

# The UK Landscape for Robotics and Autonomous Systems

## 2015



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# Overview

This landscape collates the output from a series of workshops designed to explore the impact on the UK of advances in Robotics and Autonomous Systems (RAS). In overviewing the resulting landscape it is clear that the RAS opportunity, as perceived by the UK community, is extensive and rich and that the UK has the potential to create a strong RAS market.

It is also clear that robotics and autonomous systems will impact on each UK market sector and that the total size of this impact will be significantly greater than the size of the RAS sector itself. Across these sectors strong cross cutting themes exist that can be used to drive synergies to build technical capability and market opportunity.

Within those sectors that will benefit the most from robotics and autonomous systems

technology the potential for disruptive innovation and the need to respond to change through the development of new business models is now obvious.

Robotics and autonomous systems do not work in isolation. They will require testing, regulation, standards, innovation, investment and skills together with technical progress and strong collaborative partnerships in order to fully realise the opportunity.

The resulting Landscape carries an essential message; that the UK has a unique opportunity to engage with robotics and autonomous systems, to exploit existing expertise within the UK and explore its potential, but that other nations are similarly engaged and the UK must now be bold and invest to win.

# Setting out the Landscape for Robotics and Autonomous Systems (RAS)

## Introduction

**Robotics and Autonomous Systems (RAS) are widely seen as having a deep and significant impact on nearly all market sectors within the next decade.**

This economic impact is not just related to an expansion in the market for robotics technology but to the significant impact robotics technology will have on competitiveness and service provision across all economic sectors from agriculture to healthcare.

The early signs of this impact are visible in manufacturing, agriculture, transport, logistics, energy supply and healthcare; where robotics and autonomous systems are already deployed in niche applications.

Wherever RAS impacts it will have a disruptive and innovative effect. Adapting to these changes will be critical to the translation of disruption into growth.

The purpose of the landscape is to identify the RAS

opportunity for the UK by giving it depth and structure and to highlight where the impact will be felt in order to focus the attention of policy makers.

The landscape draws on the best available expertise in the UK both in RAS and in the markets it will dominate.

**One clear direction that emerges from this landscape is that robots will no longer be confined to use within manufacturing.**

**Robotics will extend its impact into almost every human activity. Such disruptive technical advances do not occur in isolation, they impact on society and on our economy. Understanding the landscape will guide strategy, policy and its enactment.**

## A UK context for RAS

When seeking to understand the Robotics and Autonomous Systems opportunity it is important to identify a UK context.

The current deployment of RAS applications in the UK is no different from the other major developed economies engaging with RAS. However our commercial landscape is shaped by different policies and events from, for example the USA or Germany, and this creates uniqueness in our RAS landscape that must be carefully examined.

The disruptive nature of many RAS applications means that they will reshape the market and its business models. Forecasting this type of impact and the way markets will change is challenging, but by combining stakeholders, technical experts, market specialists and end users, it is possible to explore this transformation.

Developing the landscape plays an important role in identifying the broad base of opportunity and impact within the UK.

“ The value impact on sectors far outweighs the value of the RAS market itself ”



## Creating the Landscape

This landscape activity was carried out by the Robotics & Autonomous Systems Special Interest Group on behalf of Innovate UK (the Technology Strategy Board).

A series of workshops examined key sectors within the UK and engaged both RAS experts and key sector stakeholders in discussion about the impacts opportunities and barriers for RAS.

Four workshops took place during 2013.

- ♦ A RAS Landscape Workshop
- ♦ Deep Dive A: Transport and Monitoring
- ♦ Deep Dive B: Health and Domestic
- ♦ Deep Dive C: Manufacturing and Logistics

The content of this landscape is drawn from the output of these workshops.

## The RAS Opportunity

The future market for RAS is currently wide open; key markets are yet to be defined, standards set, value and supply chains created.

Embracing this opportunity will deliver various benefits:

- Increased manufacturing competitiveness and increased UK manufacturing.
- Improved service delivery in both public and private sectors from transport to healthcare.
- Improved safety and reduced risk in hazardous environments and on the roads.
- Reduced waste and improved utilisation of resources from mines to farm land.
- More efficient inspection and maintenance of key infrastructure.

Achieving these benefits will critically depend on:

- Opening the regulatory environment and establishing standards and certification processes.
- Investment in both technology and its delivery to market.
- Lowering the barriers to market entry for SMEs.
- Building a matching skills base that is focused on STEM and RAS.

