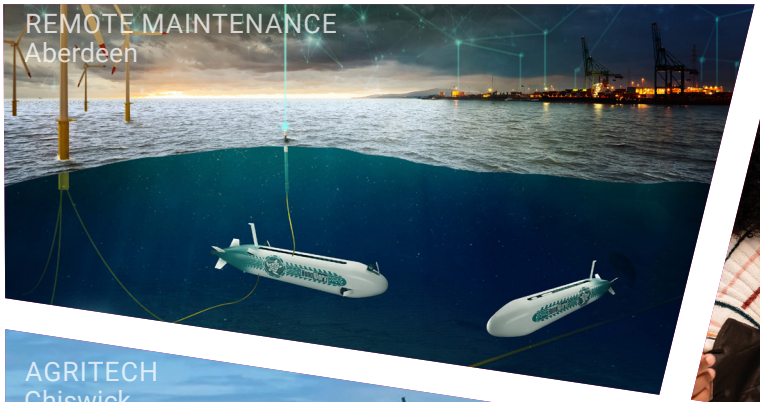
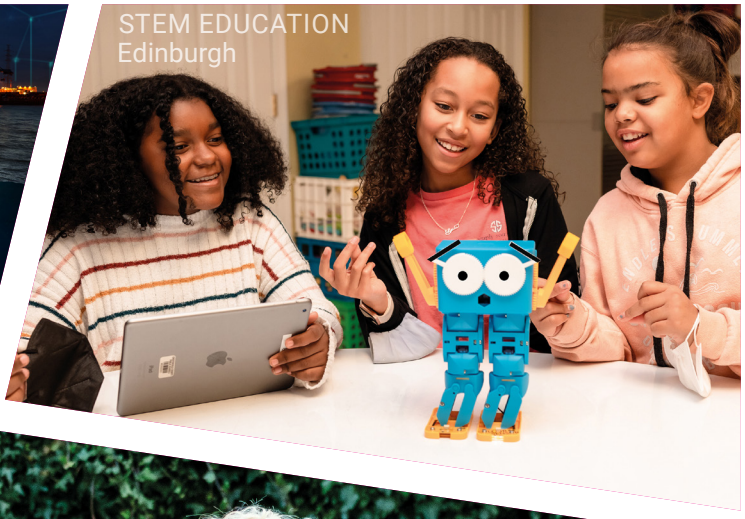
ROBOTICS
GROWTH
PARTNERSHIP



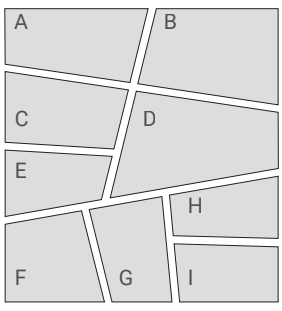


SMART MACHINES 2035

A Strategy for UK Leadership

The Robotics Growth Partnership is an independent expert committee appointed by the UK Government. It brings together representatives from across industry and academia to provide advice and insights to the UK Government. This independent report draws on the expertise of its members and those in its wider ecosystem to outline a 10 year strategy promoting economic growth.

COVER IMAGE CREDITS



A **Remote Maintenance:** HonuWorx (Aberdeen) https://honu-x.com/
B **STEM Education:** Robotical (Edinburgh) https://robotical.io/
C **Agritech:** Muddy Machines (Chiswick) https://www.muddymachines.com/
D **Prosthetics:** Open Bionics (Bristol) https://openbionics.com/en/
E **Drone Delivery:** Apian (London) https://www.apian.aero/
F **Mobility:** Oxa (Oxford) https://oxa.tech/
G **Surgery:** CMR Surgical (Cambridge) https://cmrsurgical.com/
H: **Commercial Landscaping:** Kingdom (Glasgow) https://www.kingdom.garden/
I **Warehousing:** Ocado (Hatfield) https://www.ocadogroup.com/

Prologue: The Smart Machines of 2035

Smart Machines are collaboratively networked tools acting alongside us in the physical world. With embodied intelligence they act semi-independently to assist us. Today they are transport vehicles, warehousing systems, manufacturing facilities and inspection platforms. They enhance our productivity, maintain our infrastructure and remove us from dangerous environments, keeping us safe.

By 2035 however, they will be much more integrated into our work and social communities, ubiquitous, mundane, and hiding in plain sight. They will be woven into the fabric of our society, playing essential roles in our daily lives. They will communicate and collaborate with our devices, AIs, other Smart Machines and us. They will embody artificial intelligence that assists us in the physical world.

In hospitals they will free up doctors and nurses to spend more time with patients. They will make our transport systems safer, cleaner, and more efficient. They will drive innovation in manufacturing, agriculture, and energy, helping us tackle the climate crisis. They could tidy up our homes, deliver groceries from local shops, and adapt to our needs offering support as we age. They might drive us to work, and fulfil the repetitive everyday tasks on the shop floor or a construction site. They might quietly work away at preserving the natural world, farming our crops, monitoring, protecting and repairing the environment, or building solar stations in space.

What Smart Machines look like in 2035 won't be driven by technology developments alone, but by the interplay of Smart Machines with society as they evolve. Done right, they will not only transform our economy but also rebuild trust in what technology can do for society, improving our quality of life, security and prosperity.

The UK's participation in the coming realisation of this vision will not happen by itself. It will require leadership from the Government and collaborations with business, academia, and civil society. We must create an environment where innovation and UK scaling thrives - backed by a strong industrial strategy, investment in education and skills, and a commitment to ethical and sustainable development. We must ensure that British Smart Machine businesses can compete on the global stage, while creating valued and interesting employment that builds our communities. We must create rewarding and secure careers for the next generation.

The Smart Machines 2035 Strategy is about ensuring that we seize this opportunity. It sets out a clear plan to harness the power of Smart Machines to deliver economic growth, social progress, and to improve our national security and resilience. It calls for bold actions and investments on the demand then supply sides of the ecosystem, as well as in regional innovation, talent, research and development and a regulatory framework that promotes trust and safety. We are grateful to everyone who has contributed to this strategy, especially those who provided feedback and participated in the consultation process.

Above all, it places people at the heart of technological change, ensuring that no one is left behind in this new era.

Authors
January 2025

Contents

The Robotics Growth Partnership

The Robotics Growth Partnership (RGP) was announced on 10 July 2019 by HM Government and tasked to '*help put the UK at the cutting edge of the global smart robotics revolution, turbo-charging economic productivity and unlocking benefits across society*'.

David Bisset
Director iTechnic Ltd

Professor Rob Buckingham OBE FREng
Executive Director UKAEA

Paul Clarke CBE FREng
RGP Co-chair, CTO Emeritus Ocado

Professor Sabine Hauert
University of Bristol

Dominic Keen
Founder & CEO, High Growth Robotics (BRITBOTS)

Professor James Kell FIMechE
Robotics Technical Director, Amentum

Professor David Lane CBE FREng FRSE
RGP Co-Chair, Founder Edinburgh Centre for Robotics

Professor Samia Nefti-Meziani OBE
Director of the Birmingham Robotics Institute

Professor Robert Richardson FIMechE
Real Robotics Lab, University of Leeds

Dave Swan MEng
CTO Tharsus

Executive Summary

The **Smart Machines 2035 Strategy** provides a bold roadmap to position the UK as a global leader in robotics and Smart Machines. It emphasizes their transformative potential to address pressing societal challenges, enhance economic productivity, and establish national leadership in a rapidly evolving technological landscape. This 10-year plan builds on the UK's strengths in research, innovation, and entrepreneurship, laying out strategic goals and actionable steps to unlock the full potential of Smart Machines by 2035.

Vision for Smart Machines in 2035

By 2035, Smart Machines - intelligent, semi-autonomous systems that integrate seamlessly into the physical world with people - can revolutionise diverse sectors of the UK economy. These systems will automate mundane and hazardous tasks, drive sustainable economic growth, and improve quality of life. From assisting the elderly and protecting natural ecosystems to advancing defense capabilities and supporting public infrastructure, Smart Machines will become indispensable across industries. Their evolution will depend not only on technological advancements but also on cohesive action to integrate them into society responsibly and ethically.

Unlocking Prosperity -The Size of the Prize

If fully adopted, Smart Machines could increase UK Gross Value Added (GVA) across sectors from £6.4bn to a massive £150bn by 2035. This growth will stem from reduced costs, improved productivity, and the creation of new industries and jobs, boosting employment prospects. This strategy positions the UK to compete with global leaders like the US, China, and South Korea by fostering innovation and supporting scalable businesses. A thriving Smart Machine ecosystem would boost the UK's ability to achieve climate resilience and national security.

The Need for Action

The UK lags behind global leaders in industrial robotics adoption and Smart Machine deployment, in part due to perceived risks, regulatory hurdles, and conservative business practices. The UK's Smart Machine ecosystem is characterised by fragmentation and silos, limiting collaboration and scalability. Smart Machine startups often struggle to secure growth-stage funding due to longer life cycles and lower capital efficiency compared to software startups.

Strategic Goals

The strategy is built around two key goals:

Goal 1: DEMAND - Driving Adoption and Uptake
Drive the adoption of Smart Machine technologies by public services, national infrastructure and UK businesses across a range of sectors, to deliver benefits in productivity, competitiveness, resilience and sustainability for the economy, society and national security. Create also a regulatory framework that supports innovation and the ethical use of Smart Machines that are trusted and accepted by society.

Goal 2: SUPPLY - Developing the Ecosystem of Innovation and Business
Building on progress developing the UK Smart Machine ecosystem over the last 10 years, to now enable faster acceleration. Make the UK a creator of thriving new Smart Machine businesses and solutions across regions and sectors and a preferred location for investors and global talent. Ensure the UK is home to world leading science and engineering in Smart Machines, growing UK knowledge and skills to underpin employment and the economy.

Strategic Actions

The strategy views the processes of supply and demand for creation and deployment of Smart Machines as a flywheel. When conditions are right, demand and supply reinforce each other, creating an acceleration effect that underpins economic growth. To overcome perceived fragmentations and frictions in order to make the Growth Flywheel spin and become self-sustaining, ten recommendations are made on demand then supply side.

Demand Side:

1. Establish an Office for Smart Machines (OSM) inside Government to stimulate demand-side through public procurement, joint industry projects and financial incentives.
2. Expand and replicate regional Smart Machine Translation Hubs federated and co-located with regional scientific Centres of Excellence and local industrial-sector strongholds. This enables try-before-you-buy in Living Labs, proving grounds and certification facilities.
3. Task the OSM and Translation Hubs to address opportunities in the Government's five Missions and eight Growth-Driving Sectors identified within the Industrial Strategy Green Paper, with systems thinking and component re-use across applications.
4. Support the work of the the National UK RAS Regulations, Standards and Ethics Committee[1] connecting regulators, coordinating with UK Government and UKRI AI Safety organisations to establish trusted kite marks for Smart Machines. Build these from practical experience with citizens within Living Labs and with regard to UK law.
5. Task the OSM to build upon the outcomes of the ARIA Expert Committee on modularity, interoperability and common standards in robotics, through the various public and private bodies across the Smart Machine ecosystem.

Supply Side:

6. Establish a Centre of Excellence to bootstrap and curate community development of the open software and hardware tools that realise the modular simulation and physical building blocks within the Growth Flywheel. These enable try-before-you-buy, component reuse and ultimately commoditisation to help onshoring of supply to the UK.
7. Support the regional Smart Machine Translation Hubs of recommendation 2 to provide spaces for incubation of new businesses and accelerator style business training making use of their Living Labs. Also to mobilise private capital to create regional facilities for serviced manufacturing provision that growing Smart Machine businesses can use as they expand, thus onshore UK supply.
8. Create the £100m Smart Machines venture investment fund recommended by the Tony Blair Institute report to increase the level of venture and Series A round sizes to £eight figures, deploying with private capital using the Scottish National Investment Bank model.
9. Address the supply of advanced technical talent and innovative ideas by scoping and launching a patient 10 year Smart Machine Research and Innovation programme top down across all the Government's funding agencies.
10. Create a national Skills Maintenance and Development programme across the HE, FE and Schools sectors. Thus ensuring a pipeline of talent from technicians to specialist researchers and engineers to underpin the Growth Flywheel, promoting STEM opportunities early in schools and a diverse workforce in the long term.

To demonstrate faster impact on Growth, the strategy proposes an ordering of immediate, medium and longer term actions from these 10 recommendations. These move through the cold start, tipping point, escape velocity and maturity/ moat phases[2] that spin up the Growth Flywheel of the Smart Machine producer/ consumer ecosystem.

1 https://www.linkedin.com/groups/13025439/
2 https://www.amazon.co.uk/cold-start-problem-Network-Effects/dp/0062969749

1. Introduction

1.1 Historical Context

The Robotics and Autonomous Systems (RAS) 2020 Strategy[1] was published in July 2014, with the objective of capturing value in a cross-sector UK RAS innovation pipeline through co-ordinated development of assets, challenges, clusters and skills.

Key landmarks since its publication include: significant advances with autonomous vehicles reaching live trials without safety drivers; proliferation of drone applications including surveying, monitoring and logistics; increased capabilities of robots leading to a significant increase in the diversity of robot use cases; UK ISCF programmes including Robots for a Safer World and Future Flight; the Robotics Growth Partnership (RGP)[2], established by the UK government in July 2019, authored a vision for Cyber-Physical Infrastructure (CPI)[3], published in February 2022, in which Smart Machines play a leading role; advances in Large Language Models (LLMs) and generative AI which will have implications for embodied AI.

The term "robot" typically conjures-up for the general public a stationary six-axis robot working on a car production line or a terminator style creature in a movie. The reality is that robots come in many different shapes and sizes, with widely varying behaviours and capabilities. Many of the most successful robots are hiding in plain sight in the form of Smart Machines such as washing machines, connected smart cars and drones. Those with embodied intelligence and mobility can exhibit behaviours such as autonomy, collaboration and swarming. The proportion of Smart Machines will only increase and it is for that reason, and to future proof this strategy for 2035, that we have taken the conscious decision to shift the narrative from "Robotics and Autonomous Systems" to "Smart Machines".

1 http://ukrgp.org/wp-content/uploads/2024/06/13781-RAS-Strategy-report-SCREEN-AW.pdf
2 https://ukrgp.org/
3 https://www.gov.uk/government/publications/cyber-physical-infrastructure

1.2 Motivation

The UK faces a growing list of exponential challenges and opportunities, both at home and abroad.

