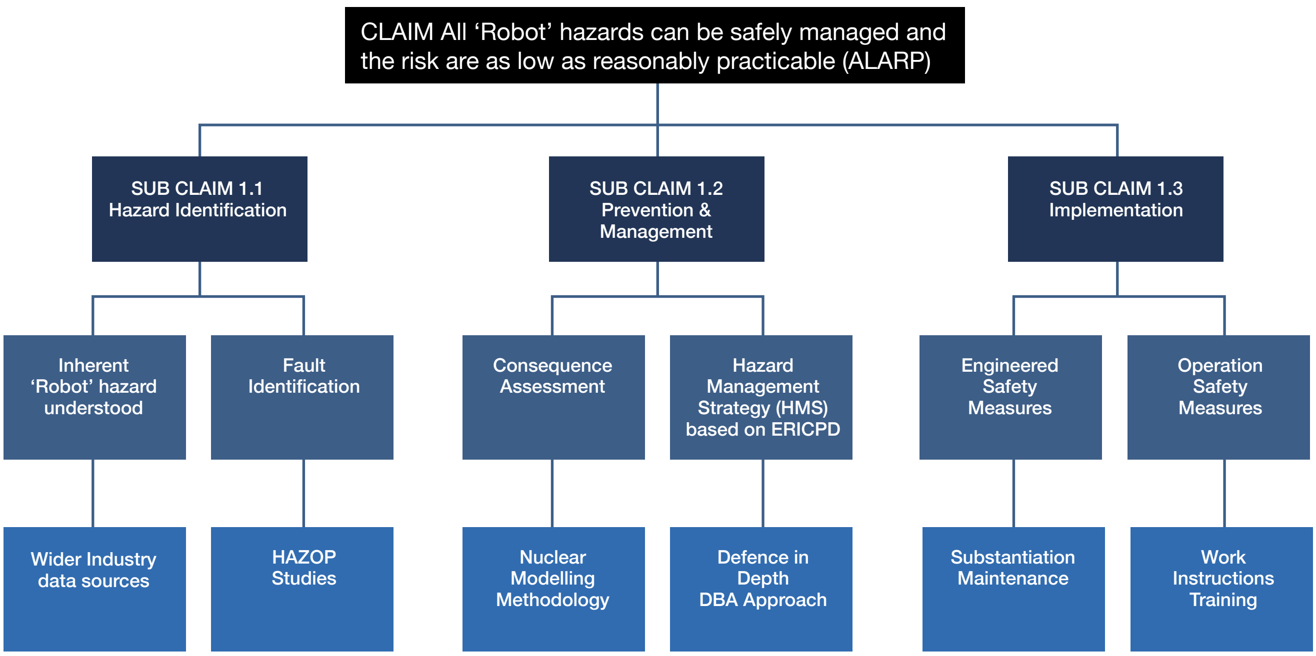


Figure 5: Claims Arguments Evidence approach used by power industries.

[8] https://claimsargumentsevidence.org/

[13] (which is currently being updated). However, these standards are largely suited to stationary robots, as might be seen on car-production lines, rather than the full spectrum of RAS.

In short, the existing legislation appears to be broad enough to address the use of RAS, with the caveat that AI may soon be subject to new statutory controls. This introduces new considerations as RAS systems evolve with sensors that generate data to inform AI, with information gathered in the performance of one purpose, to achieve a task, having the potential to be reused to achieve another, inform the development of processes and management, for example. There will, therefore, be a need for a coherent approach to regulation that spans both technology domains. While there is already a growing body of guidance notes and case studies relating to the development and deployment of RAS, and new technologies more broadly, it is as yet unclear how well known they are and to what extent they are suited to different industries and types of RAS. Overall, there is a need for specific standards to enable organisations across all sectors to identify, understand and meet their legal and ethical obligations in relation to RAS (and associated software, including AI), and adequately assess and manage the risks that the technologies present in a proportionate manner.

1.5.4 Components & Interfaces

A final and important aspect of standardisation relates to components and interfaces. To enable integration of the modular form envisaged by delegates for various cross-functional elements (e.g. propulsion system, wheel or tracks and so on) would require a commitment and considerable pan-industry co-operation and investment to developing open-source libraries relating to both hardware and software. The performance requirements of key components could be specified in British Standards (or similar), helping to provide clarity, transparency and confidence about quality underlined by the articulation of common conventions or design standards, cybersecurity and other risks, while also addressing concerns about the longevity, maintainability, replaceability and compatibility of different technologies to boost confidence within industry.

PART TWO

2. LESSONS LEARNED

2.1 ADVANCING NATIONAL CAPABILITY

The work undertaken with the range of challenge holders must be seen as a "skim" over the surface of what can be achieved with greater effort. It has established that key public domain actors across a wide range of sectors are looking to RAS and other related technologies to address future needs concerning net zero, labour and skill shortages as well as the need to significantly improve safety, productivity and bring down costs and delivery times. It shows that while investigating these new technologies they have identified a set of common problem areas that act as barriers to progress and uptake. They have identified that these common barriers can potentially have common cross-sector solutions and recognise that a collaborative approach will be the most effective way forward.

It is therefore incumbent on this report to make recommendations on that way forward, to build on this snapshot of experience and formalise an approach that can deliver national benefit. The impact of the organisations engaged in this process has national dimension from the management of transport networks to the supply of energy and the development of new infrastructure. Making these organisations more effective, both in the delivery of new projects and in the maintenance of existing infrastructure, is significant and as such demands government support.