Realising this will require public and private collaboration. By synchronising research, innovation and investment with market opportunity and need the UK has the potential to realise the RAS opportunity.

## Landscape Limits

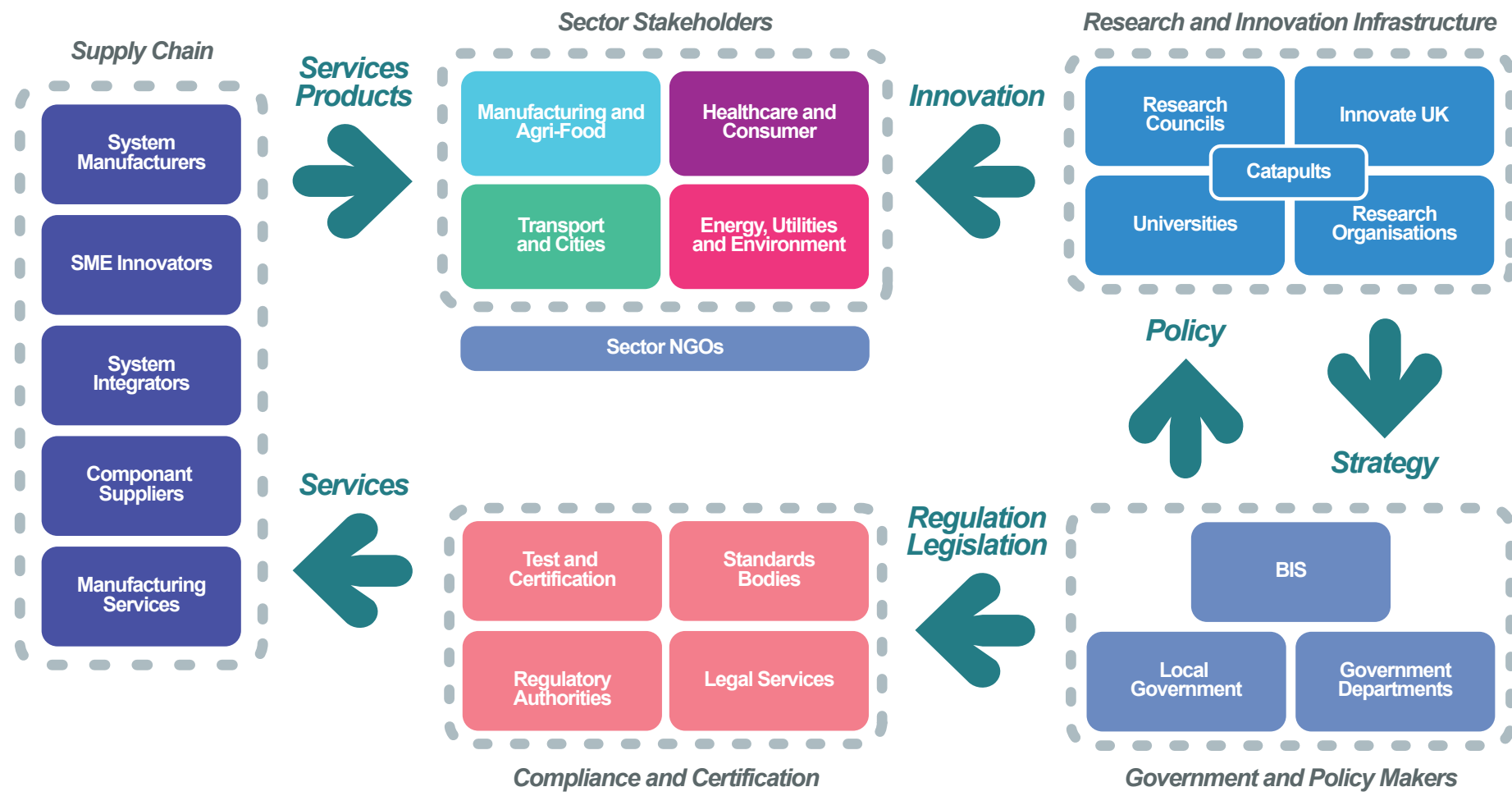
The workshops that provide the material for the landscape were necessarily limited in scope.