Data released by the Office for National Statistics[4] (ONS) in 2023 shows the UK's productivity has historically been amongst the lowest in the G7[5] and the Government is now prioritising economic growth. Further, there are nascent emergencies presenting national risks that require national preparedness and resilience - war in Ukraine and elsewhere, climate change, energy and food security, demographic change, pandemics and Brexit. There is a national perception that the UK quality of life is diminishing as we fall behind the EU and the US in the provision of public services. The NHS is short of 60,000 nurses, the average age of a construction worker is 55 whilst we plan to build 1.5m homes by 2029[6], and £200bn of our infrastructure requires maintenance by 2035. 'No plan survives contact with the enemy[7]' and so we need tools to respond flexibly and rapidly to such shocks, to preserve and advance the quality of life for UK citizens.

Beyond industrial robots, Smart Machines are collaboratively networked tools acting in the physical world that use AI to interpret sensor data, team with people and each other, and formulate semi-independent action plans to move, touch, grasp and communicate. They support or replace humans in complex tasks and/ or hazardous environments. Today they are autonomous transport vehicles, warehousing systems, inspection platforms and weapons. In the future they will work as personal assistants and companions, alongside farmers, builders, surgeons, fire fighters, and other roles we cannot imagine from the present; supporting citizens in their everyday lives.

Used appropriately they improve productivity, reduce costs, increase yields, take people out of harm's way, enable remote operations, and improve the quality of life. For many applications there are no alternatives - affordable agile defence, automation of flexible assembly and

4 https://www.ons.gov.uk/
5 https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/bulletins/internationalcomparisonsofproductivityfinalestimates/2021
6 https://www.bbc.co.uk/news/articles/c5yg1471rwpo
7 Helmuth von Moltke (1800–1891)

manufacture, maintenance of fusion reactors and offshore energy infrastructure.

Recent advances in Large Language Models (LLMs) and Generative AI have given us a taste of the role that AI could play as a potential "force for good" in tackling these issues. However many of the most important applications of AI will require interventions in our physical world and AI lacks that physicality. AI needs Smart Machines to be its scalable "arms and legs" and Smart Machines need AI as their embodied intelligence.

This cocktail of AI and Smart Machines is even more potent in combination with other technologies such as Synthetic Environments and Living Labs. These are at the heart of the RGP's vision for a Cyber-Physical Infrastructure. It could enable automation of our industries, public services and national infrastructure; for climate change intervention/ resilience, UK energy security, and our national defence; to underpin our competitive advantage and our aspirations to be a major innovator on the world stage.

To thrive and compete in a fragmenting and uncertain world, the UK must grow a strong community of companies, innovators and researchers creating world-leading Smart Machine businesses (supply side), fuelled by domestic demand to adopt them as solutions (demand side) before exporting. By doing so we have the opportunity to create value-add and innovation in our domestic Smart Machine capabilities that can compete with the Chinese one size fits all, cheapest, race to the bottom strategy. In other words, the UK must grow its Smart Machine ecosystem.

This strategy is the result of a year of work by the RGP in 2023/ 24 during two successive Governments. From initial ideas and discussion a draft Smart Machine 2035 Strategy Consultation[1] was published in June 2024. Written responses to specific questions were initially sought, of which 54 were received. Thereafter two in person and one online discursive consultations took place in September and October 2024 attended by 101 individuals from across industry, academia and the public sector (Appendix B).

The inputs from these responses and events have been distilled into the goals, issues, potential actions and framing of this Strategy offering ways forward to make Smart Machines a key ingredient generating UK economic growth and preparedness.

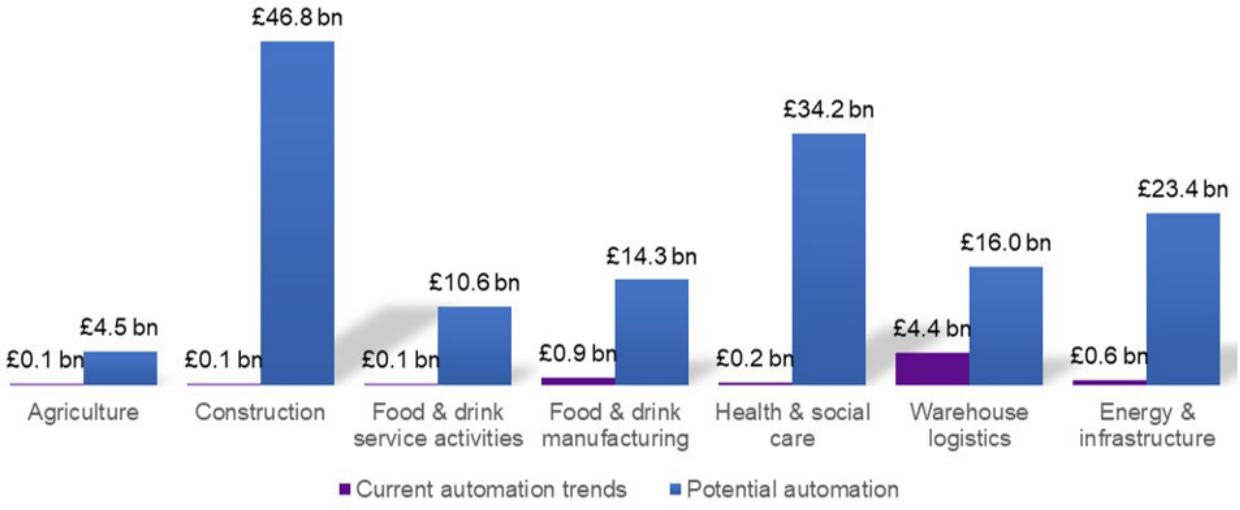


Figure 1.1: Potential value of GVA attributable to RAS by 2035 if potential rates of automation are achieved

1.3 Unlocking Prosperity - The Size of the Prize

A recent HMG commissioned independent report[2] estimated UK Gross Value Added (GVA) could be boosted from £6.4bn with UK current automation trends to an enormous £149.9bn with Smart Machine adoption across sectors by 2035. The estimated sector breakdown is in Figure 1.1.

1 https://ukrgp.org/smart-machines-2035-strategy-summary-draft-for-consultation/

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

Further indirect economic benefits include reducing prices of goods and services which increases demand, increased foreign direct investment into a leading Smart Machine nation, further advancement of enabling technologies including AI, internet of things, sensors, batteries and materials, and new roles along the supply chain improving business resilience.

1.4 Stagnation from Inaction - The Automation Abyss

The UK lags internationally on supply and uptake of Smart Machines.

On the demand side, the UK utilisation of industrial robots substantially lags internationally using only 101 robots per 10,000 workers in 2020[1]. This compares to Korea (932), Japan (390), USA (255), China (246), Italy (224) Canada (176) and even Slovakia (175)[3]. Our rate of adoption (18%) was half the Czech Republic (36%), France (42%) and Switzerland (40%).

On the supply side the UK advanced robotics science has the 6th highest international h-index for publication citations, is 3rd highest for proportion of publications in the top 10% providing 4.2% of the research[2]. This is a sign of the quality and potential but we are not yet internationally leading. For companies, Beauhurst's industry tracker counts 2,204 robotics and automation companies headquartered in the UK. From the 195 of these companies reporting full financials, the average turnover is £13m with 110,708 total employees and a company average size of 83, so modest. Of these 2,204 companies, 1,090 raised funds in the period 2011-2021. However only 10 achieved raises greater than £185m, and only 2 greater than £500m (CMR Surgical, £838m; Wayve £1,014m). Whereas the UK has typically averaged 100+ Smart Machine deals in the period 2018-2024, the US has averaged 600-700. As a proportion of Gross Domestic Product (GDP)[3], Pitchbook[4] suggests the UK has gone some way to catch up with the US. However, the UK GDP is not growing at the same rate as the US, QED[5].

1 https://balloonone.com/blog/2022/05/04/robot-density-in-the-uk-in-2022/
2 https://techtracker.aspi.org.au/tech/advanced-robotics/?colours=true
3 https://www.ons.gov.uk/economy/grossdomesticproductgdp
4 https://pitchbook.com/
5 quod erat demonstrandum

An International Government Forum[6] at the London 2023 IEEE International Conference on Robotics and Automation illustrated strong future strategic thinking and Government Robotics investments in the US, China, Japan, Canada, the EU and Korea. These Governments are acting to support their Smart Machines industry in the national interest by tipping the balance of market forces in their favour.

Through Government convening power, the UK must respond if it is to reap the economic and resilience rewards and not be relegated behind other G7 nations, as its productivity already is.

1.5 Progress to the Future - The UK Smart Machine Ecosystem

Following the 2014 Eight Great Technologies[7] and RAS2020 Strategy, the UK has a healthy but still emerging ecosystem of researchers, startups, SMEs and mature companies developing Smart Machine technologies, products and services.

On the demand side, initiatives such as Made Smarter[8] have encouraged the UK manufacturing industry to embrace and embark on digital transformations generally, including robotics. The Manufacturing Technology Centre[9] offers impartial advice to companies on automation and undertakes projects[10]. The UK Atomic Energy Authority RAICo[11] in Cumbria shows how public agencies can come together to support translation in the nuclear industry. The new Cradle Robotics Prosperity Partnership[12] at the University of Manchester works with industry across sectors to demonstrate the art of the possible. Through the Edinburgh City deal the National Robotarium[13] was constructed in 18 months and in its first year of operation generated £1.8m in revenue supporting demand side businesses on a sustainable commercial basis.

6 https://www.icra2023.org/forums/government-forum
7 https://policyexchange.org.uk/publication/the-eight-great-technologies-10-years-on/
8 https://www.madesmarter.uk
9 https://www.the-mtc.org/what-we-do/technologies/automation-robotics/
10 https://www.the-mtc.org/case-studies/elera-autonomous-robotic-manufacturing-processes/
11 https://raico.org/
12 https://cradlerobotics.co.uk
13 https://thenationalrobotarium.com

On the supply side at least £600m of subsequent public and private investment flowed into the sector including UKRI ISCF programmes[1], the EPSRC UK RAS Network[2], DfT/ DBT Centre for Connected and Autonomous Vehicles (CCAV)[3], and investments from the Nuclear Decommissioning Authority (NDA)[4] and the Ministry of Defence[5]. Clusters of strength with ecosystems of researchers and startups emerged in centres including Bristol, Edinburgh, Oxford, London, Manchester, Sheffield, Birmingham. The corresponding 10X uptick in venture and corporate investment produced successful new businesses including Ocado[6], Oxa[7], CMR Surgical[8], Dyson 360[9], SLAMCore[10], Wayve[11], Covvi[12]. An ecosystem of smaller SMEs are also growing (e.g. Wootzano[13], Robotical[14], Automata[15], Bioliberty[16], Open Bionics[17], Engineered Arts[18], Crover[19], Extend Robotics[20], Kingdom Technologies[21], Inovorobotics[22], Rovco/Vaarst[23], Ice9[24], Frontier Robotics, Acuity Robotics), have exited (5AI[25], SeeByte[26], Touch Bionics[27]) or closed (Reach Robotics[28], Karakuri[29], Small Robot Company[30]) across sectors including Edtech, Agriculture, Inspection, Prosthetics, Medical, Drones, Offshore Energy and Mobility.

1 https://www.ukri.org/what-we-do/our-main-funds-and-areas-of-support/browse-our-areas-of-investment-and-support/robots-for-a-safer-world/
2 https://www.ukras.org.uk
3 https://www.gov.uk/government/organisations/centre-for-connected-and-autonomous-vehicles
4 https://nda.blog.gov.uk/robots-reduce-radioactive-risks-for-workers-in-nuclear-decommissioning/
5 https://www.gov.uk/guidance/robotics-and-autonomous-systems-defence-science-and-technology-capability
6 https://www.ocadogroup.com
7 https://oxa.tech
8 https://cmrsurgical.com
9 https://www.dyson.co.uk/vacuum-cleaners/robot/360-vis-nav/sign-up
10 https://www.slamcore.com
11 https://wayve.ai
12 https://www.covvi.com
13 https://www.wootzano.com
14 https://robotical.io
15 https://automata.tech
16 https://www.bioliberty.co.uk/#/home
17 https://openbionics.com/en/
18 https://www.engineeredarts.co.uk
19 https://www.crover.tech
20 https://www.extendrobotics.com
21 https://www.kingdom.garden
22 https://inovorobotics.com
23 https://www.rovco.com/who-are-we/
24 https://ice9robotics.co.uk
25 https://www.five.ai
26 https://www.seebyte.com
27 https://www.scotsman.com/business/livingston-based-touch-bionics-sold-for-aps275m-1478992
28 https://guce.techcrunch.com/copyConsent?sessionId=3_cc-session_66c8339d-c425-4d6d-b82e-31b5892f8a58&lang=en-US
29 https://karakuri.com
30 https://www.smallrobotcompany.com

1.6 Size of the Challenge and The Role of Government

Despite the above progress, there are frictions on both supply and demand sides that are slowing and limiting UK growth. The Smart Machine ecosystem is complex, non linear and interconnected in numerous ways (Figure 1.2).