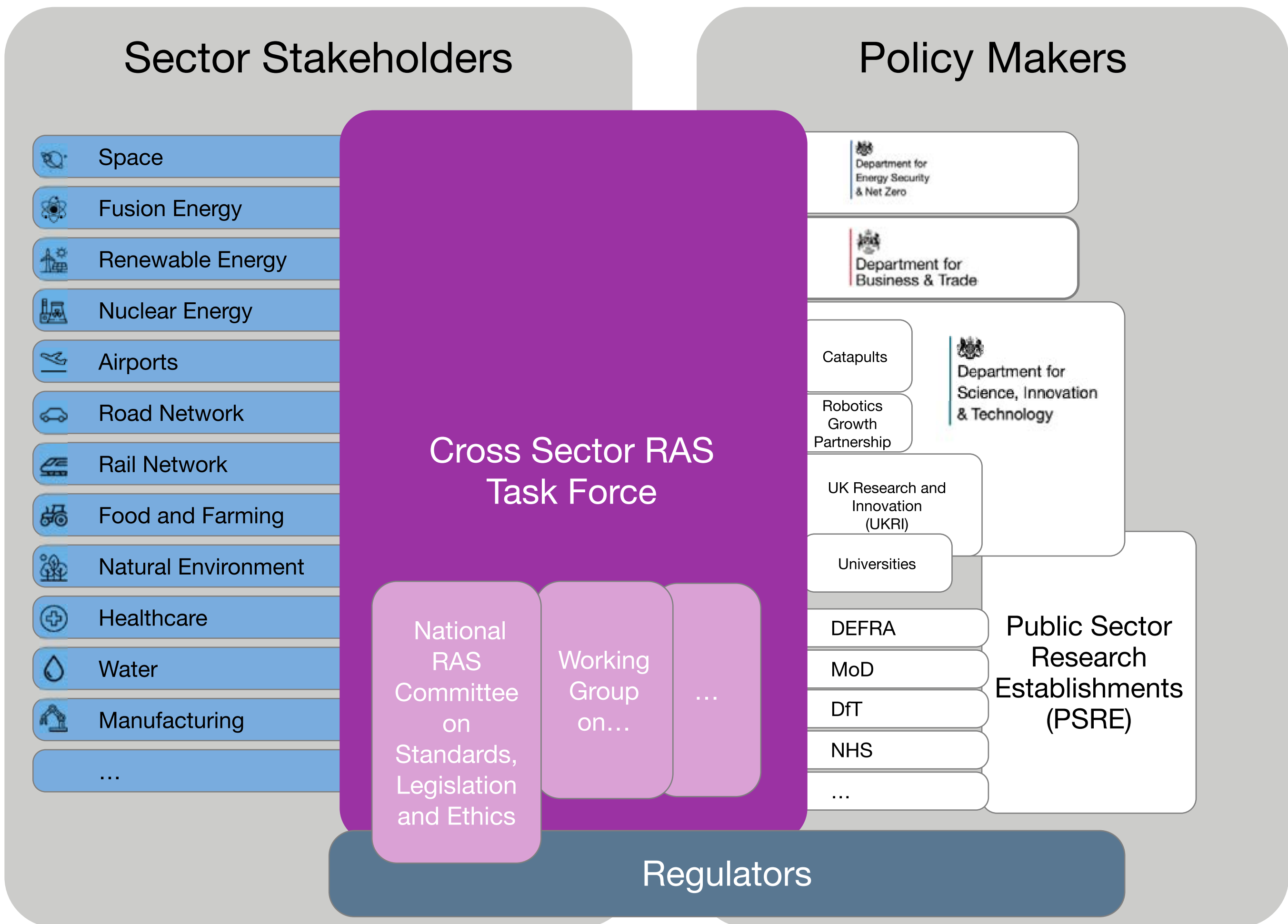


Figure 6: Stakeholders engaged in carrying the work of the UK Cross-Sector RAS Development Task Force to the next stage. A National RAS Committee on Standards, Legislation and Ethics is already formed, and other initiatives are planned.

Amongst the contributing organisations there is a mix of different approaches to development and different motivations for engagement. Each sector will inevitably need to shape the outcomes to their own circumstances, but to do so based on a common set of approaches based on a shared understanding of developing knowledge, practices, regulations, skill sets and value generation. Such an approach will yield an opportunity to develop maturity in the supply of technology and the manufacturing of systems. It will help develop ways of coordinating to both determine and communicate clear common requirements to systems integrators and wider supply chains, and specify the investments in for example, online collaboration tools, data platforms, satellite data, and other developments that would be beyond the scope of a single organisation, or even sector.

This requires a strategic view that can be developed by acting on knowledge that is currently buried in the lived experience at the point of adoption. It requires the ability to test scenarios not just focussed applications, and to arm a supply chain with understanding of the requirements and innovation opportunities that can address common requests, and deliver significant value, at lower cost.

2.2 LOOKING TO THE FUTURE

RAS is seen as a transformative technology. It is already introducing the ability to map working environments, track, monitor and repair assets and develop new ways of construction and management, which can help raise productivity and meet targets for lower cost and carbon net zero. It is possible to imagine a future where assets will be able to self-monitor and repair. The expanded knowledge obtained by robots is expected to help identify inefficiencies and operational issues, delivering the potential to correct problems early and at lower cost, thereby optimising asset lifespan and operational capacity.

By removing people from harmful environments and using robots to augment human tasks, through teleoperation or by using exo-skeleton suits, RAS is advancing potential to increase safety and reduce injuries. Regulation can be adapted to new working practices to alter or remove current constraints based on human-only working. The increased capabilities inherent with the use of RAS, for example when carrying out repairs, can be factored into the certification of assets with the potential to reduce downtime and decrease costs while lengthening operating life. In some cases, for example in space or undersea, RAS is the only way that assets can be maintained or even constructed in the first place.

Unlocking such ability requires end users to engage in a journey. While RAS cannot be adopted "out of the box" because each system must be tailored, to some extent, to the task and sector, there is significant room for collaboration on core systems, transferable technologies and common building blocks. It is acknowledged that this journey is complex and that stakeholders engaging in it alone are less likely to succeed. Building a common approach to project engagement with new technology, to procurement and to skills and regulation will provide a "bootstrap" to deploying RAS that in turn will accelerate uptake more broadly across sectors.

In new areas of opportunity, a well-focused national capability will put the UK on a competitive footing in terms of its ability to utilise technology and provide services into a global market. New ways of working, developing and operating driven by new technology, will transform business models and the means of providing and maintaining public infrastructure to support them. End users, including our challenge holders, are already striving to understand how these new technologies can and will be integrated now and in the future. There is an urgent need to establish national capability to accelerate their knowledge, drive regulatory reform, enhance skills and share best practice to ensure that lessons are shared and used cross-sector to benefit all.

Their ambitions underpin current dependencies across the economy and can advance growth and productivity as well as societal wellbeing. The cost of not taking the opportunity to share this growing body of experience strategically would be significant.

2.3 RECOMMENDATIONS

The following recommendations for moving forward are expressed directly by the stakeholders in our community of interest that are driving current development. They are offered as the essential next steps drawn from the collective work undertaken by the Task Force that is summarised in this White Paper. All have articulated significant interest in establishing ongoing opportunities to not only share knowledge, but to engage on specific measures that address current challenges and improve development of the solutions and technologies that can serve the interests they have identified as common. Their recommendations reflect a collective appreciation for the opportunity to improve prospects for their specific ambitions that would emerge from working collectively to federate strengths and progress cross-sector RAS capabilities nationally. Their desire is to formally develop such capability, initially working with the public sector to align and scale the considerations that are already in development:

1/ Continued support for the RAS cross-sector community and conversation network

It is critical to formalise the inception of the Task Force to actively continue the knowledge exchange established with this work, and establish topic-specific leadership through working groups, networking events, and sign posting to relevant practical experience. Considerations include:

- Creating cross-sector continuity will require the convening power of government to enable widespread engagement.
- Senior end-user champions will be needed to extend the community of interest to include professional bodies, industry associations active in RAS, and other representative bodies and stakeholders.
- Creation of an open network of shared experience will help accelerate uptake and develop greater and broader awareness and confidence to invest.
- Driving a skills development initiative that promotes RAS skills uptake in end users and down into their supply chains.

The expectation is that this will facilitate and accelerate the formation of a national RAS capability with innovation and deployment infrastructure and the mechanisms for information exchange that underpin development of best practice, standards and regulation, skills and other enabling programmes.

2/ Assembly of standards bodies into a National RAS Committee

The initial project brought regulatory bodies together with industry initiating the formation of a National RAS Committee on Standards, Legislation and Ethics to collate 'lessons learned' from the development and deployment of new technologies (e.g. BIM, CAP, ProjectCAVForth and so on). They have kick started efforts to work towards identifying common areas of practice that will require formal recognition and funding to establish cross-sector processes, good practice and update standards, regulatory and other requirements where relevant. Actions include:

- Preparing a legal register relating to the use of RAS which will help to inform discussions regarding operational requirements, regulatory expectations and so on, as will a standards register, to record all British, international and industry standards that have a direct impact on the design and deployment of RAS.
- Reaching common approaches to the development of safety cases involving RAS that can be used cross-sector will help technology suppliers and system installers support more effective supply chains.
- Developing information exchange, interaction and interface standards for RAS and its enabling technologies will create opportunities in supply chains, in procurement and will accelerate uptake.

The expectation is that this will lower barriers to uptake by clarifying the regulatory position and where applicable align regulatory mechanisms that enable innovation translation and drive end-user engagement.