The forward looking approach taken during the workshops means the Landscape illustrations tie together market needs and high level technical capabilities with the objective of mapping out the application space for RAS. Inevitably deep technical detail is missing, as is any analysis of priority.

“The early stage nature of RAS presents both an opportunity and a challenge in assessing the potential”

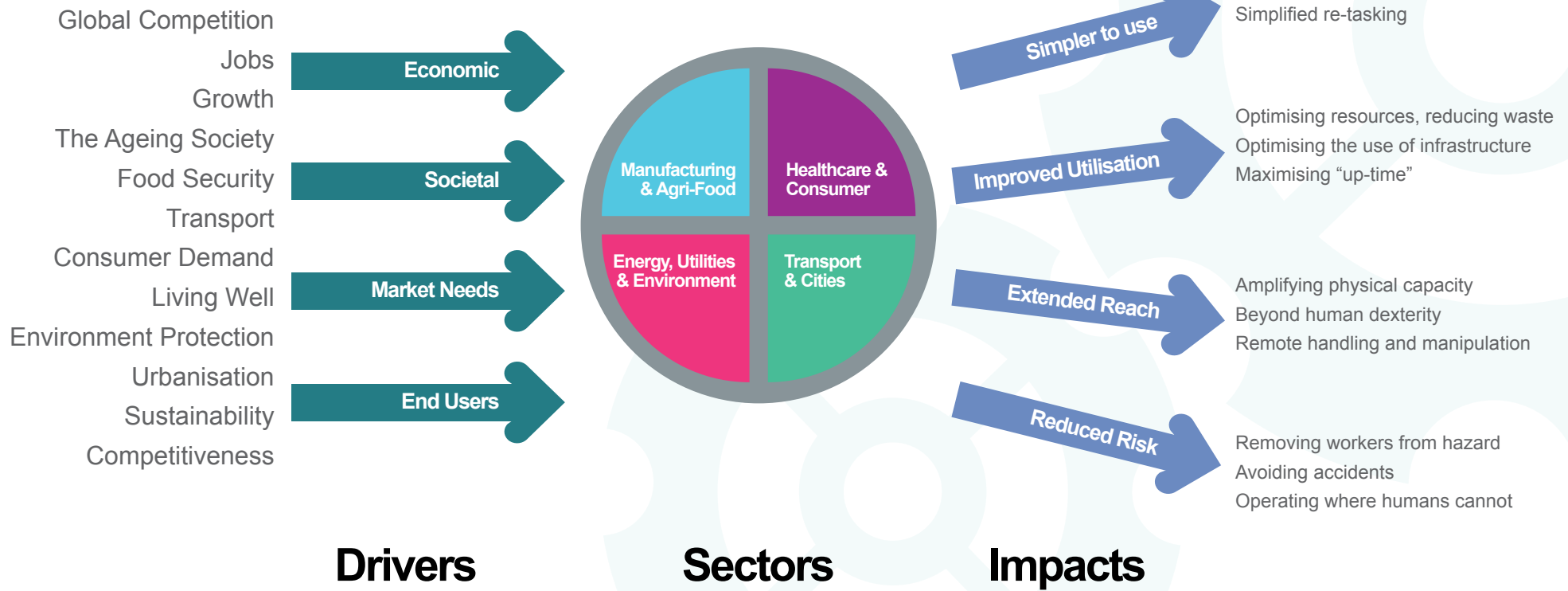
# The RAS Stakeholders

Implementing RAS cuts across disciplines and sectors it requires stakeholders to collaborate and create supply chains, validate applications and create standards and certification processes.