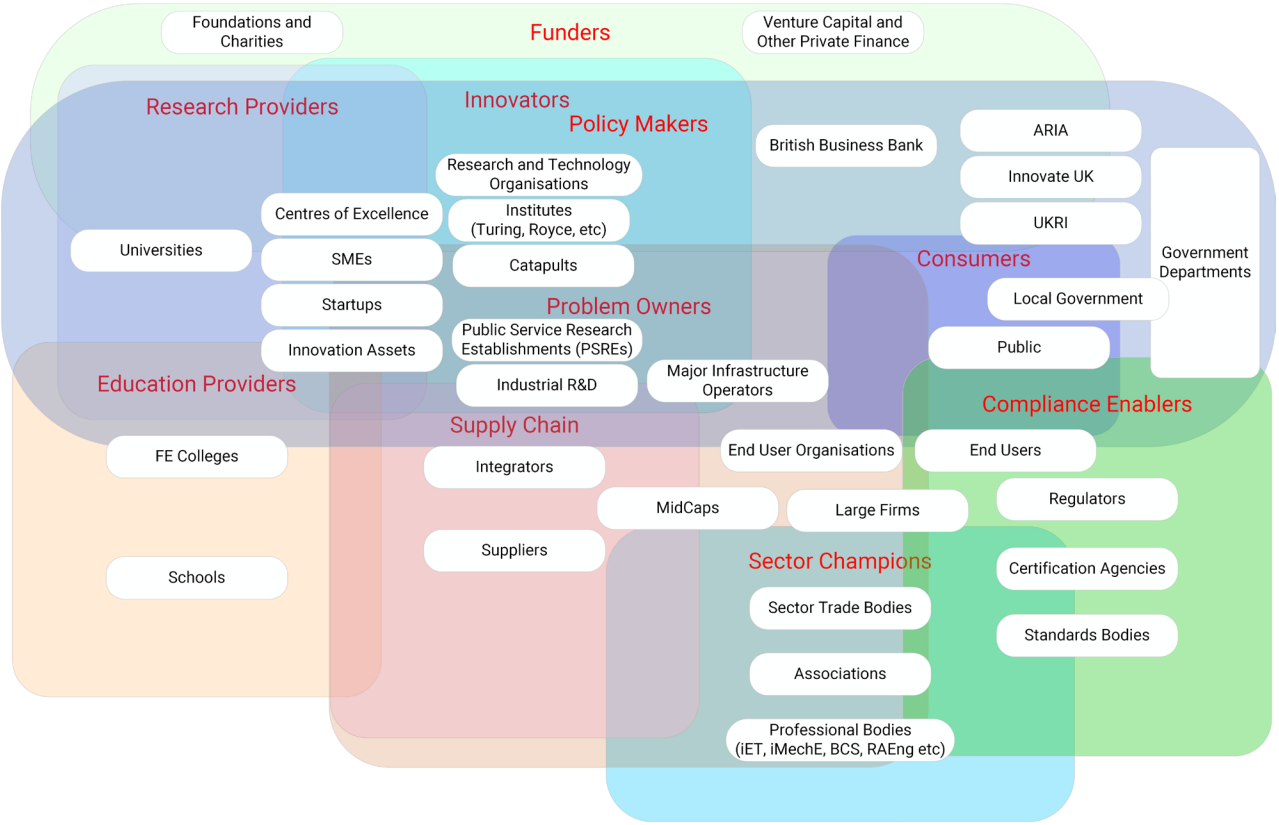


Figure 1.2: The Smart Machine Ecosystem

UK demand for Smart Machine products and services is muted because new solutions are often unproven. UK managers are cautious in adoption because of the risks in success and the time taken for a return on investment. If UK Smart Machine businesses can more rapidly scale and test their new solutions as products or services, this will strengthen the investment case on the demand side by reducing the risks of failure and speeding up the return on investment. There are other challenges of awareness, procurement complexity, siloed behaviour within sectors and lack of tools/ skills/ appetite for modelling new solutions in synthetic environments.

On the supply side UK Smart Machine startups struggle to demonstrate evidence of product/ market fit to investors at series A and beyond without directly exporting. UK adoption on the demand side is too little or too slow to achieve sufficient scale within the cash runway. Exporting requires greater resources in sales, marketing, product support than typical UK seed investment rounds will bear, particularly for deep tech hardware. Further there are insufficient suitable sites with infrastructure (transport, power, buildings) where manufacturing can scale. UK startups reaching Series B therefore go overseas to manufacture at this crucial phase. The UK does not get the broadening base benefit of any product-market fit success.

Left unsupported, the Smart Machine ecosystem will not overcome these frictions, fragmentations and challenges of supply and demand sides. This leaves the nation critically unprepared, unproductive, internationally overtaken and exposed. Crucially if unsupported, the UK misses a massive opportunity hard won over 10 years since the RAS2020 Strategy. There is a crucial role for Government action therefore.

1.7 Framework For Action

As HMG considers its Modern Industrial Strategy[1] and Milestones for a Mission-Led Government[2] there are strategic actions that should be taken to stimulate the UK's Smart Machine ecosystem to help achieve the potential 100X on the 10X growth we have seen to date. To consider these, this Smart Machine 2035 Strategy builds upon the RAS2020 Strategy around two connected goals:

> **Goal 1 - Demand:** Drive Smart Machine adoption and uptake by UK businesses across sectors to improve the density and availability of systems. Alongside this create a regulatory framework that supports innovation and the ethical use of Smart Machines that are trusted while protecting UK capabilities and therefore national security (Section 3).

> **Goal 2 - Supply:** Further stimulate the ecosystem of innovation and business to create world leading and disruptive Smart Machine products and services, de-risked and deployed domestically then exported around the world. Alongside this, ensure the UK produces, attracts and keeps world leading Smart Machine science, engineering and entrepreneurship skills from school onwards and stimulates long term scientific and innovation progress to maintain a disruptive edge. (Section 4).

We first present a Growth Flywheel framework as a different architecture for action to think about these goals, the frictions that are preventing their unaided organic evolution and some possible interventions.

1 https://www.gov.uk/government/consultations/invest-2035-the-uks-modern-industrial-strategy/invest-2035-the-uks-modern-industrial-strategy
2 https://www.gov.uk/missions

2. The Smart Machine Flywheel Generates Growth

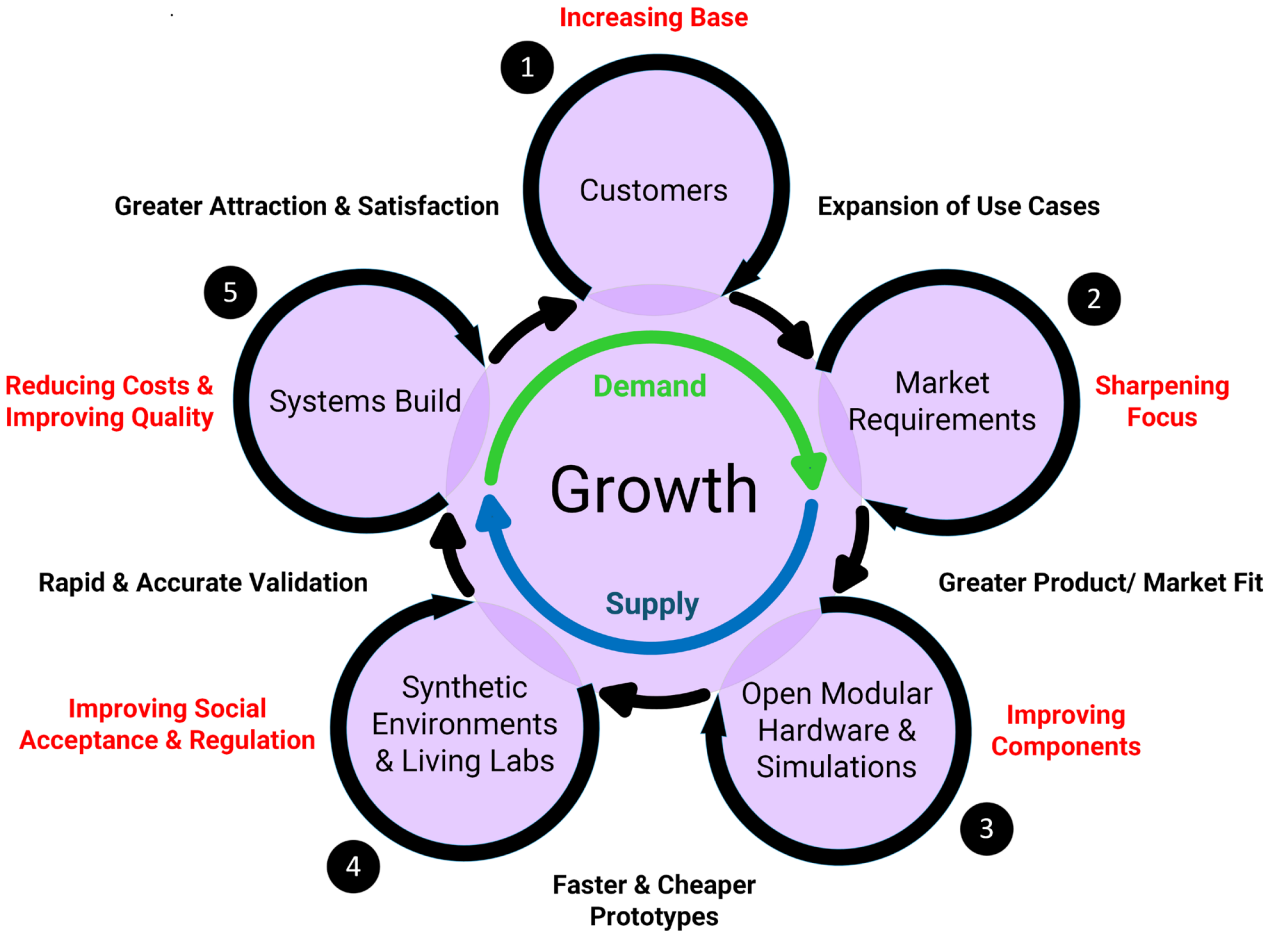


Figure 2.1: Growth Flywheel for self-reinforcing adoption and supply of Smart Machines to generate Growth

We envisage the processes of supply and demand for creation and deployment of Smart Machines as a *flywheel* (Figure 2.1). We do this because demand and supply are connected, and if conditions are right each re-enforces the other creating an acceleration effect. As a result, the ecosystem of UK businesses who both use and provide Smart Machines can grow together in lock-step, gathering momentum for free, supported by innovative research and talent development. *The Growth Flywheel creates economic growth in both the industries that use Smart Machines to improve their productivity and flexibility, and the companies that provide and create the systems*.

The Growth Flywheel starts on the supply side with Customers (ring 1) from whom Market Requirements (ring 2) are obtained usually by companies. Using systems thinking, the pain points in a market segment where Smart Machines can improve productivity and/ or competitiveness are identified and prioritised. This expands use cases and creates a product/ market fit advantage with sharper focus over competitors.

The Growth Flywheel must translate this product/ market fit advantage into fast and cheap simulation-first prototypes enabling try-before-you-buy with customers. Following the principles of Cyber-Physical Infrastructure, synthetic environments and open modular simulations form digital twins (of their corresponding hardware modules) that can be federated into bigger systems to achieve this (ring 3).

The faster and cheaper in-silico prototype advantage must then lead to a validation advantage using physical prototypes that can be produced quickly and cheaply, and then tested

within Living Labs (ring 4); hybrid so-called hardware-in-the-loop simulations are also useful. Testing with people and regulators within Living Labs nurtures social understanding, trust and acceptance.

The Growth Flywheel must then take the resulting rapid and accurate validation advantage and create a customer satisfaction advantage by building systems for them that reduce costs and improve quality over time (ring 5). Early adoption of open modular hardware and simulation components (ring 3) helps to commoditise Smart Machine components which facilitates this faster, cheaper and previously-tested system-build downstream.

The customer satisfaction advantage leads ultimately to an increase in the size and quality of the customer base (ring 1). This in turn leads to an expansion of use cases following exemplars of success, a sharpening of the market requirements focus (ring 2) and hence even greater product/ market fit. Further open modular hardware components are developed and federated (ring 3) and so the Growth Flywheel continues to spin up and gather momentum

A key challenge for the UK is that this Growth Flywheel is not spinning. We have many but not all of the ingredients in our facilities and resources, and the way successful companies do business. However it is not ubiquitous and there are a variety of frictions and gaps. For example, many companies of necessity devote resources to developing proprietary subsystems that are really commodities with little value add.

We turn now to expand on the components in this Growth Flywheel by considering demand (section 3) and supply (section 4) sides in more detail and to shine a light on some of the opportunities to develop momentum and hence growth.

3. Goal 1: Demand - Driving Adoption and Uptake

Drive the adoption of Smart Machine technologies by public services, national infrastructure and UK businesses across a range of sectors, to deliver benefits in productivity, competitiveness, resilience and sustainability for the economy, society and national security. Create also a regulatory framework that supports innovation and the ethical use of Smart Machines that are trusted and accepted by society.

3.1 Building The UK Customer Base

For the Growth Flywheel to spin, customers (ring 1) must be attracted to try Smart Machine solutions and to engage with the supply side, preferably in the UK. For the reasons set out in section 1.5 there are currently insufficient UK companies across a range of sectors prepared to do this. Their productivity, competitiveness and therefore growth suffers. We here further identify some of the reasons for this and propose actions Government can support and/or convene to reduce or remove frictions that are limiting demand.

3.1.1 Creating Early Adoption

UK businesses have very limited role models or exemplars to stimulate their thinking or ambition deploying Smart Machines. There are too few early adopters prepared to cross the chasm and hence encourage the early and late majority then laggards[1]. Both Government and industry can play a role addressing this.

Public Procurement

On the Government side, public procurement across public services and national infrastructure could be harnessed to stimulate Smart Machine uptake that kick-starts the top of the Growth Flywheel. This requires a change in the mindset and mandate for public procurement. Rather than just issuing requirements and taking the most competitive tender, Government agencies should work in partnership with suppliers to define early requirements, test prototypes, refine requirements and repeat. In so doing, they would foster the development of shared components/ solutions and build capacity within the underlying Smart Machine ecosystem. Final procurement proceeds as a competitive tender once the spiral has converged on a workable, cost effective solution offering productivity or other gains.

The new Innovate UK Contracts for Innovation[2] that replace the Small Business Research Initiative[3] (SBRI) offer components of this. One challenge is the resulting foreground IP is owned by the Challenge Owner to avoid subsidy to the small business under the terms of the Subsidy Control Act 2022. This lack of IP ownership by the supplier(s) can hinder subsequent investments in the business or growth into other sectors or customers.

Joint Industry Projects

On the industry side a further possible solution is to also create Joint industry Projects (JIPs) in or across sectors. Large organisations close to or at the top of the value chain work together to specify a need and each provide a proportion of the funding into a pot (top down model). Companies or consortia bid into this pot and are 100% funded. Typically they retain foreground IP, but offer access to the funding companies at preferential rates without exclusivity.

Alternatively, companies or consortia bid ideas to the large organisations and those with an interest co-fund (bottom up model). Standard contracts are used for a level playing field. Government organisations could also co-fund a JIP to gain industry leverage around a common problem. The Industry Technology Facilitator[4] in Aberdeen previously ran just such a scheme in the offshore energy sector, owned and funded by 30 Energy Companies and Tier One Suppliers.