3/ Cross government requirements analysis and procurement programme

Examine how government procurement can be aligned with a common approach to the inclusion of RAS. Identify criteria for assessing where and how best RAS technology can be developed, applied, its relation to other enabling technologies and infrastructure, readiness to adopt. Steps to be taken:

- Document common public sector challenges and requirements to initiate the establishment of a cross-sector problem book that can be shared to inform innovation approaches and priorities.
- Ensure that skills are maintained to deliver technology and that these skills are propagating within the public supply chain through collaborative practice.
- Ensure that funding of new projects is shaped with new technology as a key enabler to drive change away from outdated methods and as an upward driver of productivity.
- Combine purchasing power to aggregate demand, facilitate joint bids, supported by procurement frameworks and contracts,
- Advance elements of solutions in common through modularisation, common practice and machine architectures to support the development of intelligent clients.

The expectation is that this will put the government on the front foot as an intelligent customer for RAS, able to both specify and engage with appropriate new technology as a driver for change, embed RAS considerations into government procurement, and create scale.

4/ Formulate and deploy tools that assist in bringing RAS and other technologies into the development cycle

A shared methodology with a clear process model will help extract value from new technologies at an earlier stage, help define how they can be considered, and how to avoid technology obsolescence or lock in:

- By articulating common approaches within the shared problem book and the development of a map of cross-sector dependencies, coupled to processes for technical change management to help de-risk technology step by step and ensure benefits can be optimised.
- In providing a shared repository of good practice and examples of application that align with the problem book both at a sectoral level and across sectors, knowledge and awareness can be created and propagated.
- By creating innovation and deployment infrastructure, test beds, regulatory sandpits to support innovation programmes and the articulation of common approaches and frameworks that are tried, tested and communicated beyond what might be achieved by a single project or sector.

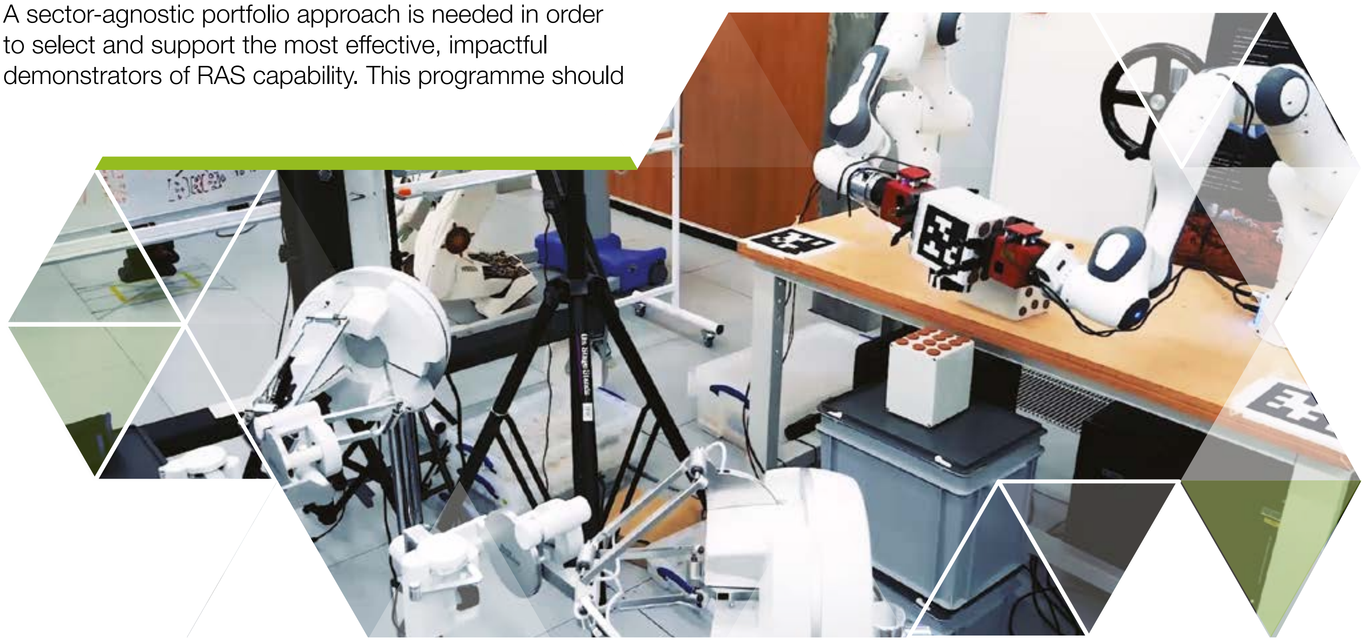
The expectation is that this can significantly lower the barrier to RAS adoption by removing the knowledge barrier, reducing adoption risks, and supporting emerging business models and supply chains that operate and scale across sectors.

5/ Define and deliver a portfolio-based innovation programme

A sector-agnostic portfolio approach is needed in order to select and support the most effective, impactful demonstrators of RAS capability. This programme should focus on deployment best practice and stimulate cross-sector knowledge exchange by enabling the highlighting of national exemplars. Such a programme is needed to test where and how RAS impacts across a range of different working environments, and to characterise and shape the innovation and deployment infrastructure. Its objectives are to:

- Support the development of RAS tools, innovation and deployment infrastructures to demonstrate on-site capability.
- Showcase exemplar RAS deployments at scale, as an incentive to drive further deployment.
- Develop common technical specifications for procurement and supply chain alignment between sectors.
- Champion skills development through a learning forum for large-scale projects that facilitates knowledge exchange and the development of competencies that drive early-stage assessment of RAS in context.
- Establish national frameworks, including funding, that enable innovation within larger projects as a tool that informs regulation, approaches to procurement, and innovation needs across sectors and with suppliers of advanced technology.

The expectation is that public leverage operating across sectors will clarify best practice through exemplar projects, particularly at scale, test regulatory reforms and provide incentives to take earlier steps towards RAS adoption thereby enhancing productivity and raising UK capability.



PART THREE

3. SECTOR INFLUENCES & USE CASES

The following contributions from members of the Task Force community of interest provide detailed snapshots of current applications of RAS, and more importantly of how RAS is already being integrated into future planning. They demonstrate the broad impact of RAS, its provision of current as well as future capability, its added value and ability to address key national economic and societal challenges. They critically highlight the opportunity and need for cross-sector alignment as presented in the first two sections of this White Paper, illustrating where knowledge already accumulated in one sector can have value in another and the importance of continuing the work of the Task Force to facilitate collaboration that will inform regulation, procurement, skills and the development of common supply chains. These examples make an unequivocal argument for the utility and economy of a national strategy for RAS.

3.1 RISK ASSESSMENTS PAVING THE WAY FOR AUTONOMOUS TRACTORS AT THE PORT OF FELIXSTOWE

Safety is one of the main considerations for the introduction of Autonomous Tractors being introduced by Hutchinson Ports at the Port of Felixstowe, where the operational design draws from deployments in Thailand and ongoing UK risk assessment workshops in the UK. The workshops analyse experience across a comprehensive set of factors such as functional performance, the impact of weather, accidents, fire and other hazards. The tractor operates with uploaded terminal layout mapping and real-time GPS information, cameras, and sensors for 360-degree monitoring of its surroundings, which allow it to "know" where it is relative to fixed objects, react to pedestrian behaviour and other road users, stop if a GPS signal or relative position is lost, and detect overhead cranes and unexpected movements. It is linked to a fleet management system in the Port control room which sets the path and tracks the vehicle, knows if there has been an incident, and excludes it from certain areas if needed. The Port also operates using remote control gantry cranes connected to the control room. Whilst in the container stack the gantries pick and place containers in fully automatic mode, accurate to 35mm, with three operators running eight machines. [14]

> "The operational design draws from ongoing risk assessment workshops. The workshops analyse experience across a comprehensive set of factors such as functional performance, the impact of weather, accidents, fire and other hazards."