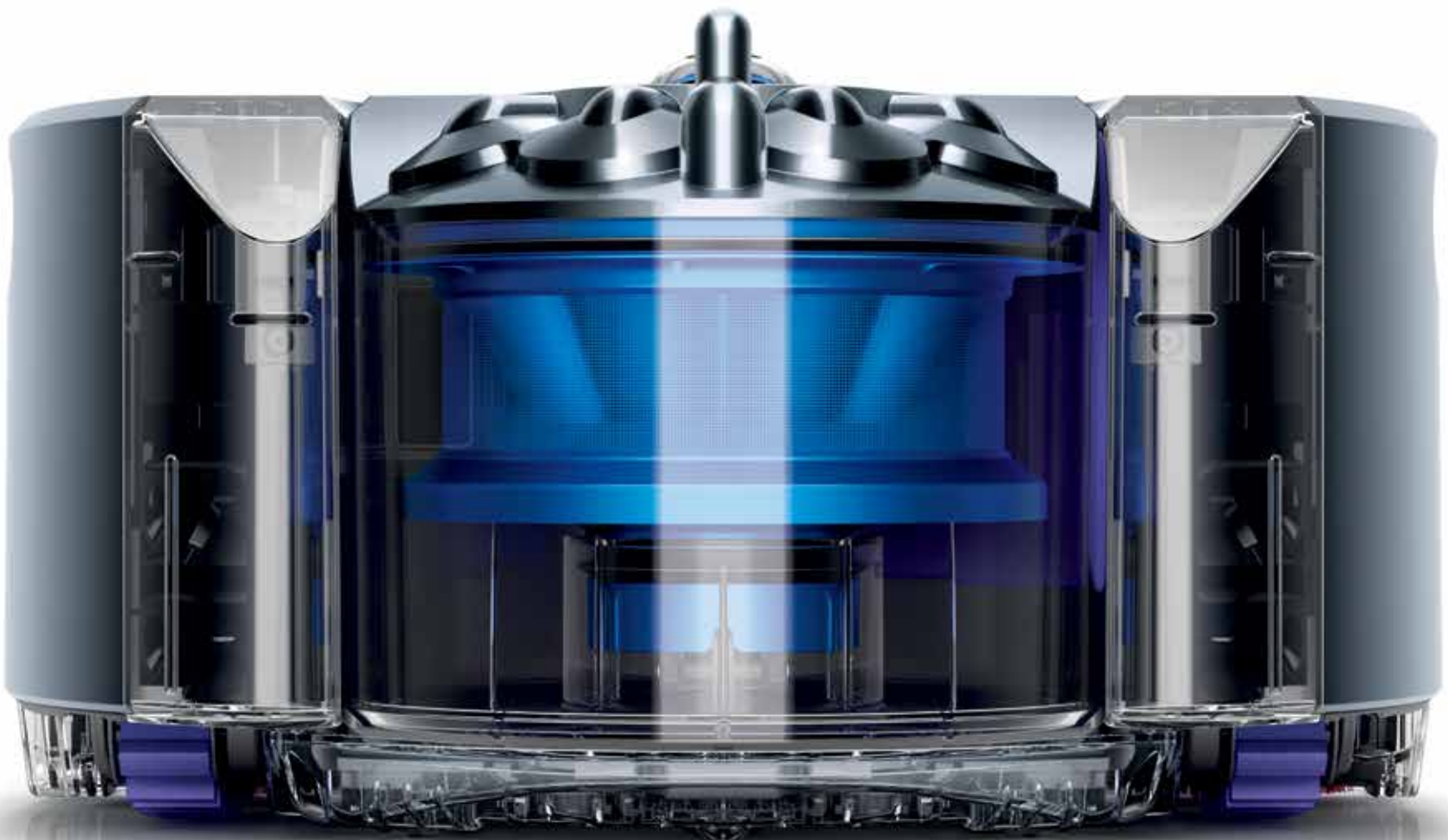


## RAS Drivers

There are a broad range of socio-economic drivers that push RAS development and a range of generic impacts that will result from its application to market sectors.







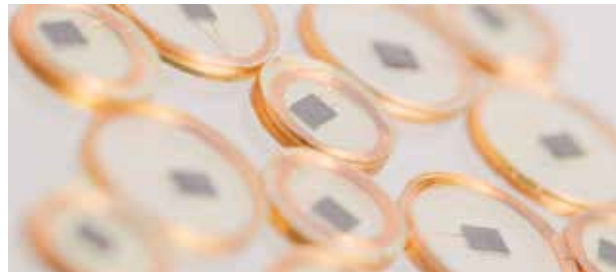


## What RAS Does

Robotics and autonomous systems are differentiated from other machines by their ability to perform physical tasks autonomously. They have the potential to enact a wide range of individual tasks. These consist of a combination of the four generic physical processes listed here.

In the following sections that detail the sector clusters each of these different types of process are illustrated with the coloured bands shown here to demonstrate the cross cutting nature of RAS along each set of application specific tasks.

Underlying these tasks is the capacity to interact with people, other robots, objects and data in the “cloud”.