Financial Incentives

Government could also stimulate adoption through financial incentives. Beyond existing schemes such as R&D Tax Credits and Patent Box, the Government could introduce a scheme of Government backed purchasing. This could take a variety of forms such as loans, vouchers or grants (as in the Singapore Productivity Solutions Grant[5]), but would directly underpin the financial risk of early Smart Machine adoption in conservative industries. Further tax incentives, for example 100% capital allowances (full

1 en.wikipedia.org/wiki/Crossing_the_Chasm
2 www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/innovate-uk-contracts-for-innovation
3 www.gov.uk/government/collections/sbri-the-small-business-research-initiative
4 https://en.wikipedia.org/wiki/Industry_Technology_Facilitator
5 https://www.enterprisesg.gov.sg/financial-support/productivity-solutions-grant

expensing) against corporation tax for qualifying businesses (as during the Covid recovery[1]), could also be envisaged. Incentives that work through the tax system do not require the machinery of proposals, review and monitoring and are more efficient to implement for all. Such incentives should also be considered to encourage companies to further co-sponsor University and FE College training and research on supply side (section 4.2) and to support innovative companies in accessing national facilities (section 3.1.3 and section 4.1.2). Financial incentives could also be used to encourage companies to share, and even open-source, their Smart Machines components and solutions.

Government Office for Smart Machines
This Government led thinking requires a trusted body, almost certainly within the government tent, to drive the necessary coordination and convening. An Office for Smart Machines (OSM), part modelled upon the cross departmental Centre for Connected and Autonomous Vehicles[2] (CCAV), could address the national strategic agenda for research, innovation and deployment of Smart Machines across public services, national infrastructure and government departments.

In combination with the independent perspective provided by the RGP and other relevant national bodies of stakeholders (e.g. the British Automation and Robot Association[3] (BARA), National UK RAS Regulations, Standards and Ethics Committee[4]), the OSM could offer trusted advice to Ministers and civil servants on matters of Smart Machine policy and strategy that promotes excellence, including establishing and nurturing the Smart Machines centric mindset discussed above.

By signposting creative opportunities to harness the power of public procurement across use-cases and government departments, the OSM would stimulate the development of the shared components, systems thinking and other elements of the Smart Machines ecosystem. These would unlock reusable and interoperable Smart Machine solutions across government missions and help drive Smart Machine adoption and growth across industry use cases. It would therefore create a Smart Machine centric mindset inside Government, leading by example.

Recommendation 1: Establish an Office for Smart Machines (OSM) inside Government loosely modelled on the cross department model of the Centre for Connected and Autonomous Vehicles (CCAV). Charge it to work across Government departments to seek out opportunities for smart, spiral procurement and help co-develop the appropriate public procurement approach. Choose early procurements with clear needs and available capabilities to maximise probability of early success. Work with Industry organisations and major companies across key Sectors to seek support for Joint Industry Projects (JIPs). Agree appropriate contractual frameworks for contract letting, IP and exploitation. Work with Ministers and Treasury to examine the role financial incentives could play promoting demand for Smart Machines.

3.1.2 Try Before You Buy

For many organisations, Smart Machines are like exotic wild animals. They don't know where to get them from, they don't understand their ecosystems, they have little idea about their behaviours and what they can and cannot do and they lack the competences to look after them properly. So we need to domesticate (and democratise) these Smart Machines so that they are within reach of all organisations, not just the Smart Machine zoo keepers and circus trainers like Ocado, Dyson, Rolls-Royce and Arup.

One of significant barriers to adoption of Smart Machines is the inability of organisations, across both the private and public sectors, to grasp the "sense of the possible" relating to how they could transform their operations. As discussed within the RGP's vision for a Cyber Physical Infrastructure, synthetic models (simulations, emulations, visualisations, digital shadows and digital twins) have an important role to play across the whole Smart Machine innovation lifecycle and the Growth Flywheel; accelerating and de-risking ideation, design, development, testing, maintenance and decommissioning, whilst also empowering greater optimisation and systems thinking. They can enable companies to try-before-you-buy and underpin business cases for investment in Smart Machines.

1 https://www.gov.uk/government/publications/full-expensing/spring-budget-2023-full-expensing
2 https://www.gov.uk/government/organisations/centre-for-connected-and-autonomous-vehicles
3 https://www.automate-uk.com/our-associations/bara/
4 https://www.linkedin.com/groups/13025439/

The open tools needed to implement try-before-you-buy (ring 3) are considered further as part of the Supply side in section 4

3.1.3 Creating Local Market Stimulation

To stimulate demand, regional initiatives are as important as national ones. Different regions across the UK have different industrial strengths, weaknesses and potential. Internationally the clustering experiences of Odense Robotics[1] in Denmark and Mass Robotics[2] in Boston have demonstrated the ecosystem benefits of a strong regional approach. Regional strengths have started to emerge across the UK but need a stronger focus if they are to be impactful.

For demand side stimulation, physical regional centres are needed as venues where companies interested in try-before-you-buy can come to work with engineers in simulated and physical spaces to prototype their thinking. Experience has shown these can be largely self-funding after an initial capital injection for infrastructure (buildings, Living Labs) especially if collocated or federated with a research centre of excellence producing skilled people. Such translation centres could also have a role in formal test and certification of developed systems.

Examples currently operating include the National Robotarium[3] in Edinburgh, Bristol Robotics Lab Technology Solutions[4] in Bristol, The Manufacturing Technology Centre[5] Automation and Robotics activities in Coventry, The nuclear Robotics and AI Collaboration[6] (RAICo) in Whitehaven, Cumbria, federates with Manchester University and is an example where different public bodies in a sector (UK Atomic Energy Authority and Nuclear Decommissioning Agency) come together to co-fund. University groups are also active including Birmingham University RESCu-M2 Hub[7], Leeds University Real Robotics Lab[8], The University of Manchester CRADLE Prosperity Partnership[9], and the University of York Centre for Assuring Autonomy[10]. However, coverage across the regions is incomplete and there is scope for a greater coordination and sharing of best practices and strengths with resources for a more federated/ cohesive effort and facilities for a bigger impact.

These Translation Hubs also have an important role to play stimulating the supply side, to be considered further in section 4.1.2.

Recommendation 2: Building on current Smart Machine translation facilities co-located or federated with research centres of excellence across the UK, establish a more extensive regional network of Translation Hubs where local conditions are suitable. Include Living Labs, test and certification facilities as well as office and conference spaces to support local companies prototyping ideas before committing to procurements and tendering (part of try-before-you-buy).

3.1.4 Joined Up Thinking - Co-ordinating and Convening the Smart Machine Demand Side

Underpinning the new mindset and public procurement strategy, there needs to be more joined-up systems thinking across use cases, government departments and sectors. The greater reuse of components, services and solutions that this would foster, would reduce time, cost, risk and wastage whilst increasing agility and interoperability. For example, we will need clean-energy autonomous logistics for our healthcare system, for defence, for supply chain resilience and for our public transport, and we need these solutions to be able to collaborate and interoperate. Yet we currently lack the systems thinking and joined-up approach required to develop such infrastructure once for shared cross-sector deployment. These outcomes are important not only for the public sector but also to stimulate investment, innovation and adoption within the private sector. By using the UK as a country-scale Living Lab, we can not only build solutions for ourselves, but also use the UK as a powerful demonstrator for new export opportunities.

1 https://www.odenserobotics.dk/
2 https://www.massrobotics.org/
3 https://thenationalrobotarium.com
4 https://www.bristolroboticslab.com/brl-tech-solutions
5 https://the-amtc.co.uk/training/our-courses/automation/
6 https://raico.org
7 https://research.birmingham.ac.uk/en/projects/epsrc-manufacturing-research-hub-in-robotics-automation-smart-mac-2
8 https://www.realrobotics.co.uk/
9 https://cradlerobotics.co.uk/
10 https://www.york.ac.uk/assuring-autonomy/

Both the OSM and the Regional Translation Hubs have a role to play in connecting applications across Government departments and adjacent sectors to illustrate the potential of new solutions to adjacent challenges.

We saw the impact that an exogenous shock such as the pandemic can have on our supply chains. Weaving Smart Machines into the fabric of our society will inevitably increase our dependence on them and on the free access to the components required to build them. The OSM could undertake a study into Smart Machine supply chain capacity, diversity and resilience, including exploring alternative options for greater onshoring.

There are a variety of other scoping and connecting activities the OSM and Regional Hubs might undertake, for example:

1. Establish international collaborations to learn from other countries.
2. Perform regular industry surveys to identify new opportunities and UK capabilities/ gaps. Integrate roadmaps from different sectors to identify synergies and opportunities.
3. Monitor sector impacts through metrics and benchmarks as evidence of the effectiveness of strategic actions.
4. Foresighting to futurecast new opportunities using a Foresight Group and/ or the RGP. Map UK strengths to international opportunities and needs.
5. Catalog early adoption opportunities and successes to demonstrate the possible.
6. Develop illustrative Return on Investment (ROI) economic costing models that others can adapt.
7. Initiate a major annual national showcase event similar in spirit to CES[1] as the UK go-to forum for demonstrating, networking and learning.
8. Initiate sector and regional based events and working groups to stimulate local ecosystems.
9. Map Government funding pipelines to identify gaps, valleys of death and unnecessary duplications.

1 https://www.ces.tech

Recommendation 3: Task the OSM and Regional Translation Hubs to promote systems thinking and Smart Machine component re-use across Government procurements and industrial sectors. In particular investigate enabling technology opportunities in the government's five Missions and the eight Growth-Driving Sectors identified within the Industrial Strategy Green Paper[2]. Also explore supply chain capacity and potential for onshoring alongside the other scoping and connection activities above.

3.2 Market Requirements and the Role of Regulation

A key part of the Growth Flywheel journey for customers and suppliers is to define the requirements (ring 2) for a Smart Machine product or service, usually ordered according to the most pressing that are feasible to meet. In general, to be successful as a supplier these should be requirements for a market or segment, not just a single customer. If initiatives such as the above are bringing customers and suppliers together then this is the moment that both regulation and assurance matter. Assured safe and acceptable operation is a requirement.

3.2.1 Co-ordinated Regulations

Smart Machine regulation and assurance across sectors is currently at an early stage of specification. There is an important opportunity for the UK to be at the forefront in sectors where we are internationally competitive and lead in trialling Smart Machine technologies. We must lead early work to identify potential risks, and to develop shared taxonomies, languages, and principles to guide their future development. Eventually new standards, kite marks, benchmarking, assurance frameworks and incident investigation protocols will shape technological development as use cases become more evident, helping to set requirements for interoperability and to measure performance within key sectors. We also have a key role to play in leading the international ethical and regulatory debate to ensure that regulation supports prosperity, security, ethical use and the UK's wider interests. This could involve bodies and branches of Government who work with bodies such as the WTO, WEF, G7, G20, OECD, NATO, Council of Europe, Commonwealth, and the UN.

2 https://www.gov.uk/government/consultations/invest-2035-the-uks-modern-industrial-strategy/invest-2035-the-uks-modern-industrial-strategy

Whilst regulations within sectors necessarily differ, it's important to seek commonality and to share lessons learnt. As the regulation landscape evolves, coordination amongst Regulators will be key to learning lessons, sharing best practice and closing loopholes.

3.2.2 Societal Attitudes and Trust

Smart Machines must be co-created with Society if people are to trust them so they can be deployed usefully. Alongside familiarity and demonstrably predictable and acceptable behaviour this requires a sufficient regulatory framework to assure the design and manufacture of the machine including its failure modes. Trust also requires an understanding that Smart Machines do not just take jobs, they create them. They make people more productive by extending their capabilities, and offer relief from tedium and danger. They free up people for more interesting and safe tasks and to concentrate on things they are good at - in particular creativity and interaction with other people following culturally varied and hard to define social norms. Trust therefore requires societal attitudes to move beyond narratives of unemployment and Terminator threats, to conversations about training, upskilling and the evolving world of employment, leisure, national resilience and sustainability. Outreach with societal testing and familiarisation in Living Labs are key to building this trust and fostering adoption. Living Labs are also key sources of data harvesting and learning for regulators and policy makers.

3.2.3 AI Regulation

Smart Machines use AI and data. The evolving international regulatory work on AI Safety and data security/ integrity has to be extended or adapted to the challenges of the real-time physical world. As with AI, in the UK development on a per sector basis is the most practical given different regulatory regimes and needs. A central Government function can work across regulators, institutes and research hubs for cross fertilisation, consistency and to reduce duplication.

3.2.4 Friction and Ethics

Over regulation can inhibit innovation and can be used by incumbents to protect their market dominance. Use cases for products and services with Smart Machines are evolving and will disrupt value chains. New regulations in sectors should be as low-friction as possible to support this disruption whilst maintaining safety and trust. They must also support ethical functioning and use of the Smart Machine, its access to and use of proprietary or personal data, and the transparency of its design and assurance framework. This requires agreement on the levels of risk that can be tolerated in different sectors for safe operation, including inserting autonomous systems into existing infrastructures.

3.2.5 Technical Standards, Modularity and Interoperability

The move to a Smart Machine mindset and reconfigurable modularity to stimulate supply side (Goal 1) requires technical standards on interfaces and functionality to be established and agreed, applicable to both physical and digital components. Rather top down, this is best done through evolution and popular use as exemplified by the software open source community. Once there is a critical mass of adoption around a sector or an application, these standards can be agreed by consensus within a community before further evolution. Regulations that are agile enough to track these evolutions are desirable. ARIA commenced this journey in November 2024 with its Call for an expert committee TA3 Facilitating modularity, interoperability, and common standards within robotics reporting by May 2025.

3.2.6 Legislative Frameworks

Regulations must work within legislative frameworks to be both legal and non-contradictory. In the UK this requires compliance with, for example, the National Security and Investment Act (NSIA), Export Controls, the Competition and Markets Authority, the Academic Technology Approval Scheme (ATAS), the Office for Product Safety and Standards, the Health and Safety at Work Act, the Consumer Rights Act and related sector based regulation for example the CAA for aviation. This produces an inevitable tension between prosperity, safety and security objectives. Further regulations should take into account any legal frameworks for assigning accountability and liability in cases of harm caused by Smart Machines. The responsibility of manufacturers, operators, programmers, and users to ensure adequate protection and recourse must be considered.

3.2.7 Human Oversight and Control

At first glance, the idea of having humans in the loop when it comes to the oversight of Smart Machines, or indeed AI, may appear like

Apian[1]

Apian is a healthcare logistics company that has developed a software platform connecting the NHS to a network of drones for delivering medical supplies. This innovation aims to address the challenges of traditional road transport, which accounts for a significant portion of the NHS carbon footprint.

Apian's platform streamlines the delivery of critical and patient-specific medical supplies, such as chemotherapy drugs, pathology samples, and medicines.

In October 2024, in partnership with Google Wing[2], Apian launched a delivery service between Guy's and St Thomas' hospitals. Soaring above existing delivery vehicles on congested roads, electric drones are 10x faster, half the cost and zero emissions. By speeding up testing times, this service is delivering efficiency, productivity and sustainability benefits for NHS staff and patients.