3.2 UNDERPINNING CAPACITY IN MANUFACTURING & SUPPLY CHAINS

UK manufacturing, although it has declined as a contributor to GDP over the last 40 years, is still within the top 10 globally. It employs 2.7 million people in the UK, and contributes 51% of UK total exports and 64% of UK expenditure on Research and Development (R&D). [15]

There are a number of challenges currently faced by the UK manufacturing sector including labour and skills shortages, fragility of supply chains and poor productivity in comparison with major competing nations. One answer to these challenges is the greater adoption of robot automation within the manufacturing sector. In advancing the opportunity to produce goods as energy efficiently as possible, including enabling more local manufacture, automation in manufacturing also presents a key contribution to the nation's commitment to a carbon net zero economy by 2050. A study by Copenhagen Business School identified that by implementing automation to the same level as the most productive countries in Europe would increase UK productivity by 22.3%.[16)] This would more than close the gap between UK productivity and these countries.

However, the UK has been relatively slow at utilising robot automation particularly outside the automotive sector, and does not feature in the table of countries that exceed the global average for robot density (robots per 10,000 workers). The International Federation of Robotics has identified the UK is currently 24th in the world for robot density in manufacturing, with a density of 111, well below the world average [17].This sits in sharp contrast to UK's position within the top 10 manufacturing countries, globally.

In addition to impacting the performance of our manufacturing this lack of adoption has also impeded the growth of a significant robot automation supply chain in

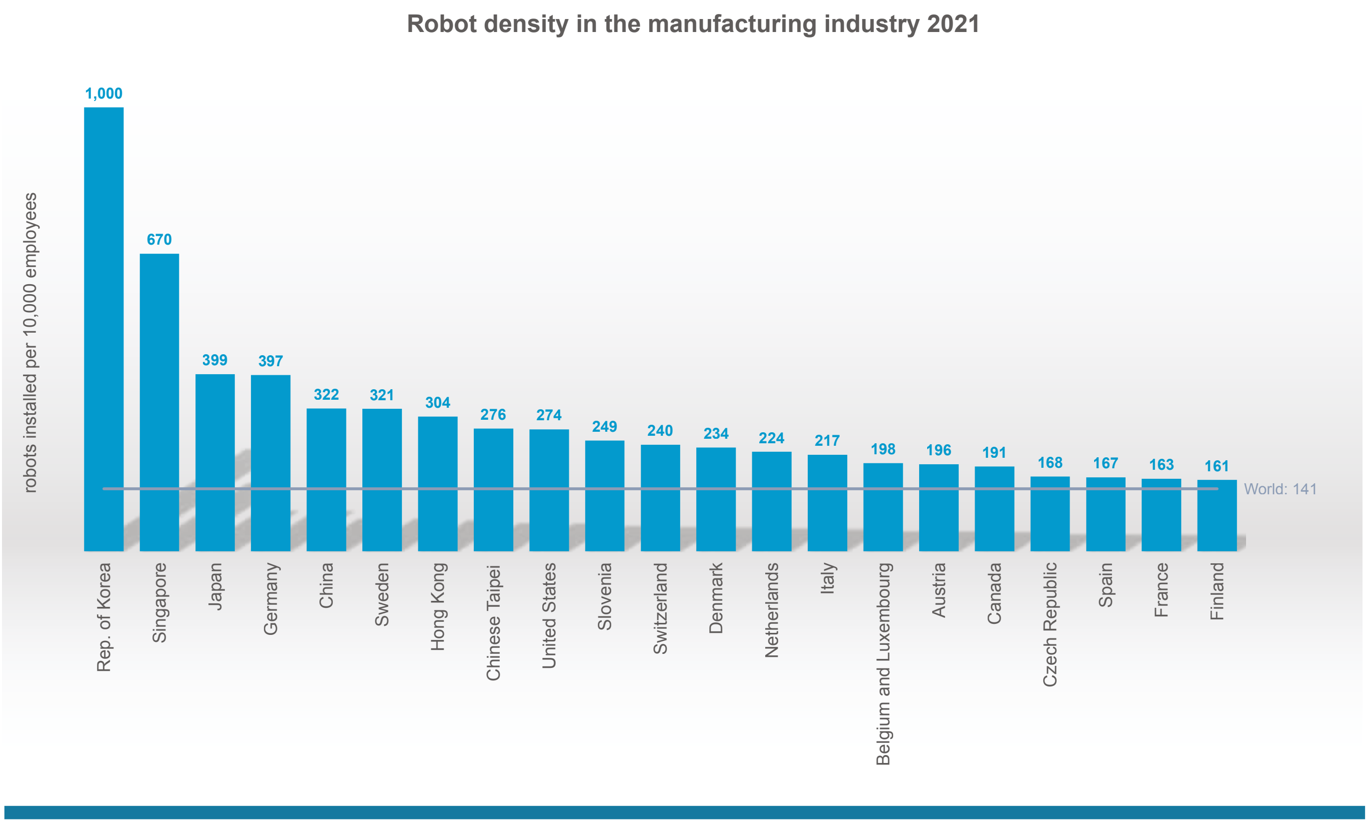


Figure 7: : International Federation of Robotics (IFR) estimation of robot density in manufacturing.

the UK. The major robot suppliers are all based outside of the UK and although they operate subsidiaries in the UK, these are largely sales and service operations with R&D being performed elsewhere. There is a network of system integrators, building solutions for manufacturing businesses, but these are largely small businesses with little capability to develop new products and solutions.

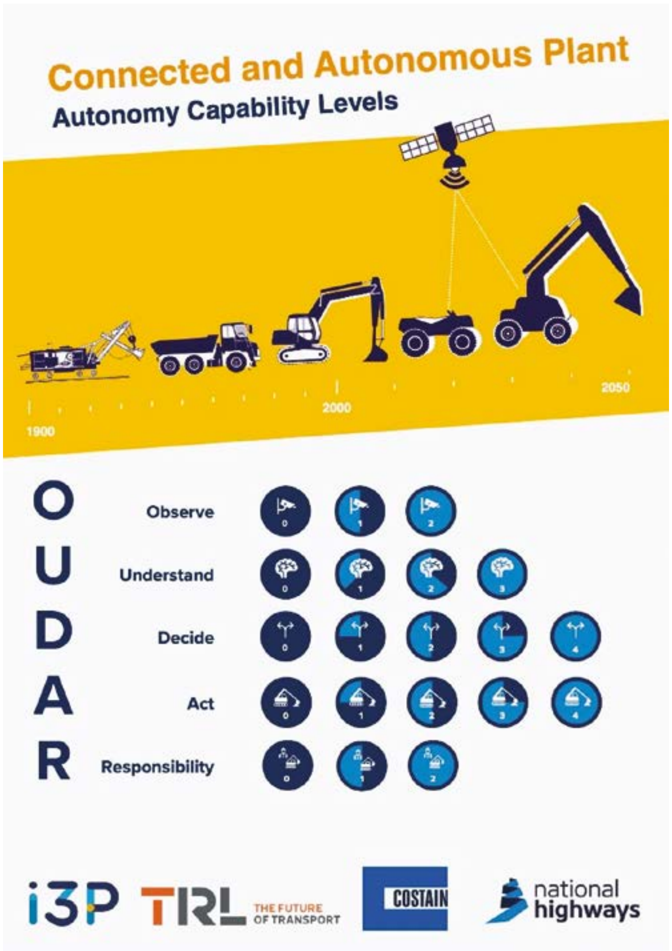
It should be noted that the adoption of robotics solutions within our competitor manufacturing countries is accelerating. Enabling a competitive manufacturing sector in the UK requires the adoption of robots to accelerate significantly, with a doubling of robot density within a few years being a reasonable target. Based on current numbers, this would put us into a bracket with Denmark, Netherlands and Italy and ahead of France and Spain. An increase on this scale would provide significant financial benefit to the existing automation supply chain, achieve sound growth for the system integrators and thereby strengthen the overall robotics delivery capability in the UK.