### Manipulation and Processing

RAS interacts with objects and materials. It recognises, selects, grasps and manipulates raw materials, objects and parts. It can assemble or disassemble them, apply processing or interact with them even with flexible materials and soft objects; bending, shaping, fitting, cutting, polishing, grinding, drilling holes, cleaning, etc.

### Data Gathering Monitoring

RAS systems are used to observe and inspect a process, infrastructure or system, assess performance, identify failures or features, or simply provide status data. These monitoring operations can be carried out on people or farm animals, on bridges, roads and harbours, or on industrial plant and historic buildings.

### Sorting and Storage

RAS systems are used to sort, pack, unpack and store goods, raw materials and parts. The system is responsible for the correct identification of parts and of keeping track of where each item is in the system. The items being sorted and stored might be blood samples in a hospital, packages in a delivery chain, parts in a warehouse or fruit in boxes in the back of a van.

### Transportation

RAS systems are used to convey items over a distance, short distances inside a factory, or long distances on roads, under water or in autonomous aerial vehicles. The RAS system needs to know where it is, where it can go and where it needs to go. It may be transporting goods or people.



## RAS Value Chains

Robotics and autonomous systems do not just impact on one aspect of a value chain they impact at multiple points along whole chains. It is possible to identify three generic types of value chain where RAS is likely to impact. Greater detail is provided later in the Landscape for each sector cluster where the spread of tasks impacted by the different types of RAS process are illustrated.

### Producing goods

RAS has traditionally been deployed in the production of goods; food, cars, aeroplanes, etc. The new technologies will allow RAS to be widely deployed interacting with people in production and throughout the supply chain from producer to consumer. RAS will not only be engaged in manufacture but inspection, monitoring, logistics, transport and maintenance. RAS will enable flexible, agile, new ways of producing goods.



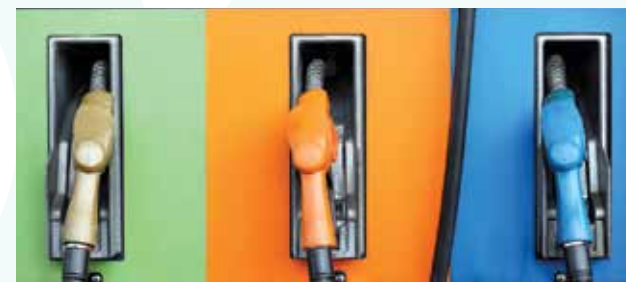
### Providing services

RAS can be used to provide or enhance the provision of services. Focusing on delivering services that are bespoke to the consumer. While RAS technology is already used in some service tasks, such as cleaning, in the future it will be deployed in human centric services and will provide the data used to shape service offerings.



### Delivering goods and resources

RAS systems are already deployed to a limited extent in materials processing, in logistics within warehouses and in the energy sector. Their use in raw materials exploration, extraction, and in the delivery of goods and materials is being explored. In the future RAS will be deployed in every stage of this process including the construction and maintenance of the associated delivery infrastructure.



“ Services will be delivered through increasing interaction between people and robots ”





Image courtesy of Viappy / Shutterstock.com

# Sector Clusters

The following sections illustrate how and where RAS will impact on the sector clusters. These sections add depth and structure to the landscape by detailing individual value creation opportunities and by presenting the key drivers, enablers and impacts in each sector cluster.

The diagrams in each section depict the typical chain of tasks in each sector that RAS will impact on and maps these to the generic RAS processes using coloured bars. These tasks therefore give a sense of the breadth of impact RAS will have in each value chain and show the cross cutting nature of the technology.



**MANUFACTURING AND AGRI-FOOD**

**HEALTHCARE AND CONSUMER**

**TRANSPORT AND CITIES**

**ENERGY SUPPLY, UTILITIES AND THE ENVIRONMENT**





## Manufacturing and Agri-Food

Robotics and Autonomous Systems will keep or bring back manufacturing into high value economies such as the UK. The deployment of RAS systems can now be extended to impact on every manufacturing sector from agri-food to aerospace. RAS provides a competitive edge that should be exploited to the full.

### Reshoring

Rebalancing the economy requires an increase in manufacturing output and competitiveness. In high value manufacturing, advanced systems will enable SMEs to bring manufacturing back to the UK and in turn create jobs and improve product choice.