This service is the first of its kind in the heavily contended and regulated airspace of a capital city such as London, and getting to this point has required close collaboration between Apian, NHS, Wing, CAA, NATs and other parties. It is anticipated that this six month pilot will lead to a much wider service across a network of London hospitals.

While Apian has made significant strides in demonstrating the viability of drone delivery in healthcare, challenges remain regarding aviation regulation and public acceptance. The company is actively engaged with regulatory bodies to ensure the safe integration of drones into UK airspace. Apian's next steps involve expanding the NHS drone delivery network through further trials and increasing the number of participating Trusts across the UK. The company envisions a future where drone delivery becomes a standard practice in healthcare, benefiting patients, staff, and the environment.

1 https://www.apian.aero/
2 https://wing.com/

an attractive and viable proposition. However as Smart Machines (and AIs) become more ubiquitous, they will inevitably be performing roles in areas such as defence, emergency services, healthcare, transportation and critical national infrastructure. Such application areas will necessitate connected federated real-time decision making (swarm intelligence) and any humans in the loop simply won't be able to react fast enough. We have observed this with autonomous vehicles whereby it is impractical to put a human back in control fast enough to avoid an accident.

The capabilities required to enable Smart Machines to be trustworthy, understand their limitations and provide transparency about their decision making, will need to be baked in. This includes the hard stuff such as governance, safety, regulation, security, privacy, trust and ethics, which will need to be performed in near real time at the edge. This in turn means these activities will need to be automated and that in turn means using AI, with the inevitable circularities that leads to. Digital twins have an important role to play in this area, including exploring exceptions, facilitating post mortems, preventative maintenance, generating synthetic data and so on. Humans can of course provide high level oversight but sufficiently abstracted from the coal face that they do not "get in the way".

Oxa[1]

Autonomous vehicles are rarely out of the news. They offer a new way to think about and execute the movement of people and goods. This promise comes from Machine Learning and vitally the sharing of that learning. ML is what allows these self-driving machines to be trained to elicit subtle behaviours. Simultaneously, the scaling force of allowing, in principle, every future self-driving machine to share the learnings of every other self-driving entity and mile driven is utterly compelling. It is the antithesis of how humans learn to drive one at a time.

The dual of learning is teaching. At Oxa, we have a profound focus on hyper efficient teaching, and beyond that, the teaching of teachers. We think in terms of syllabus generation that is customised not only for the student (the various AIs in vehicles) but also for the specific location where a particular vehicle will operate. Our software will learn to drive everywhere by quickly moving through lots of "somewheres" (unique locations where AVs are deployed). In these locations, Oxa Driver is quickly configured via intense training to become a local expert (like a cab driver before Uber). Automatic syllabus generation (to train the AVs) and exam generation (to test the AVs) allows us to generate an assurance case at speed for each deployment. Gen AI is used to describe, synthesise, and adversarially manipulate training and test data which covers the expected dynamics in appearance of scenes and their dynamics - so "what it looks like" and "what's going on".

Therefore, we are not only deploying AIs on the vehicles but also using them as the teachers and the teaching of teachers. This last point is fascinating: who trains the teachers to ensure that their syllabi are the most compact, allows for the greatest ease of learning, and yields students with the largest capacity to generalise, while also providing the required assurance that the students behave as expected in the places they will work. That is where the music is.

1 https://oxa.tech/

Recommendation 4: Continue to support the work of the National UK RAS Regulations, Standards and Ethics Committee[1] which has already assembled key industrial and Government entities. Working with the OSM, connect Regulators around a sensible-risk, pro-innovation approach, and co-ordinate with the new UK Government Regulatory Innovation Office[2], AI Safety Institute[3], the UKRI TAS Hub[4] and its progeny UKRI Responsible AI UK[5] to help cut back red tape. Seek to establish trusted kite marks to indicate adherence to regulations covering design, operation and assurance of Smart Machines, building from practical experience and public engagement in Translation Hubs Living Labs. Consider the constraints and implications in the body of UK law that governs all.

Recommendation 5: Task the OSM to encourage and build from the work of the ARIA Expert Committee on modularity, interoperability and common standards in robotics through the various public and private bodies in the Smart Machine ecosystem. Work also through relevant IEEE and ISO bodies on standards for international alignment.

1 https://www.linkedin.com/groups/13025439/
2 https://www.gov.uk/government/news/game-changing-tech-to-reach-the-public-faster-as-dedicated-new-unit-launched-to-curb-red-tape
3 https://www.aisi.gov.uk
4 https://tas.ac.uk
5 https://rai.ac.uk

4. Goal 2: Supply - Developing the Ecosystem of Innovation and Business

Make the UK a creator of thriving new Smart Machine businesses and solutions across regions and sectors and a preferred location for investors and global talent. Ensure the UK is home to world leading science and engineering in Smart Machines growing UK knowledge and skills to underpin employment and the economy.

Powering up the supply side of the Growth Flywheel requires a thriving, scalable and sustainable ecosystem of growing companies, universities, researchers, engineers and investors. For example, fueling the alchemical cauldron of creativity, discovery and innovation; helping to drive the transfer of advances within applied research into transformative impacts within society and the economy; fostering engineered serendipity and intersectional collaboration; reducing sources of friction in order to accelerate investment and adoption; growing, attracting and retaining the talent essential for keeping the UK a world leader in the field of Smart Machines.

Like any ecosystem, this is a living and evolving environment with complex non-linear interactions, behaviours and dependencies. For it to be scalable and sustainable requires a long-term vision for its future investment, governance and evolution.

Achieving Goal 2 requires attention in two areas. First, addressing points of friction in rings 3, 4 and 5 of the Growth Flywheel and acting to give them some initial propulsion to spin. Second, ensuring the underpinning support of research and innovation generates ground-breaking developments that lead to market disruption in the UK's favour, alongside the essential people and skills development that fuel everything.

4.1 Building the UK Supply Base

4.1.1 Open Innovation Assets and a Systems Approach

Modular, networked, open source Smart Machine components

An important stimulant to demand is try-before-you-buy (section 3.1.2). This is difficult to achieve on the supply side with the current monolithic generations of Smart Machines, whose builders typically start from scratch, realising systems that lack extensibility, adaptability and multi-purpose capabilities. By contrast, modularisation and standardisation of components and services, particularly on the back of Open Source[1] and Cloud Computing, have transformed the software industry.

A similar "Smart Machines Lego™" would pave the way for a new generation of Smart Machines that are much more extensible, adaptable, maintainable, and interoperable. By providing researchers, innovators and companies with access to shared open-source pre-competitive foundational building blocks, tools, frameworks, platforms and infrastructure, new products and services could be created by UK businesses in less time and at lower cost. Such a common approach also speeds up talent flow because skills become cross sector transferable and shared spares reduces maintenance costs.

Furthermore Smart Machines become more powerful when they can communicate with one another and coordinate their actions, in order to collaborate on performing complex tasks. Integrating them into a wider Cyber-Physical Infrastructure would further amplify their powers. For example in hospitals of the future, Smart Machines working alongside medical professionals assisting with the cleaning, security, porterage, logistics and even treatment, communicating and collaborating as trusted members of the team. A suitable communication fabric of protocols and standards should be available to British businesses. The UK is compact and diverse enough to champion this approach, incorporating technology at the application level and with a global rather than UK centric approach. For example building on the new 6G specifications[2] which deliberately target Smart Machine communications.

The open tools in ring 3 of the Growth Flywheel are key to this and more. By iteratively developing the architecture of modular connected hardware and software components that can be federated into complete Smart Machine systems the basis of a try-before-you-buy approach can be

1 https://en.wikipedia.org/wiki/Open_source
2 https://eu-robotics.net/wp-content/uploads/one6G_WhitePaper-Robotics_Jun24_v1.2-1.pdf

realised. This goes beyond currently available open simulation tools from the Open Source Robotics Foundation (ROS, Gazebo, Open-RMF) and NVIDIA (ISAAC) as both the digital and the physical worlds are involved. At the heart of this is using modularity and federation to maintain a strict 1:1 relationship between these two worlds, in order to unleash the power of the digital-physical twin amalgam.

The Wider Vision - Cyber Physical Infrastructure
Smart Machines are a key ingredient within the Cyber-Physical Infrastructure (CPI) vision. Expanded investment in the development of this CPI vision would magnify and accelerate the impact of the component technologies. The symbiotic relationship between AI and Smart Machines is fueled by real world data from the Internet of Things, the in-silico rapid prototyping and optimisation offered by Synthetic Environments, and the secure maturation environment provided by Living Labs. The CPI paradigm would transform the end-to-end innovation and invention pipeline for all manner of products and services, including public services and national infrastructure, taking out time, cost, wastage and risk, whilst at the same time increasing reuse, interoperability, resilience and competitive advantage.

Connectivity and Signposting
A thriving Smart Machines ecosystem should power the end-to-end Smart Machines innovation lifecycle, connecting and coordinating a diverse spectrum of actors including researchers, entrepreneurs, investors, accelerators, regulators, vendors, policy makers and students. Poor knowledge flows alongside fragmentation slows development, reduces uptake, undermines the exploitation of intersectional opportunities, and retards benefits to the economy. Creating strong connectivity between the different parts of the ecosystem is a priority and wards against fragmentation, including crowdsourcing the landscape of Smart Machine resources, facilities, exemplars, use cases, events and other assets.

Government also has a role to play in this signposting, by convening and establishing awareness across its own Smart Machine activities, and linking these to private initiatives and the actions of UKRI to invest more cohesively and with focus.

A Smart Machine Centre of Excellence
To develop, curate and sustain the CPI based modular open tool development in ring 3 as the main Growth Flywheel spins requires a dedicated Centre of Excellence (CoE). This would also have the convening role to promote connectivity and signposting across the ecosystem. Various operating models are possible, but It should be transformational, operating by working back from the imagined future, not by incrementing forward from the present.

The invention institute at the XEROX Palo Alto Research Centre (PARC)[1,2] is exemplary and was foundational in its impact on computing, the internet, programming and operating systems. In the 1970s it carried out foundational development that moved the monolithic computing world of the 1960s to the distributed, interoperable, mobile world we know today. It laid the foundations that others (e.g. Apple, Microsoft) used to create a multi-trillion dollar industry therefore. At inception team members were mainly top post doctoral researchers previously funded on related nascent ARPA efforts. Although an adjunct to the Xerox Corporation they had great autonomy.

An equivalent Smart Machine CoE could be set up in the UK as a not-for-profit Community Interest Company[3] funded by Government, Industry or both. Keeping it outside the purview of the University and Catapult ecosystems would maintain its autonomy and neutrality. As well as technical development and prototyping, its key role would be to kick start community involvement and development to arrive at shared components and tools available to all. These would be a mixture of open source for community development and maintained closed source for reliable community use in practice, including within applications such as defence and critical national infrastructure (c.f. the exemplar of Linux and Red Hat operating systems). This in turn involves the cold start of nurturing a producer/ consumer ecosystem where users “come for the tools and stay for the network”[4].

1 https://youtu.be/id1WShzzMCQ?feature=shared
2 https://en.wikipedia.org/wiki/PARC_(company)/
3 en.wikipedia.org/wiki/Community_interest_company
4 https://www.amazon.co.uk/COLD-START-PROBLEM-Network-Effects/dp/0062969749

Ocado Technology[1]

The penetration rate of people shopping for groceries online in the UK has almost doubled since 2016[2]. To offer a viable online grocery service, retailers must be able to fulfil large basket orders from a wide range of products with different temperature regimes and short shelf lives, whilst achieving cost-efficient productivity.

To enable this service, Ocado Technology has developed highly-scalable automated fulfilment technology. In automated facilities, fleets of mobile retrieval robots operate on giant storagegrids, fetching containers that hold the grocery items that shoppers have ordered.

The retrieval robots follow instructions from a central AI control system. The system instructs the robots to deliver containers to robotic arms that pick and pack items into customer bags. Traditionally people pack the items at a pick station. Developing robotic arms to pack customer bags without human touch offered significant productivity improvements.

Automating the picking and packing of groceries into bags was a complex technological problem to solve. Human grasping is an innate skill, but replicating this in robots is difficult as machines lack the sensory capabilities and cognition that humans use to learn and adapt to new situations. The robotic arms need to handle tens of thousands of different items, without prior knowledge, ranging from fragile eggs to uniquely-shaped fruit and vegetables. To achieve this, the system uses machine learning and computer vision. It takes inputs from the cameras and sensors on the robot and outputs the motor-control instructions to move the robotic arm and the end effector.

The system was originally trained using a technique called behaviour cloning where a person guides the robot through a number of picking and packing examples. It learned, adapted and generalised so it would be capable of handling more items over time. If the robots currently working in production encounter unfamiliar products or scenarios, teleoperation crews can assist them in the completion of their task. With each teleoperation intervention, the data gathered further improves the ML model.

1 https://www.ocadogroup.com/
2 https://www.statista.com/statistics/1319926/online-grocery-market-penetration-rate-uk

The CoE could provide a range of facilities such as co-working spaces for both permanent and temporary residents, Living Labs for showcasing demonstrations, conference spaces, research labs and so on. The CoE would be architected from the outset to facilitate digital remote access, including the use of immersive media, in order to provide levelled-up access from anywhere. As well as being the natural home for the delivery vehicle that would develop the shared “Smart Machine Lego” outlined above, it would open its doors to the general public to engage them in the innovation lifecycle and foster adoption and trust.

Recommendation 6: Government should put in place a Smart Machine Centre of Excellence (CoE) to bootstrap and curate community development of the open tools that realise the modular simulation and physical building blocks in Growth Flywheel ring 3. Elements of this are also described in more detail in the RGP’s Cyber Physical Infrastructure vision paper. The CoE is the natural place to take up and focus outputs from the work of the ARIA Expert Committee on modularity, interoperability and common standards in robotics (section 3.2.5, recommendation 13).

Tharsus[1]

At the heart of the UK's Smart Machine revolution stands Tharsus, a leader in product design and manufacturing. As a key integrator in the Smart Machine ecosystem, Tharsus is reshaping the landscape of innovation across multiple sectors and manufacturing these machines at scale.

In response to the housing crisis and demands for sustainable construction, Facit Homes partnered with Tharsus to revolutionise home-building. Their collaboration brought advanced manufacturing techniques directly to construction sites.