Such stimulus would benefit the RAS supply chain and sectors outside of manufacturing. As solutions have advanced with an increasing transferability between industry sectors for key enabling technologies such machine vision, sensing, visualisation, connectivity, mobility and AI. Many RAS solutions are based on industrial robot technologies which provide reliable and robust platforms on which advanced capabilities can be implemented. It would support a growing system integrator community providing both skills and markets to enable implementation and deployment at scale, of both industrial solutions and the associated RAS technologies, and underpin the development and implementation of modular building blocks within the technology stacks. Solutions built for manufacturing would provide a ready market and a proving ground to ensure the development of robust and appropriate modules, that can serve many interests across sectors and fuel strong growth for a RAS sector in the UK. This presents a clear opportunity for all the relevant stakeholders in RAS and industrial robot solutions to work together to maximise the benefit for UK plc.

Given the stature of the sector, it is important that such investments go beyond the sector objective of assuring a competitive position in UK manufacturing, and that other significant and growing sectors, space, nuclear, construction etc, work together to strategically assure the development of UK RAS capability with solutions for UK businesses serving UK markets and their export capabilities. This will not only serve UK customers, but also the UK as a whole maximising the gains, in both technology and financial benefit from these investments.

3.3 ROADMAPPING MILESTONES WITH CONNECTED AUTONOMOUS CONSTRUCTION PLANT

National Highways set out a vision whereby the use of connected and autonomous construction techniques become business as usual activity in the UK by 2035. [18] The aim is to deliver step changes in safety, productivity, and skills of this sector's workforce. To support this vision, it funded a project to describe and define autonomy levels for construction plant. Similar to (semi) autonomous passenger vehicles, for the purposes of understanding capability and liability, it is important to describe whether the machine or the human operator is in control. But unlike passenger vehicles, construction plant has different forms and functions. Therefore, it is important to have the ability to describe the technology in common terms, as set out in the illustration here.



The initiative is part of National Highways Connected and Autonomous Plant (CAP) Roadmap, referring to construction plant that is connected to its environment, through sensor or wireless transfer of data between a remote operator and the machine; the autonomy element refers to aspects of the vehicle's operation and also movement around a site. CAP offers potential for the sector to:

- deliver safe, automated, efficient processes across a wide range of applications,
- accelerate project delivery, and
- reduce both the frequency of errors and demand for labour, leading to higher levels of output and improved productivity.

If the benefits found in autonomous smart machines in manufacturing are mirrored across construction, CAP-generated productivity improvements could exceed £200bn in value by 2040.

According to the 2017 McKinsey Global Institute report "Reinventing Construction", construction is one of the least productive sectors in the UK economy, despite accounting for 8% of GDP and 9% of the workforce [19]. As a national industry, and one that delivers the buildings and infrastructure required by every other sector in the economy, there is a risk that poor productivity inhibits wider UK economic growth. The UK government has committed £600bn of infrastructure spend over the next 10+ years. Initiatives such as CAP could accelerate the modernisation, digitisation, and industrialisation of the sector.

The definition of CAP recognises that autonomous construction is not about the transition of plant into self-operating machines. It is about transforming construction into a highly digitised industry, that takes full advantage of technology to improve productivity, efficiency and reduce its environmental footprint across the lifecycle of infrastructure and construction projects.

National Highway's CAP Roadmap to 2035[9] sets out a future vision for CAP. This was the result of engagement with over 70 organisations from government, academia, contractors, suppliers and manufacturers. The Roadmap takes an holistic perspective of the technology, examining not just the technical and equipment innovations that are required, but enabling factors such as adjacent skills in data and requirements for connectivity; and standards/regulation along with people and skills, and contractual and liability aspects.

To advance these factors, the initiative sets out milestones which, if achieved, would lead to a 10% reduction in on site accidents by 2025, as the trialling and use of semi-autonomous plant solutions advance in the majority of construction activity (fully autonomous by 2030); 50% improvements in construction data accuracy by 2027 with the development of national construction data platforms; and a 20-50% reduction in real-time of construction as CAP becomes embedded in procurement processes by 2033, is accepted as standard across the UK industry by 2035 and delivers 50 billion in savings.

Delivering this roadmap requires consistent and sustained effort. There is an opportunity to increase the pace of introducing CAP technology into construction. However, there are several practical and strategic challenges, such as the lack of a clear central direction and unified approach to

[9] Connected+Autonomous+Plant+-+Autonomous+Capability+Framework+V1.1a.pdf

implementing CAP. This results in industry carrying all the risk of investing in new systems with uncertain market demand. Although there is a growing awareness of CAP, there is a lack of understanding about the technology's capability and a lack of clarity about the risks, liabilities, and acceptability of its use, or support that will scale up the use of CAP to the point where it achieves significant economic impact. Without coordination, strategy, and direction, achieving productivity improvements via CAP is unlikely. A delay of just five years could reduce the 2040 savings by over 50%, but accelerating the take up of CAP could see significant benefits of £18bn across the sector within five years. That is why government is exploring ways to stimulate, and increase confidence in the CAP market.

BSI PAS 1892 Connected and automated plant (CAP)

The construction industry is defined by the contractual relationships between client and, often an integrator; and between the integrator and suppliers of materials, plant and labour. In order to embed a consistent language, a BSI Publicly Available Specification (PAS) is in development to aid those contracting CAP services to consistently define their requirements.

Next steps

The Department for Transport and its Arms' Length Bodies National Highways, Network Rail and HS2 Ltd continue to support the development of CAP as a recognised technology through further examination of the contractual and liability implications and through early work to define the standards for design data required to programme automated machines.

3.4 SUPPORTING THE UK'S MISSION IN THE INTERNATIONAL SPACE ECONOMY

The UK government published its first National Space Strategy in September 2021[10], acknowledging the £16.4 billion industry as a high-growth area for the UK, strategically important for defence, and for a space satellite infrastructure that underpins £360 billion per year in UK economic activity [20]. It also identified a priority to remain at the forefront of earth observation technology delivered by this satellite infrastructure in tackling national commitments and leading the global fight against climate change, alongside other global challenges, such as the monitoring and mapping of crops, and biodiversity loss.

A unique influence comes from the increasing commercialisation of space infrastructure where the UK has developed its role on the back of a flexible regulatory and insurance landscape and cutting edge-research in space science and technology. As one of the first states to adopt national space legislation to regulate operational activities of private commercial entities, The UK's clear licensing and regulatory requirements for space technologies, and the unified authority in the CAA defining liabilities has underpinned a UK insurance market. As a result, private investment represents 82% of deals across venture capital, private equity, and seed funding in the UK space sector.

Globally, the space economy expanded by 4.4% in 2020. Reports of private-sector funding in space-related companies ranged from $10 to over $14 billion in 2022, as the sector saw 50% increases on the year before. This sector is driven by high-profile international collaborations,: including Artemis, A US-led initiative to restart manned-missions to the Moon from 2025, develop sustained lunar exploration and conduct a first human mission to Mars; the European Space Agency's ExoMars project and mission to produce drinkable water or breathable oxygen on the moon; Heracles: A mission to gain knowledge on human-robotic interaction while landing a spacecraft on the Moon, collecting samples with a rover; and the development of a Lunar Gateway to facilitate further space exploration and easing access to Mars in particular, among others.