### Key Drivers

- Raising UK competitiveness and rebalancing the economy
- Reducing waste and cost
- Speeding up time to market

### Key Enablers

- Cross industry collaboration and standards
- Easy installation and reconfiguration
- Design for automation tools

### Key Impacts

- Automation and up-skilling of complex assembly tasks
- Maximisation of capital investment through reconfiguration
- Amplification of physical capability
- Integrated safe co-operative human robot working



New RAS manufacturing technologies will raise competitiveness and enable reshoring. Standardisation and more intuitive programming interfaces, greater awareness of human factors and the use of high level system modules will enable flexible and agile manufacturing, decreasing implementation time and improving the response to changing customer demand.

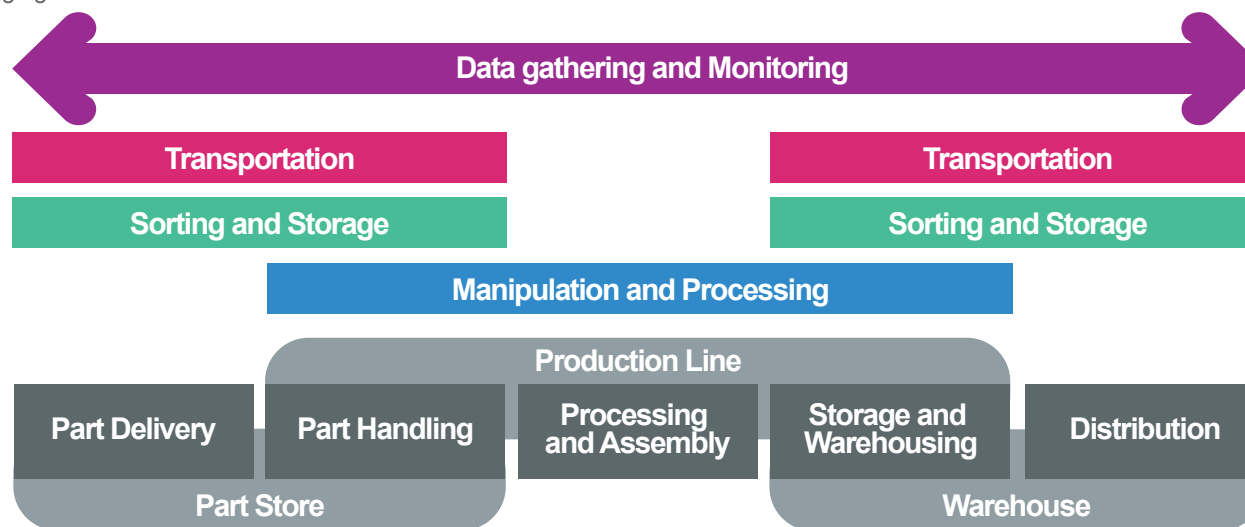
“ New technology will stimulate innovative business models leading to disruption ”

## Hybrid Factories

Mixing Human and robot co-workers in hybrid factories and utilising reconfigurable robot cells will optimise the manufacturing process and drive up competitiveness.

Hybrid factories will improve conditions for workers and will create jobs.

**Both SMEs and larger producers will benefit.**



## Smart Manipulators

Smart manipulators are needed to handle cloth and flexible objects, food etc. End effectors that can learn and tell other devices what they know via the “cloud”.

They can optimise material usage, allow for greater product customisation, and can be used across a wide range of sectors from Agri-Food to healthcare.

**Smart manipulators increase capability.**

## Standardised System Modules

System standardisation will create a market for modules and systems. Standards and modules will enable faster reconfiguration and widen the range of application across all types of manufacturing.

With standardisation, skills become transferable and system installation speeds up.

**Standardisation will increase the uptake of RAS in manufacturing.**

## RAS Logistics

Optimising the task distribution between RAS and human co-workers is a cornerstone of RAS application.

SME warehouse and distribution operations will benefit from the application of RAS and collaborative working.

**RAS in logistics will improve warehouse efficiency.**

## Disrupted Manufacturing

New technology has the potential to disrupt the manufacturing chain and allow RAS to be applied in all types of manufacturing.