The construction industry faces a severe housing shortage, a skills gap, and pressure for sustainable practices. Facit Homes recognised the need to rethink the entire home-building process, moving towards a more efficient, technology-driven approach.

At the core of Facit's innovation is the Smart Machine that is the Mobile MicroFactory (MMF), an on-site manufacturing system. Tharsus optimised this system, introducing greater automation, thermal printing technologies, and integrated waste management. Scaling manufacturing capabilities while maintaining on-site production flexibility was a primary challenge. Tharsus' multi-disciplinary approach and customised technology roadmap were crucial in addressing this issue, mitigating risks and accelerating market entry.

The Facit-Tharsus collaboration focused on delivering tangible commercial value at every milestone, to facilitate faster market adoption and attracting aligned developers. The lower capital expenditure for each Mobile MicroFactory offered a more agile solution with on-demand fabrication capabilities. The optimised MicroFactory has the capacity to deliver 80-100, individually bespoke, low-carbon homes per year per machine. This innovative approach has positioned Facit with a competitive advantage.

As an integrator in the Smart Machine ecosystem, Tharsus continues to drive innovation across various sectors. By leveraging its expertise in robotics, automation, and strategic machine development, Tharsus is shaping the future of the UK Smart Machine ecosystem. Through partnerships like the one with Facit Homes, Tharsus demonstrates its commitment to solving real-world challenges and cementing its position at the centre of the UK's Smart Machine revolution.

1 https://tharsus.com/

4.1.2 Place Based Innovation, Adoption and Scalable Maturation

Regional Smart Machine Translation Hubs
Section 3.1.2 highlighted the need for regional Translation Hubs to help local demand side market stimulation and to implement the try-before-you-buy approach enabled by the modular open simulation tools of Growth Flywheel ring 3. These Translation Hubs also have an important role to play stimulating the supply side in Growth Flywheel ring 4.

After modelling within synthetic environments, eventually Smart Machines have to be tested within the real world within proving grounds, testbeds and Living Labs. As with AI, maximising their potential benefits whilst minimising the dangers and unintended consequences, requires scalable processes and infrastructure to support their maturation lifecycle, with a strong focus on the safety, security, ethics and trust of section 3.2.

Given the physical nature of Smart Machines, providing accessible access to relevant advice, demonstrators and Living Labs, means these resources need to be regionally distributed. Thus a network of regional Smart Machine Translation Hubs can also provide spaces where both new and established businesses can come to develop prototype solutions to pressing problems, to foster this place-based innovation and adoption. They can also be the place where XPrize[1] style competitions can nucleate to bring forward technical advances and motivate the public around worthwhile societal goals.

Co-locating new and established businesses supplying and using Smart Machine systems helps to create the regional network effect that drives the ecosystem of demand and supply in the Growth Flywheel. It also provides a regional focal point where potential investors interested in deal flow for their funds can gather. These centres therefore also feature a strong business development and engineering function that nurtures demand and supply side businesses and engages with the public.

Of necessity these facilities should also be colocated with strong centres of relevant scientific excellence. They therefore build on research ideas coming to fruition, have an influencing effect on the direction of both use-inspired and basic research. They also provide pathways for skilled staff to transition from the world of science to the world of business and value generation, helping to retain skills in the UK through access to opportunity often currently sought overseas.

Experiences at the Bristol Robotics Lab Technology Solutions and the Edinburgh National Robotarium have demonstrated that these facilities can be self-funding once constructed making the regional Growth Flywheel start to spin. If created outside rather than inside the University management structure they can have greater agility and independence to grow. The Government's role is therefore convening power to set them up and resources to establish their initial infrastructure. Some infrastructure already exists attached to scientific excellence for example in Manchester, Leeds, Sheffield, Edinburgh, Bristol, Birmingham, York and London providing foundations from which to build.

With the CoE focusing on the earlier-stage disruptive opportunities (ring 3) and a network of regional Smart Machine Centres focused on the translation and adoption of solutions (ring 4), these two initiatives would complement one another.

Onshoring and Serviced Manufacturing Facilities

Being able to physically build Smart Machine production units to satisfy demand is the key action of Growth Flywheel ring 5. In the early stages of sales when volumes are low this can be realised largely as an assembly operation in relatively small spaces within typical industrial units. However, with successful product-market fit comes the challenge of production at greater scale. As Smart Machines become more commoditised and prices fall, so the efficiency of their manufacture has to increase to maintain the unit economics and the commercial viability of the business.

Outsourcing manufacturing overseas, typically the far east, has been a traditional route to achieve this. However with distance come issues of quality assurance, cost of transport and sustainable business practice as well as strategic dependence in a climate of geopolitical fracturing. For growing businesses who are starting to outgrow their early industrial premises there are no ready made serviced facilities available they can move into and start implementing efficient manufacturing straightaway. This in turn means there is cost and delay converting larger premises into a suitable facility.

Consultation in the community suggests such serviced manufacturing facilities could be a viable business proposition for a third party supplier, in much the same way office provision is commercially outsourced; indeed some Smart Machine integrators already provide such manufacturing services. Businesses could rent premises appropriate to the size and need of their manufacturing operation, moving up and perhaps down as market demand changes. Addressing this regionally is something the Translation Hubs should consider as nascent businesses grow from initial incubation. Using their convening power and connections into local Government, they can advocate for incentives for private capital to invest and support onshoring of the assembly part of manufacture to the UK.

1 https://www.xprize.org

Recommendation 7: Building on the demand side Smart Machine Translation Hubs of Recommendation 2, these regional facilities should also provide spaces for incubation of new businesses and accelerator style business training alongside the Living Lab and test/certification facilities. They should be connected and preferably colocated with regional scientific centres of excellence such as Universities, but operated independently from them as agile SMEs or not-for-profit CICs. Use the Hubs to consider regional opportunities for serviced manufacturing provision. By working together a business case nationally should be made.

4.1.3 Investment

There needs to be a better understanding of the Smart Machine lifecycle and how this differs from those for other technologies, such as AI.

Private investors, initially investing under the SEIS and EIS schemes, are currently investing tens of millions of Pounds each year to support innovative Smart Machine startups. Alongside this funding, similar levels of grants are received by companies from Innovate UK and other public-sector grant-funders. Within this climate, up to fifty British startups have now graduated to a stage where they are generating annual gross profits in excess of £2 million.

Despite the phenomenal productivity impact that a Smart Machine startup can unleash, this category of investments is generally perceived to be less attractive to larger venture capital investors because the lifecycle-to-exit tends to be longer than, for example, consumer software businesses, with lower levels of capital efficiency. For this reason, some Government-backed investment vehicles such as the British Business Bank working through traditional venture partners have also not participated significantly in this sector yet.

As Herman Hauser recently put this more eloquently: "*We don't have a startup problem - we have a scale up problem*"[1].

This scarcity of institutional capital at the scale-up phase remains a significant headwind for Smart Machine innovators and is preventing the UK from creating world-leading companies, in contrast with other Northern European countries like Denmark and of course the US.

The recommendations of the October 2024 Tony Blair Institute Report[2] highlighting Robotics as a national opportunity for UK leadership includes creation of a £100m Robotics Investment Programme through British Patient Capital, to provide follow-on funding to support early-stage and growth-stage robotics startups. This could be an excellent support to crowdsource other private sources of venture capital, provided it is deployed appropriately.

Currently the British Business Bank (BBB) deploys investment capital into the UK startup ecosystem through private venture capital partners. Recent trends in UK and EU venture capital at Series A have been to behave more like formulaic private equity using traction and turnover to determine valuation and quanta of funding to invest. This is problematic for UK businesses in Smart Machines who largely have to export to gain traction using the modest seed funds available at the outset. Consequently deep tech hardware businesses often fail at Series A through lack of customer traction. The BBB model investing alongside UK VCs re-enforces this behaviour, as funds are used to mitigate the VC investor risk. Conversely in Scotland, the Scottish National Investment Bank (SNIB) invests in its own right and crowds in other investment support. In some cases it leads on investments, which can be key. This model of deployment favours deep tech businesses and enhances the level of venture behaviour over private equity. The downside has been the levels of due diligence and lengthy timescales to close investments in order to evidence best use of public funds and reduce risk, creating friction in the company growth journey.

Recommendation 8: The UK Government should create the £100m Smart Machines venture investment fund recommended by the Tony Blair Institute but should consider alternative ways of deployment more aligned with the SNIB model. The aims are to increase overall round sizes into £eight figures at Series A, be prepared to take the lead and crowdsource in other private venture investment. Also increase the venture in UK venture investing and consider ways to reduce time and friction in the diligence process without increasing the deployment risk of public funds.

1 https://www.forbes.com/sites/johncumbers/2021/03/31/using-technology-sovereignty-to-create-local-unicorns/

2 https://institute.global/insights/tech-and-digitalisation/a-new-national-purpose-the-uks-opportunity-to-lead-in-next-wave-robotics

4.2: Talent - Growing our World Leading Research and Skills

Research and skills are the foundations from which the future ecosystems of UK innovation and businesses will be built. We must therefore create ambitious programmes of scientific endeavour with appropriate skills development as the rocket fuel for success. We here consider specific aspects of these underpinnings that are needed to support the continued acceleration of the Growth Flywheel.

4.2.1 Science and Innovation Research

Underpinning Science and Innovation Supporting the Growth Flywheel
From discussion following the inter Government Forum at ICRA2023[1] and consultations in the community, some of the priority science and innovation areas the UK should pursue to support spinning up of the Growth Flywheel include:

- **Embodied AI:** Recent developments in Large Language Models (LLMs) such as GPT4 (OpenAI 2023), LaMDA (Google 2021), Llama (Meta 2023), Orca (Microsoft 2023), PaLM 2 (Google 2023), StableLM (Stability AI 2023) and others have demonstrated impressive emergent properties in pure-data activities such as query, language translation, automated coding, text and video generation. More recently (May 2024) ChatGPT-4o can reason across text, images and sounds together in dialogue with a user. This is a fast moving field and there is an urgent need to understand how these models and their future descendents will perform attached to physical systems operating effectively with varying levels of autonomy. This must include developing small LLMs that can work 'on the edge' (i.e. in local embedded processors) on specific use cases with low power silicon. Software engineering approaches including widely available open source and development tools are also needed for ease of integration onto physical machines and for transparency in their operation. Access to the UK's new high performance computing capabilities will be an important contributor.
- **Advancing Physical Capabilities:** Advanced, embodied Smart Machines will only be realised with advances across their physical capabilities including energy storage, actuation, new materials (including bio-inspired fabrication and soft-robots), resistance to extreme environments, sensing and imaging technologies, wireless power technologies, communications, new approaches to manipulating objects, and to locomotion on land, sea, and air. This also includes new tools for computational design and emergent embodiments realised through natural selection. The ARIA opportunity space on smart bodies is making a start in this area, focusing on manipulation, but there is more to do.
- **Modularity and Reconfigurability:** Individual Smart Machines are starting to move from 'one machine for one purpose' towards modular component-based systems, which can be used in different combinations across applications and can be reconfigured quickly (and eventually autonomously) to tackle emerging challenges and reduce time to market. This requires research into modularity and scalability of physical components and their digital twins supporting developments in Cyber-Physical Infrastructure for development, test and operation.
- **Orchestration and Adaptability:** At the multiple machine level, federated groups can perform much more complex tasks than a single machine, giving robustness, flexibility and reconfigurability. This requires services for discovery and negotiation between Smart Machines that don't "know" each other. For example a smart autonomous ship negotiating with a smart autonomous port or a patient care robot negotiating with an autonomous ambulance or drone to deliver the patient into a hospital or home. At a larger scale, swarm robotics is a nature-inspired emerging technology exploring how robots can naturally interact with each other, their environment and people to robustly solve problems at scale. These will require advances in their dependability, communication, autonomy and self-regulation for adoption.

1 https://www.icra2023.org/forums/government-forum

- **Human-Machine Interaction and Collaboration:** Key for adoption is ease of use and mutual understanding for humans working alongside Smart Machines. This requires advances in interaction mechanisms including dialogue, emotional engagement, co-operative planning and replanning, intention prediction, failure detection and recovery and maintaining a shared world view. Also managing human oversight with networked and geographically distributed systems interfacing on human rather than machine timescales (Section 3.2.7). It could also include the use of implants for more direct communication for example with prosthetics.
- **Effective Assurance of Smart Machines:** Higher levels of autonomy and adaptability require advances in assurance capabilities to ensure Smart Machines reliably operate as we expect. This includes security, verification, testing, validation, safety, ethical operation and responsibility. It also includes trustworthiness (section 3.2) particularly where LLM architectures operate with safety critical systems to detect and remove hallucinations and mistakes. Where appropriate, this will benefit from being a cross sector effort to avoid duplication, with well defined assurance processes and standards that are recognised globally.

These are multidisciplinary challenges requiring contributions from engineering, computer science, biology, materials science and psychology.

Smart Machine Research and Innovation Programme

A national 10 year Smart Machine Research and Innovation programme in multiple phases would pool all the strengths of the UK's companies, researchers, innovators and public agencies. It could contain a variety of programmes in foundational research, mission-driven discovery research and user-led or capability-challenge innovation bid for through peer-reviewed responsive-mode and managed programmes in UKRI, the Office for Smart Machines, DSIT, MoD or other Government departments.

Of particular note the ARIA Programme Thesis on Robot Dexterity[1] and associated projects have made a welcome and focused patient R&D intervention on a topic of importance. Its Programme Director led approach that moves beyond pure peer review enables a complementary portfolio of activities to be constructed with a high degree of dialogue at the outset. It also opens opportunities to organisations and individuals outside HEIs and companies. As well as supporting follow through from this programme the Smart Machine Research and Innovation programme should support further such interventions on the ARIA model by whatever funding agency.

Together these would raise the Technology Readiness Level[2] (TRL) sufficiently for higher TRL public or privately funded innovation efforts to engage. It will transform these technologies from simple machines used in limited environments to more sophisticated and connected prototype machines working in complex environments and situations. It will help to both create and meet new market demands. Involving Government departments with procurement interests in the gap analysis of missing capabilities would help focus.

Oiling the Wheels Between Research and Commerce

To better realise the potential wealth created by University research there should be greater porosity between Universities and external companies involving both people and IP.

Whilst various forms of fellowships are available to enable staff secondments in both directions, they are an ad-hoc practice. However with the advent of the Translation Hubs there is a natural conduit for a greater volume of co-working on something practical and achievable. Similarly, to encourage starting-up, permanent University staff should have a pathway to spend time growing a new business through the early phases, with the safety net of a position to return to after a set period. Secondment arrangements should not be punitive on the startup requiring full University staff overheads to be paid for by the startup.