While countries agree not to pollute space, active discussions are underway to make this a binding legal agreement internationally creating demand for highly responsive systems to address growing risks from space debris and advance sustainable development of satellite infrastructure. New businesses are emerging to support missions to develop Active Debris Removal (ADR) and in Orbit Service and Manufacturing (IOSM), capable of close-proximity operations and manipulation of non-standard objects, where AI and robotics can play an important role. Similarly, in-orbit servicing (IOS), where the life of spacecraft can be extended, or systems can be augmented to, for example, add systems in orbit that enhance propulsion will also involve close-proximity operations and manipulation. These will need the support of recognised frameworks or mechanisms to establish trust, guarantee that the autonomous system will work as intended and not cause damage to assets in space. It is also necessary to ensure that the legal frameworks are adequate, covering who can remove debris from orbit, what classifies as debris, and other considerations, such as additional regulation that may be required for the augmentation and repurposing of legacy satellites for different use cases.

UK contributions to both high-profile projects, and such emerging services making use of AI and robotics pave the way for future innovation of value beyond the sector's direct requirements. Investments are fuelling UK capacity with material suppliers, space test facilities, and a UK innovation landscape with significant capabilities across the

[10] https://www.gov.uk/government/publications/national-space-strategy

space sector value chain that is also applicable for space AI and robotics applications, from academic institutions and government laboratories investing in the scientific research; industrial & academic collaborations; qualification and licensing and operational services (see figure 8).

Functional innovations, soft robotics, and autonomous systems are being advanced address requirements for:

- Precision needed for close proximity operations
- Teleoperation, and remote management
- Rovers and planetary explorers
- Advanced mining and extraction, including horizontal drilling
- Autonomous spacecraft
- Human support, health monitoring and augmentation

The UK Space Agency has particularly identified low-cost RARMs (Robotic Arms); modular robotic interconnectors enabling transfer of mechanical, electrical, data & thermal loads; advanced robot control operating systems; close-range 3D imaging; fault detection Isolation and recovery solutions, and navigation capabilities as enabling technologies for the projects within its programmes.

Overall requirements present particular opportunity to advance strengths in high-end autonomy and sensing technologies to develop the UK offerings in operational support for established and emerging markets, including:

Satellite Telecommunications (Satcom), a well-developed area of the space sector in the UK and globally, which is largely delivered by the private sector. Satellite technology has long been used for communications applications, typically from geostationary orbits, such as television broadcasting, telephony, and secure data communications, widely used by government public and third-sector bodies. Increasingly satellites are being used to underpin the provision of broadband as well, with low-latency networks enabled through the operation of large constellations of low-altitude satellites (LEO)   In-Orbit Service and Manufacture (IOSM) generally covers space systems that intervene with other orbital space objects (e.g. satellite life extension systems, in-orbit transportation systems and debris removal

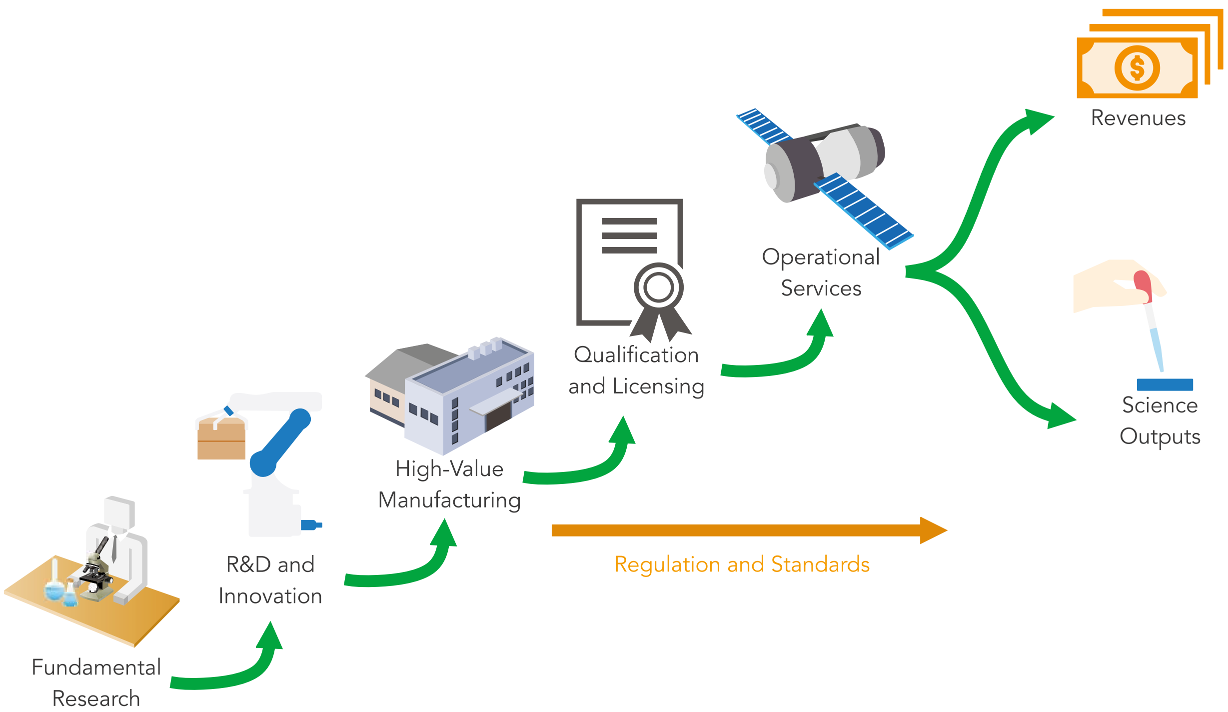


Figure 8: Existing in Space, elements for advancing the RAS Value Chain.

systems) and in-space manufacturing (e.g. construction of large space structures and manufacturing of materials for use in-space or on-ground. Manufacturing in space will be a big step forward for the space sector, reducing the cost of producing a satellite with savings on launch costs, novel manufacturing processes and materials, the opportunity to involve the recycling of space debris, and defunct satellites to get the materials required for the manufacturing process, while companies like SpaceForge are evolving to support in-space manufacturing and microgravity as a service with weekly/daily delivery back to Earth as early as 2025.

Energy harnessing with current attention on the potential for developing solar farms in space to provide power to Earth. The most prominent development is the Space Energy Initiative (SEI), which is focussed on the provision of Space Based Solar Power (SBSP) to meet net zero targets. SEI "brings together government, research and industry in the energy and space sectors to develop and deliver a co-ordinated programme of technology development and demonstration." In early 2022, The Government announced £3m of funding for SBSP solutions and European Space Agency (ESA) also announced funding of 13 activities focussed on SBSP technologies.

Space Science and Exploration incorporating astronomy missions and interplanetary and deep-space missions. Instruments and technologies include UV and X-ray detectors, deep-space probes, and landers / rovers. Space science and exploration missions have traditionally been institutionally led, however private companies such as Space-X have strategies including inter-planetary transportation and off-world colonisation. Future commercial applications of space exploration may include asteroid mining and in-situ resource utilisation (ISRU).

3.5 AUTONOMY FOR SAFER, FASTER, AND SUSTAINABLE NUCLEAR OPERATIONS

Nuclear Power has been a key sector within the UK since the world's first civil nuclear programme was established in 1956 with the construction of Calder Hall at Windscale. As of 2021, this sector provides around 15% of the UK's electricity and is viewed by the UK Government as essential to both advancing the green energy mix and securing our overall supply of energy for the future.[21] The UK sector is a global leader in nuclear waste management, having successfully pioneered processes for compacting and storing low, intermediate and high-level nuclear waste from the UK and overseas at Sellafield for over 50 years. The pioneering of new developments for nuclear fusion and nuclear co-generation of hydrogen energy also underpins both national and international ambitions.

This sector, which has a long history of deploying robotics, is currently advancing the development of integrated remote or robotic solutions that could access confined spaces, rooms, cells and buildings, accurately measure radioactivity levels and deploy robotic equipment to demolish plants enabling size reduction, segregation and retrieval of waste for safe storage.

Innovative technology using robotics, virtual reality and 3D imaging is being advanced for clean-up operations on Nuclear Decommissioning Authority (NDA) sites. The NDA has set out four areas for improving productivity, efficiency and effectiveness:[22]

- Reducing our waste - finding new ways to drive the waste hierarchy, increasing recycling and reuse by 50% to reduce volumes sent for disposal;
- Intelligent infrastructure – using autonomous technology to manage assets and buildings proactively and efficiently and reduce lifetime costs by 50%;
- Moving humans away from harm – reducing the need for people to enter hazardous environments using autonomous systems, robotics and wearable technology;
- Digital delivery - adopting digital approaches for capturing and using data, to improve planning, training and aid decision making.

A core element of the work includes moving radioactive and contaminated materials and packaging them, including components and pieces removed from a plant decontamination wastes, tools, wastepaper, and clothing, such as the personal protection PVC and air-fed suits (PPE) worn by operatives. Efficient sorting and segregation of this material saves storage capacity. Given the risks to operatives, productive manual operations are typically two-to-three hours out of an eight hour shift, allowing for tolerance of work area temperature, radiation dose, and the need for PPE. The secondary generation of waste including the suits and tools to support manual operations is high in proportion to primary waste removed, up to 12 times. Productivity gains from deploying robotics come from reducing the time to perform a task, the need to produce the suits, as well as the time scales for operatives to get in and safely out of them, and then dispose of them.

Functional challenges driving development of robotics solutions for sorting and segregation include identifying different types of material, picking and placing, and sorting and stacking them within a waste container; as well as identification and removal of materials' contamination.

Within the nuclear construction industry major areas of functional similarity exist with others including inspection and quality assurance, non-routine construction operations, and plant modifications. Typically, as-built drawings exist only for safety-related piping, almost every plant modification effort involves the preparation of as-built drawings of the area involved just before the design of the modification, while there are targets to produce accurate and up-to-date 3-D virtual models for all key NDA sites by 2030. In many cases, this is a radiation area with the attendant concern of personnel exposure, such work is being supported with smart robotics and drones. There are also targets to enable remote external monitoring of buildings by 2025; and for all new buildings to be self-monitoring and energy neutral by 2030.

The sector, alongside space, underpins significant levels of research into smart machines and artificial intelligence to analyse operational data and optimise processes, enable collaboration between machines, and sustain harsh environments, alongside significant work to devise approaches and frameworks to address regulatory requirements and safety cases, as outlined above. The sector is advancing remotely controlled manipulators closely tied to control systems that rely on sensor feedback for adaptive behaviour in an unstructured environment. This includes systems with collision avoidance capability; sensors built to measure forces accurately to permit the use of adaptive end-effectors, the tools that perform a given task. Tactile and Infrared sensors facilitate object identification applications and adaptive control systems while thermographic scans of operating systems detect defects such as leaks, insulation failures, and hot spots.

Sellafield, which is the largest site on the NDA estate (estimated to manage around 75% of long-term decommissioning costs) is also investing in systems capacity and focussed research to advance standardised platforms & systems, communications and vision systems, data kits and stores, and software, underpinning both structured teleoperations and autonomy within unstructured environments.

Such capabilities are underpinning Sellafield's journey toward increasing levels of autonomy where a declared aspiration for routine use of human supervised robotic systems increases the safety and productivity of operations. For example, the introduction and confirmation of: reversing

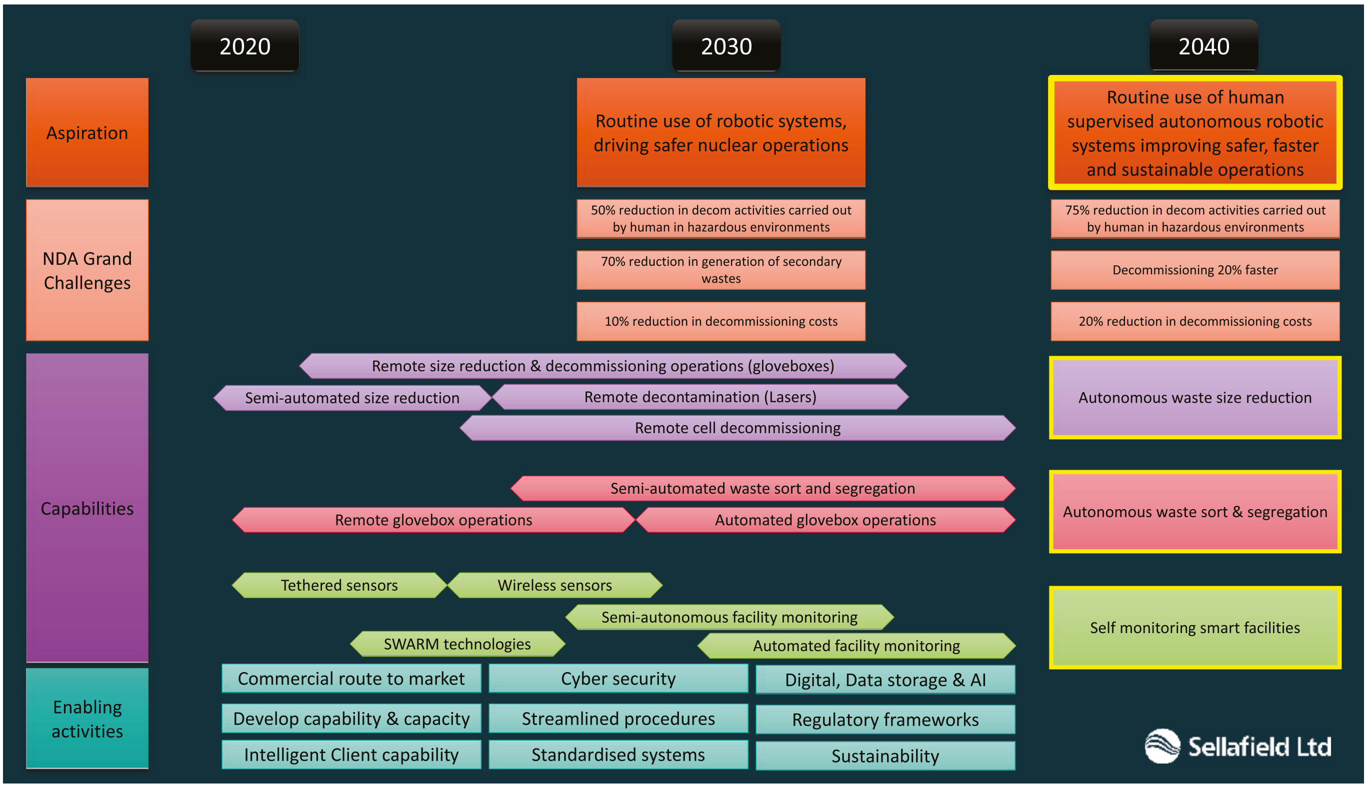


Figure 9: A high-level overview of Sellafield's roadmap to autonomy

camera, blind spot monitors, adaptive cruise control, 360 camera views, lane departure systems, and auto parking is contributing towards people accepting automated vehicles on sites. Ambitions for nuclear decommissioning (see Figure 9) include a 50% reduction in decommissioning activities carried out by humans in hazardous environments, and a 70% reduction in the generation of secondary wastes by 2030, leading to greater efficiencies underpinned by the self-monitoring smart facilities and autonomous systems for waste management by 2040.