1 https://www.aria.org.uk/wp-content/uploads/2024/02/ARIA-Robotic-Dexterity-Programme-Thesis-v1.pdf
2 https://en.wikipedia.org/wiki/Technology_readiness_level

Similarly it is still the case that spinning out or licensing technology from a UK University is a long drawn out process where the University often over-values its IP. Venture investors are put off by this, also discouraging staff to consider this route. Too much IP therefore remains locked into Universities. The 2023 Independent Review of University Spin Outs[1] addresses these points well and should be supported using the REF[2] framework as leverage.

4.2.2 International Partnerships

Smart Machine science and technologies are a global effort. We want to work with allies and partners to achieve mutually beneficial outcomes, whilst ensuring that the UK plays a leading role and promotes its interests as soft power. The UK now has a strong profile internationally in its research activities with recognised companies trading internationally.

We already take an open and collaborative approach to our research through the UK RAS Network[3] and through international industrial involvement for example in the ISCF Robots for a Safer World Programme[4]. However the time is now right to expand this through direct Government to Government Ministerial contact involving also their respective agencies.
Our aims for international engagement are to:

- Collaborate and share expertise with international partners on the opportunities, challenges and key uses of Smart Machines, especially where technologies could help to achieve major societal goals.
- Drive progress in Smart Machine R&D by deepening collaboration with international partners, including those in Europe, and continuing to participate in leading multilateral research partnerships globally.
- Lead the global definition of the risks and opportunities of Smart Machines. Work with international partners to develop shared principles for the responsible, secure and trustworthy development and deployment of Smart Machines, building on our existing international leadership in Trustworthy Autonomous Systems[5].
- Work closely with industry, academia, civil society and with international partners to ensure UK interests are represented at key standards and wider international bodies. This includes the internationally organised Institute of Electrical and Electronics Engineers (IEEE) where conversations on technical standards are at an early stage.

We expect these relationships to also grow links between centres of excellence; running exchanges, workshops, and summer schools to support knowledge exchange; supporting intellectual property (IP) literacy; exploring missions or 'grand challenges' with leading countries around specific scientific breakthroughs or societal outcomes; and sharing access to key UK and international facilities. There will also be opportunity to work with a broad range of countries through multilateral fora, such as the OECD and the Global Technology Forum, the World Economic Forum, the G7, and NATO, and take advantage of broader collaborative R&D opportunities born out of defence pacts such as AUKUS.

Recommendation 9: Working from and through the Office for Smart Machines, the UK Government should scope and launch a patient 10 year Smart Machine Research and Innovation programme top down across all its funding agencies. Connecting a planned portfolio of initiatives from the top reduces fragmentation, disconnection and overlap compared to current bottom up programmes, improving the opportunity for impact. Nevertheless, curiosity driven basic research must still be supported bottom up in responsive mode, to maintain the flow of new and exciting ideas and technologies. The above topics and translation fellowships are relevant. International collaboration opportunities e.g. with Europe, US, Japan, S. Korea and others for cost sharing in research and development, exchanges and co-investment into the UK ecosystems should be considered.

4.2.3 Skills

Underpinning thriving UK Smart Machine ecosystems are vibrant skills development pathways including higher and further education, through life learning and schools. Working with UKRI and leadership groups such as the RGP and the Royal Academy of Engineering, the Office

1 https://www.gov.uk/government/publications/independent-review-of-university-spin-out-companies
2 www.ukri.org/who-we-are/research-england/research-excellence/research-excellence-framework
3 https://www.ukras.org.uk/
4 https://www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/robots-for-a-safer-world/
5 https://tas.ac.uk

for Smart Machines should lead creation of a national skills maintenance and development programme across the HE, FE and schools sector.

In Universities, Research Institutions and Translation Hubs this national programme should support:

Advanced Degrees and Scholarships:

- Create a greater diversity of specialised and cross-disciplinary (including humanities and social sciences) Centres for Doctoral training on key scientific and social underpinnings of Smart Machines, co-funded with industrial sponsorships and placement.
- Provide financial assistance for Masters and similar conversion programs specialising in Smart Machine technologies. Create demand to trigger supply from providers.
- Promote degree programmes containing Entrepreneurship.
- Continued support for Degree Apprenticeships in Smart Machines.

Leadership Development:

- Support a range of Fellowships to attract, grow and retain world research leaders in HEIs at junior, mid and senior career stages. Create international talent visas to match these fellowship appointments and promote diversity.

Continuous Learning and Professional Development:

- Convene continuous education programs and workshops with CPD accreditation leading to Chartered Smart Machine Engineer status to keep professionals updated with the latest advancements in Smart Machines.
- Offer online platforms and resources for professionals to upskill at their own pace. This could also include signposting to relevant free and paid courses from Udacity[1], Harvard EdX[2] and others.
- Support the Royal Academy of Engineering to convene the relevant Professional Institutions (IET, IMEchE, BCS et al) to work on qualification and certification frameworks.
- In Colleges, Vocational Institutions and Translation Centres (including the British Automation and Robotics Association BARA[3]) the national programme should support:

Training Programs:

* Create engineering apprenticeship programs focused on upskilling technicians in the installation, maintenance, and repair of Smart Machines and to support the Smart Machine research and innovation ecosystems.
* Grow initiatives (such as UKRAS STEPS[4]) to build a thriving UK Smart Machine Research Technical Professional (RTP) community to deliver real technical innovation.
* Find ways to resource technical institutes and online platforms to offer certified and recognised courses in robotics and AI technologies. This should include incentives for industry to further train their staff in house as part of their employment providing revenue models for colleges and vocational institutions.
* Incentivise creation of maker academies to encourage bespoke hardware prototyping and evaluation.

Certifications and Licensing:

* Offer incentives for technicians to obtain relevant certifications, encouraging continuous professional development.
* Establish a system of licensing and certification beyond HNC/ HND to ensure a standardised skill level among technicians.

1 https://www.udacity.com/catalog/all/any-price/autonomous%20systems/any-skill/any-difficulty/any-duration/any-type/most-popular/page-1
2 https://www.edx.org/search?q=robotics
3 https://www.automate-uk.com/our-associations/bara/
4 https://www.ukras-steps.org/

In schools also there is much that the Government should do. These include:

- Early years curriculum review to emphasize core skills relevant to engineering and Smart Machines with diversity at its heart.
- Through tax incentives, encourage industry and other sponsorship of schools facilities e.g. maker labs, support for competitions such as F1 in Schools[1] FIRST Robotics Challenge[2], and imaginative community relevant school initiatives such as Futures Institutes[3].
- Encourage online programmes for teacher upskilling from colleges and/or the Open University.
  - * Mandate schools outreach and engagement from Translation Hubs to capture the imagination of young minds early, present role models to support diversity, and organisation/ running of regional Smart Machine competitions. These can also support teacher retention in a time of scarcity by enhancing the learning experiences they can provide.
- Support Fellowships for undergraduate summer internships in hi tech startups as the Royal Academy of Engineering will start to do in 2025 for AI[4].

Recommendation 10: Working with UKRI and leadership groups such as the RGP and the Royal Academy of Engineering, the Office for Smart Machines should trigger creation of a national skills maintenance and development programme across the HE, FE and Schools sector involving also the Department of Education as above.

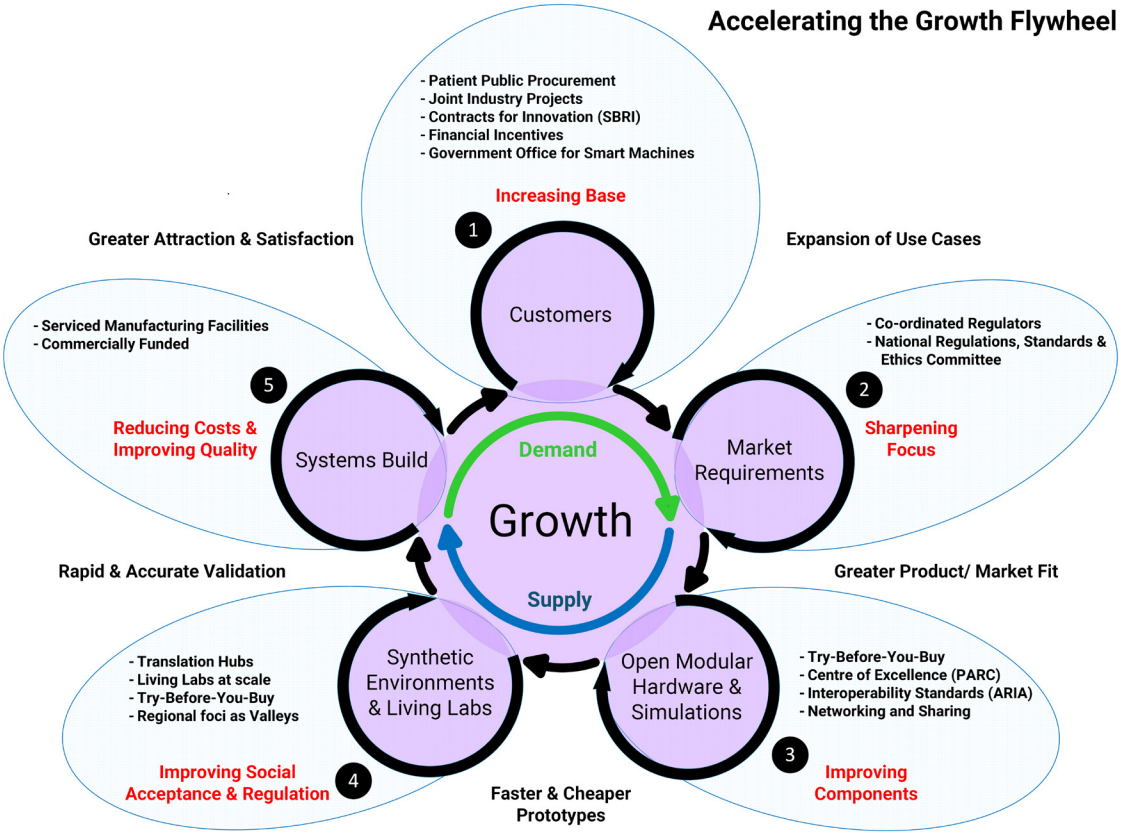


Figure 5.1: Summary of Actions to Accelerate the Growth Flywheel

1 https://www.f1inschools.co.uk/
2 https://www.firstinspires.org/robotics/frc
3 https://dollaracademy.org.uk/hub/
4 https://raeng.org.uk/google-deepmind-research-ready

5. Spinning Up The Growth Flywheel

We here consolidate the demand and supply side recommendations of sections 3 and 4 in one place for clarity, and then consider the ordering of actions to take the Growth Flywheel through its different phases of startup and acceleration to build momentum.

5.1 Summary of Recommendations

Figure 5.1 summarizes in high level terms where specific recommendations from this Strategy can operate to unstick and accelerate the Growth Flywheel. We also list the recommendations in one place for clarity.

5.1.1 Demand Side

Recommendation 1: Establish an Office for Smart Machines (OSM) inside Government loosely modelled on the cross department model of the Centre for Connected and Autonomous Vehicles (CCAV). Charge it to work across Government departments to seek out opportunities for smart, spiral procurement and help co-develop the appropriate public procurement approach. Choose early procurements with clear needs and available capabilities to maximise probability of early success. Work with Industry organisations and major companies across key Sectors to seek support for Joint Industry Projects (JIPs). Agree appropriate contractual frameworks for contract letting, IP and exploitation. Work with Ministers and Treasury to examine the role financial incentives could play promoting demand for Smart Machines.

Recommendation 2: Building on current Smart Machine translation facilities colocated or federated with research centres of excellence across the UK, establish a more extensive regional network of Translation Hubs where local conditions are suitable. Include Living Labs, test and certification facilities as well as office and conference spaces to support local companies prototyping ideas before committing to procurements and tendering (part of try-before-you-buy).

Recommendation 3: Task the OSM and Regional Translation Hubs to promote systems thinking and Smart Machine component re-use across Government procurements and industrial sectors. In particular investigate enabling technology opportunities in the government's Modern Industrial Strategy[1]. Also explore supply chain capacity and potential for onshoring alongside the other scoping and connecting activities in section 3.1.4

Recommendation 4: Continue to support the work of the National UK RAS Regulations[2], Standards and Ethics Committee which has already assembled key industrial and Government entities. Working with the OSM, connect Regulators around a sensible-risk, pro-innovation approach, and co-ordinate with UK Government AI Safety Institute[3], the UKRI TAS Hub[4] and its progeny UKRI Responsible AI UK[5]. Seek to establish trusted kite marks to indicate adherence to regulations covering design, operation and assurance of Smart Machines, building from practical experience and public engagement in Translation Hubs Living Labs. Consider the constraints and implications in the body of UK law that governs all.

Recommendation 5: Task the OSM to encourage and build from the work of the ARIA Expert Committee on modularity, interoperability and common standards in robotics through the various public and private bodies in the Smart Machine ecosystem. Work also through relevant IEEE and ISO bodies on standards for international alignment.

5.1.2 Supply Side

Recommendation 6: Government should put in place a Smart Machine Centre of Excellence (COE) as in section 4.1.1 to bootstrap and curate community development of the open tools that realise the modular simulation and physical building blocks in Growth Flywheel ring 3. Elements of this are also described in more detail in the RGP's Cyber Physical Infrastructure vision paper. The CoE is the natural place to take up and focus outputs from the work of the ARIA Expert Committee on modularity, interoperability and common standards in robotics (section 3.2.5, recommendation 5).

1 https://www.gov.uk/government/consultations/invest-2035-the-uks-modern-industrial-strategy/invest-2035-the-uks-modern-industrial-strategy
2 https://www.linkedin.com/groups/13025439/
3 https://www.aisi.gov.uk
4 https://tas.ac.uk
5 https://rai.ac.uk

Recommendation 7: Building on the demand side Smart Machine Translation Hubs of Recommendation 2, these regional facilities should also provide spaces for incubation of new businesses and accelerator style business training alongside the Living Lab and test/ certification facilities. They should be connected and preferably colocated with regional scientific centres of excellence such as Universities, but operated independently from them as agile SMEs or not-for-profit CICs. Use the Hubs to consider regional opportunities for serviced manufacturing provision. By working together a business case nationally should be made.