3.6 AN IMPERATIVE FOR CONSTRUCTION'S GRAND CHALLENGES

The construction Industry is one of the UK's largest sectors contributing nearly 170 billion in added value to the economy and employing nearly 3 million people in more than 400,000 businesses in 2021. Materials, practices and technologies employed in the construction sector have remained largely unchanged for decades, leading to flat productivity, a poor safety record, spiralling costs, and high material wastage. Automation and smart machines are increasingly emerging to help this sector find ways to change its traditional processes and face well-documented challenges by adopting modern methods of construction.

Construction has a poor track record in health and safety with higher-than-average levels of injuries and fatalities. Many tasks within the construction industry are highly repetitive, and physically exhausting, and there is a persistence of common risks such as falling objects, being crushed by heavy objects, or exposure to hazardous substances. It had the highest annual average rates of fatal workplace injury per 100,000 workers between 2014/15 and 2018/19 . Additionally, one-fifth of UK construction workers born in the UK were aged over 55 while just 9% of the 16-to-18-year-olds participating in a 2019 survey said they would consider a career in construction.

Emerging responses within the construction sector include targets to meet demand for affordable housing within time and resource constraints and in an environmentally sustainable manner, outlined within The UK Government's Construction 2025 strategy. They are inspiring a focus on whole life, not just the construction costs of buildings, and on targets such as reducing greenhouse emissions in the built environment by 50%.

Against this backdrop, a wide range of use cases and opportunities are emerging across the sector from the use of automated transportation for carrying goods, to static, programmable and human-controlled teleoperated robotic arms carrying out simple but labour intensive repetitive tasks like inspections and material transportation. Advancements in mobile and teleoperated robots and related platforms are supporting use cases for autonomous or semi-autonomous machines for monitoring and data collection, and often accessing small, difficult or hazardous environments. Smart machines equipped to sense and respond to their environment are also enhancing their capacity for management and quality control. Overhead, unmanned aerial vehicles (UAVs) or drones are dramatically reducing the time taken to complete surveys, enabling better informed site and building inspections.

While overall adoption rates are still low given the initial investment capital required, many distinct types of robots targeted at a variety of purposes in the construction sector exist or are at an advanced stage of development. While some strive to automate standard building methods, others such as concrete printing robots support innovative construction approaches. Their application has the potential to offer enormous economic, operational, environmental, and other advantages and numerous technologically sophisticated firms have lately been founded who intend to harness these prospects. Construction Robotic's "SAM100" robot, for example, can lay around 2,000-3,000 bricks per day using a combination of a conveyor belt, a robotic arm, gripper and a concrete pump. By comparison, a construction worker will average around 400-500 bricks per day.

Robotics use cases within construction have elements of buildings that are mass-produced in automated factories; artificial Intelligence selecting the material from a predetermined kit-of-parts, that can be produced efficiently and sustainably at scale; and GPS-linked machine control systems (eg. TOPCON's) combining GPS with construction plant and digital models to partially automate tasks like earthworks. Laing O'Rourke's Advanced Manufacturing facility in Nottinghamshire, for example, features extensive use of robotics with an aim to manufacture 10k homes a year, as well as components for infrastructure and large buildings. Employing a Design for Manufacture and Assembly (DfMA) methodology, the company works to drive sustainable construction by raising levels of design standardisation and quality employing contemporary procedures of assembly, lean automation and technologies for quality assurance. Skanska's robotic deployment of rebars, which hold concrete together, is another example. Robotics lay rebar at a rate of one hour per tonne compared to 16 hours per tonne for manual processes.

Southern Gas Networks (SGN) has trialled a new robotic roadworks system in Epsom, Surrey. SGN joined up with New York-based robotics start-up ULC Technologies to construct the robot, which it says is a global first. It took three years of research, with financing from energy regulator Ofgem, to produce the Robotic Roadworks Excavation System (RRES). The robot makes the kind of robotic arm that would be found in a factory transportable by connecting it to an all-electric tracked unit. RRES can carry out the whole end-to-end excavation procedure. The robot features a concrete cutting chainsaw, enabling it to carve any form onto a road surface. It achieves this by detecting the hardness of the surface and altering the cutting speed and strength of the chainsaw. This 'keyhole' method decreases the amount of the excavation required. The portion of road which the robot chops off may then be reinstalled at the conclusion of the operation.

SGN further argues that because RRES is autonomous and can carry out the full excavation operation, it has a far less physical and carbon impact. Utility excavations generally need many trucks, heavy equipment and numerous personnel. RRES is also capable of scanning below ground to map subsurface pipelines before any digging takes place. It also employs supersonic air nozzles to stir the dirt, which it subsequently removes using vacuum suction. The tool head employs sensors to identify any asset nearby to prevent damage and keep field employees safe.

BAM Nuttall's robot dog collects data on a remote Shetlands site, in a trial that marks the robot's first 5G deployment in the UK. The contractor fitted the Boston Dynamics-made Spot robot dog with a Trimble X7 3D laser scanner.[11] It used a private standalone 5G network for remote control. BAM then controlled Spot and the Trimble X7 remotely to collect data and create site records via the 5G network. The network covers the 55,176 sq. m site in the Shetlands.[12] Given the site's secluded position, steep terrain and the bad weather, remote operation was vital to the trial's success. It demonstrated the robot could do days of manual surveying labour and operate in regions and situations harmful to humans. No operators were required to be on site or even go to the isolated island at all.

BAM Nuttall installed Spot as part of a 5G test supported by the Department for Digital, Culture, Media and Sport. It led a collaboration, including Attocore and BRE, to not only develop a private 5G standalone network on a distant construction site in Shetland, but to deploy numerous new technologies and analyse their merits for construction.

Scottish Water is utilising LiDAR-equipped drones to examine its network of sewers. According to Scottish Water, the action removes individuals from potentially risky environments and decreases carbon emissions. Scottish Water has more than 33,000 km of sewers. Some, going back to the Victorian period, have previously been impossible to access. However, Scottish Water is addressing this obstacle by cooperating with Caledonia Water Alliance (CWA), civil engineering trenchless expert Environmental Techniques and drone company Good Friday Robotics. Environmental Techniques created the drones and accompanying software alongside CWA and Good Friday Robotics. Its purpose is to enhance sewer surveys and safety by lowering the number of personnel required to travel below ground. A worker controls or pilots the drone as it flies along the pipe and utilises video for visual inspection and LiDAR for measurement. The results are then manually examined by operators to detect and code the faults. The drones are built particularly for sewers and are composed of carbon fibre to minimise weight and enhance battery life.

It is envisaged that the future of construction will involve increasing uptake of new automation and robotic solutions playing a central role in design, manufacture and assembly of construction components and structures. Exemplar use cases being explored include highway maintenance and automated approaches for upgrading roadside chambers to hold key communication cables; and novel underground infrastructure deployment techniques by internet service providers with narrow, micro and slot trenching; robotic digging and new horizontal directional drilling (HDD) capabilities. Those investigating the sector point to opportunities for recovering more value from construction and demolition waste through reuse and recycling with mobile sorting and reprocessing machines; systems to identify the materials and components present in existing structures; and systems for identification and separation at source. Other highlighted opportunities include aerial/space and ground-based sensing to improve brownfield land-release processes, and the use of exo-skeleton suits and wearable technology for hazardous work, to avoid uncomfortable postures and detect biomarkers to reduce risk of worker injury. (23)

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"Our challenge holders are already striving to understand how these new technologies can and will be integrated now and in the future. There is an urgent need to establish national capability to accelerate their knowledge. Their ambitions underpin current dependencies across the economy and can advance growth and productivity as well as societal wellbeing."

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