Recommendation 8: The UK Government should create the £100m Smart Machines venture investment fund recommended by the Tony Blair Institute but should consider alternative ways of deployment more aligned with the SNIB model. The aims are to increase overall round sizes into £eight figures at Series A, be prepared to take the lead and crowdsource in other private venture investment. Also increase the venture in UK venture investing and consider ways to reduce time and friction in the diligence process without increasing the deployment risk of public funds.

Recommendation 9: Working from and through the OSM, the UK Government should scope and launch a patient 10 year Smart Machine Research and Innovation programme top down across all its funding agencies. Connecting a planned portfolio of initiatives from the top reduces fragmentation, disconnection and overlap compared to current bottom up programmes, improving the opportunity for impact. Nevertheless, curiosity driven basic research must still be supported bottom up in responsive mode, to maintain the flow of new and exciting ideas and technologies. The above topics and translation fellowships are relevant. International collaboration opportunities e.g. with US, Japan, S. Korea and others for cost sharing in research and development, exchanges and co-investment into the UK ecosystems should be considered.

Recommendation 10: Working with UKRI and leadership groups such as the RGP and the Royal Academy of Engineering, the OSM should trigger creation of a national skills maintenance and development programme across the HE, FE and Schools sector involving also the Department of Education following section 4.2.3.

5.2 Timeline

Whilst this is a ten year strategy to 2035 to achieve change we cannot wait that long. We must act on shorter timescales in the first instance to demonstrate faster initial impact on growth. Flywheels take time to gather momentum. We therefore propose an indicative ordering of immediate, medium and longer term actions with suggested measurable outcomes to move through the cold start, tipping point, escape velocity and maturity/moat phases[1] that spin up this producer/consumer ecosystem. (Recommendations are referenced as R1, R2 etc)

5.2.1 Cold Start

Initially the flywheel is stalled. The cold-start focus is on laying the groundwork to start its movement by fostering early adoption and building momentum through collaboration and infrastructure development.

COLD START Stimulate Demand To Make The Flywheel Turn	
DEMAND SIDE ACTIONS	**OUTCOMES**
Establish an Office for Smart Machines	
● Create a centralized Government body to drive public procurement of Smart Machines in key IS sectors (e.g., healthcare, renewable energy) (R1) ● Identify and implement 5-10 key pilot public procurement and private joint industry projects (JIPs) with demonstrable societal and economic benefits. (R1)	● Office for Smart Machines launched within 12 months with a 3 year operational strategy ● At least 3 pilot projects completed within 2 years, showcasing Smart Machines' impact on productivity and quality of life. ● 50% Increase in Government use of Smart Machines in 3 yrs
Create Regional Translation Hubs	
● Develop translation hubs in regions with industrial and academic strengths, providing Living Labs and testbeds for experimentation and prototyping. (R2) ● Offer support to demand side SMEs exploring use of Smart Machines in their business	● Launch hubs in 5 regions within 18 months ● Support 100 SMEs in prototyping Smart Machine solutions within 2 years. ● 50% increase in SME adoption of Smart Machines within 3 years
Promote Systems Thinking Across Government and Industry	
● OSM convenes a cross-sector task force to identify shared needs and synergies for Smart Machine applications (e.g. Industrial Strategy sectors). (R3) ● Pilot integrated solutions demonstrating the benefits of interoperability across sectors	● Publication of 3 cross-sector roadmaps within 18 months. ● Two cross-sector Smart Machine systems deployed in public services within 3 years.
Develop and Align Regulatory Frameworks	
● Establish pro-innovation safety, ethical and assurance standards for Smart Machines, connecting Regulators and with the Regulatory Innovation Office (R4) ● Create a "kite mark" certification program for trustworthy and compliant Smart Machines. ● Partner with international organizations to ensure alignment with global standards.	● Certification standards implemented across 3 priority sectors within 3 years. ● Certification of 100 Smart Machine products within 5 years. ● 25% reduction in time-to-market for certified Smart Machines by year 4.

1 https://www.amazon.co.uk/COLD-START-PROBLEM-Network-Effects/dp/0062969749

5.2.2 Tipping Point

At this stage the flywheel is starting to spin but there is a need to make its operation self-sustaining. We do this by stimulating the supply side through the development of open shared tools to increase the ease with which Smart Machine solutions can be realised. Also by ensuring there is underpinning support from the flowthrough of relevant new technologies from research/innovation and a sustainable talent pipeline of all kinds to businesses.

TIPPING POINT Stimulate Supply to Make The Flywheel Self-Sustaining	
SUPPLY SIDE ACTIONS	**OUTCOMES**
Create a Centre of Excellence to Develop Open Tools	
● Curate community development of the open tools that realise the modular simulation and physical building blocks to help try-before-you-buy and commoditisation of Smart Machine building blocks (R5, R6) ● Support scale up transition of new supply side SMEs to address anticipated growth in Smart Machine demand (R7)	● Centre of Excellence created and launched within 12 months ● First release of open tools within a further 12 months ● Regional translation hubs each supporting 10 supply side SMEs within 2 years
Enhance Research and Innovation Funding in Key Areas	
● Invest in frontier research areas such as embodied AI, modular robotics, and Cyber-Physical Infrastructure (R9) ● Collaborate with international research institutions to maintain the UK's competitive edge.(R9)	● Smart Machine Research and Innovation Programme launched within 12 months ● Publication of 300+ peer-reviewed research papers annually within 3 years ● Secure £100m in private-sector co-investment for research within 3 years.
Support Development of a Sustainable Talent Pipeline	
● Launch Smart Machine-specific Masters courses and PhD programmes in partnership with regional universities and technical colleges. (R10) ● Collaborate with industry to create reskilling programs and apprenticeships for transitioning workers.(R10) ● Expand national STEM programs to emphasize robotics, AI, and advanced manufacturing.(R10)	● Train 1,000 postgraduates in robotics and AI within 4 years. ● Place 5,000 individuals in Smart Machine-related roles annually by year 5. ● Increase STEM enrollment by 25% within 3 years, with at least 30% participation from underrepresented groups.

5.2.3 Escape Velocity

At this stage the flywheel is self-sustaining and the goal is to gain acceleration through the mutual reinforcement of supply and demand. Making scale-up growth investment available, reducing the barriers to domestic manufacturing and curating accepted open standards from the crowdsourcing interoperability work in the Centre of Excellence are the key enablers on supply and demand sides.

ESCAPE VELOCITY **Integrate Supply and Demand Reinforcement to Accelerate Growth**		
DEMAND SIDE ACTIONS	**SUPPLY SIDE ACTIONS**	**OUTCOMES**
Launch a £100m Smart Machines Venture Fund		
	● Provide growth-stage funding for 50 companies to address scale-up challenges. (R8) ● De-risk early adoption projects in key sectors for the industrial strategy and missions ● Attract private venture co-investment to amplify the fund's impact using the Scottish National Investment Bank Model	● Fund 50 growth stage businesses within 3 years, with an average annual revenue growth of 20% ● Generate £2B in new economic activity by year 5. ● Achieve a 25% increase in Smart Machine exports within 5 years.
Establish Serviced Manufacturing Facilities to Support Smart Machine Scale-Up		
	● Identify 5-10 regions with strong innovation ecosystems and industrial bases to host serviced manufacturing facilities.(R7) ● Translation Hubs partner with private sector investors and local governments to fund and operate facilities. ● Co-locate facilities with Regional Translation Hubs to integrate prototyping, testing, and scaling capabilities	● Establish 5 regional serviced manufacturing facilities within 3 years, each capable of supporting at least 10 businesses annually. ● Enable 50 startups and SMEs to transition to mass production within 5 years ● Increase domestic production of Smart Machine components by 30% within 5 years. ● Reduce reliance on overseas manufacturing by 25% within 5 years.
Foster Modularity, Interoperability, and Standards		
● Through the Centre of Excellence, establish agreed open standards for Smart Machine components to ensure interoperability. (R5) ● Through Regional Translation Hubs Encourage modular system design to enable faster and cheaper integration. (R5) ● Support the creation of shared platforms for component reuse.		● Adoption of modular standards by 80% of manufacturers within 4 years. ● 30% reduction in the average cost of Smart Machine system integration by year 5.

5.2.4 Maturity and Moats

Once there is a critical mass of expanding Smart Machine ecosystem activity, the flywheel is into the Maturity and Moats phase. The goal here is to continue to reduce any frictions limiting growth and to maintain the UKs competitive edge internationally by focusing on barriers to entry (Moats) for international competitors. This is best considered through a refresh of this Smart Machine 2035 Strategy to review progress and consider any further ecosystem actions.

6. Conclusions

Smart Machines, in a multitude of different forms and with diverse capabilities, could play a critical role in delivering solutions to the growing list of exponential challenges faced by the UK, both at home and abroad.

With their embodied intelligence, Smart Machines will be the arms and legs of AI, enabling it to reach out into our physical world with scalability and resilience - on and under the ground, on and under the sea, in the air and even in space; matching the non-linearity of the challenges they will be addressing.

Despite their very different life cycles, a powerful symbiotic relationship binds these two transformative technologies. Their anticipated non-linear evolution necessitates investment in ecosystems, infrastructure and governance to enable them to mature into the responsible adults we need them to become.

Those challenges and opportunities we face demand a much greater sense of urgency and a joined-up systems-based mindset and approach. The UK Government has a catalytic role to play in stimulating the demand and supply side conditions for Smart Machines to get the Growth Flywheel spinning and accelerating.

This includes harnessing the power of public procurement, to generate shared components, tools, standards and solutions to re-engineer public services and national infrastructure with greater efficiency and interoperability, whilst nurturing their underlying innovation ecosystems for industry to build upon. Smart Machines can bolster our defensible competitive advantage, whilst delivering much needed agility and resilience in a world that is increasingly complex, fast moving and uncertain.

This all starts with a bold long-term vision for the role that transformative technologies, including Smart Machines and AI, can play in delivering sustainable growth, prosperity and wellbeing for citizens across our whole society.

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Appendix

A. The UK Science and Technology Framework

The UK Science and Technology Framework[1], published in March 2023, presents "10 big things", whose intersections with this strategy are outlined below:

- **Identifying Critical Technologies -** Smart Machines didn't make it into the list of Five Critical Technologies. However Smart Machines will have a critically important role to play in enabling, accelerating and scaling all five of these technologies, in areas such as research, manufacturing, testing, deployment and monitoring. Harnessing the power of Smart Machines will be critical to achieving our ambition to become a Science and Technology Superpower by 2030
- **Signalling UK Strengths and Ambitions -** An important outcome of this signalling would be to align investors, innovators, suppliers and other stakeholders behind these ambitions. "Clearly, credibly and consistently communicated the government's science and technology priorities and actions" will help foster new markets, and defragment existing markets, for shared solutions, including those based around Smart Machines, that can span multiple use cases, sectors and missions.
- **Investment in Research and Development -** Investment in Smart Machines research and development needs to be joined-up, including across the physical and digital worlds.
- **Talent and Skills -** The diversity talked about in the framework needs to include balancing the physical with the digital - head, hand and heart. There is also a need for new hybrid skills and qualifications that span the digital and physical worlds, including AI, cloud, IoT, sensing, mechatronics, robotics and modelling, which would be critically important in the development of the next generation of Smart Machines. The envisaged Institutes of Technology (IoTs) need to include skills related to Smart Machines.
- **Financing Innovative Science and Technology Companies -** Deep tech hardware startups typically have longer gestation cycles which need more patient funding models.
- **Procurement -** The National Science and Technology Council (NSTC) has a mission to create joined-up visions and strategies for science and technologies across government departments. This would pave the way for harnessing the power of public procurement to seed the development of the shared solutions mentioned above, across government departments, sectors, public services and national infrastructure. This would reduce time, cost, risk and wastage across the innovation lifecycle, whilst increasing reuse, resilience, interoperability, sustainability and competitive advantage. For this to be successful, there needs to be a new mindset and mandate for public procurement that embraces greater risk appetite and recognises the role and responsibility of public procurement in feeding the underlying innovation ecosystems. These initiatives would be particularly valuable for hardware based innovations such as Smart Machines, that are less attractive to venture based investment.
- **International Opportunities -** Smart Machines need to be able to cross borders both operationally and in terms of their export, which will require international collaboration and alignment on shared regulations and standards. Using the UK as a country scale Living Lab for Smart Machine solutions can foster solutions for the UK and act as a demonstrator to stimulate exports.
- **Access to Physical and Digital Infrastructure -** The testbeds, proving grounds and Living Labs discussed later in this strategy, are examples of shared infrastructure that are critically important components of the Smart Machine ecosystem. They are also an important source of the data required to generate trust and foster forward looking pro-innovation regulations and policies.

1 https://www.gov.uk/government/publications/uk-science-and-technology-framework/the-uk-science-and-technology-framework

- **Regulation and Standards -** The testing and deployment of new innovative technologies, especially for Smart Machines, often requires the licensing of exceptions to existing regulations. For this to not throttle the pace of innovation, regulators need to have sufficient bandwidth (and hence funding) to assess the safety cases associated with these exceptions. It also requires a top down approach for licensing exceptions at a national scale, rather than the current "pitched battle" across different regions and local authorities.
- **Innovative Public Sector -** We need to embed deeper knowledge and understanding of Smart Machines across politicians and civil servants in order to foster a Smart Machines centric mindset. It is encouraging that ARIA has one programme director focused on a Smart Machines related mission and great to have a new National Technology Advisor who comes from an organisation that understands potential power of Smart Machines.

B. Consultation Process

A summary draft version of this strategy was published on the RGP website on 24 June 2024 and circulated to key organisations and stakeholders; this document included a link to an online consultation form and a dedicated email address for any other feedback.

There were 47 responses via the online consultation form, the most common sector categories being: Academia/ Research (42.6%), Consultancy (14.9%), Government (10.6%) and Manufacturing (8.5%); there were an additional seven email responses.

Three consultation workshops have been held, two in-person and one online. The format for all of these was the same - brief scene setting presentations by DSIT and RGP, a Q&A session and then a series of breakout group sessions to explore the strategy and its goals. Attendees were split fairly evenly across academia, industry and government:

- In-person Workshop 1 - this was held on 24 September 2024 at the Bristol Robotics Laboratory[1] with 45 attendees
- In-person Workshop 2 - this was held on 3 October at the Manufacturing Technology Centre[2] in Coventry with 35 attendees
- Online Workshop - this was held on 14 October with 21 attendees

The feedback from all these sources was amalgamated and has helped shape this version of the strategy.

1 https://www.bristolroboticslab.com/
2 https://www.the-mtc.org/