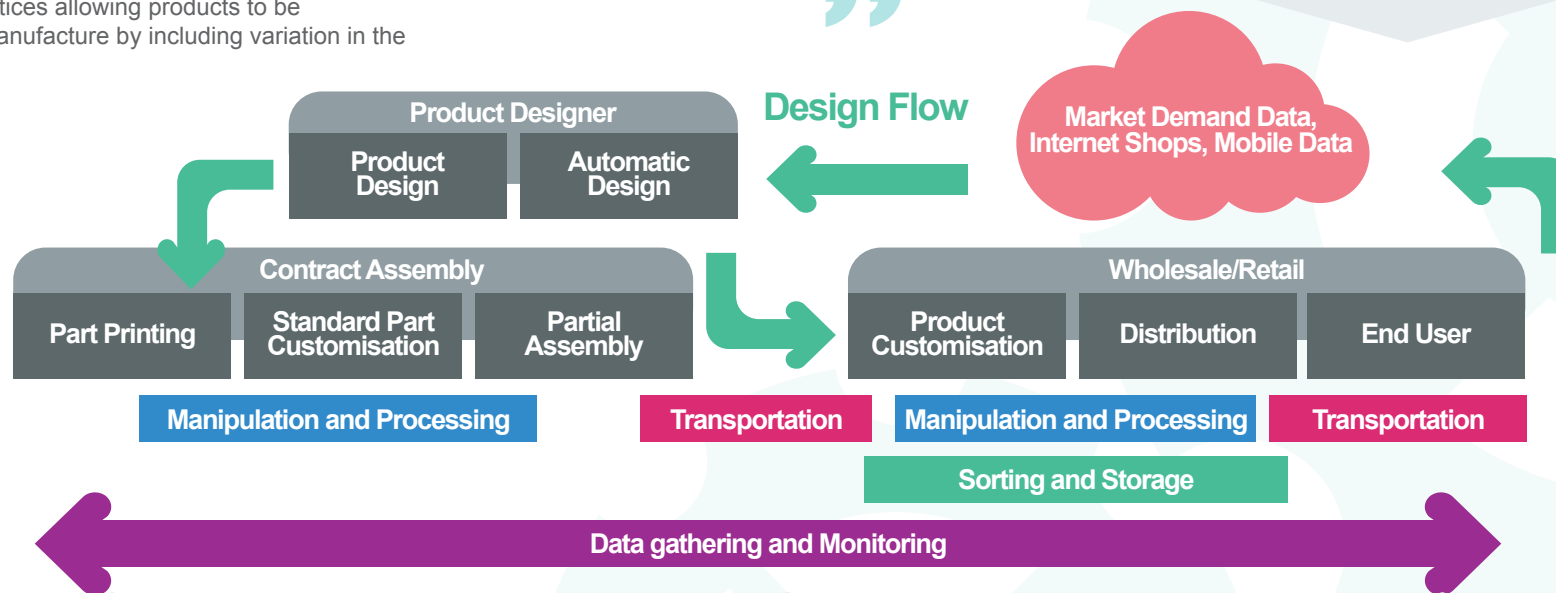
New business models and services will disrupt current manufacturing practices allowing products to be customised after manufacture by including variation in the design flow.

“ Making one off products as if they are mass produced and responding to customer trends ”

## Reconfigurable Systems

Reconfigurable systems reduce the skill needed to build a manufacturing process. They allow automation to be retrofitted within existing processes. They allow production line staff to re-programme tasks to suit current need without expert help.

**Reconfigurable systems will disrupt the status quo.**



## Bespoke Manufacture

Bespoke manufacturing will meet the increasing customer demand for unique items at a lower cost and the need to respond to fashion and trends in the market.

Advanced manufacture, rapid product innovation, and bespoke manufacturing will aid differentiation from the mass production of the BRICS economies.

**This will help bring manufacturing back to the UK.**

## Contract Assembly

SMEs can contract out automated product assembly. Reducing the capital cost of automation, reducing stock holding, lowering the cost of manufacture. Offers the opportunity of variable lot size, shorter time to market, improved product conformity, reduced lead-times and greater production flexibility.

**Concentrates manufacturing expertise, rapidly increases UK capability, optimises capital investment.**

## Integrated Design

Integrating assembly processes into the design path will reduce time to manufacture. Integrating safety into design will improve verifiability.

Allows product variability to be built into the design and manufacturing process and enables designs to be adapted to different end manufacturing methods more easily.

**Design tools are critical to competitiveness.**

## Agri-Food Production

RAS technology will impact along the whole Agri-Food chain. Data integration will enable data driven decision making with higher levels of traceability and reduce waste. The impact of RAS will be felt on farms where yields will increase through better control and better data.

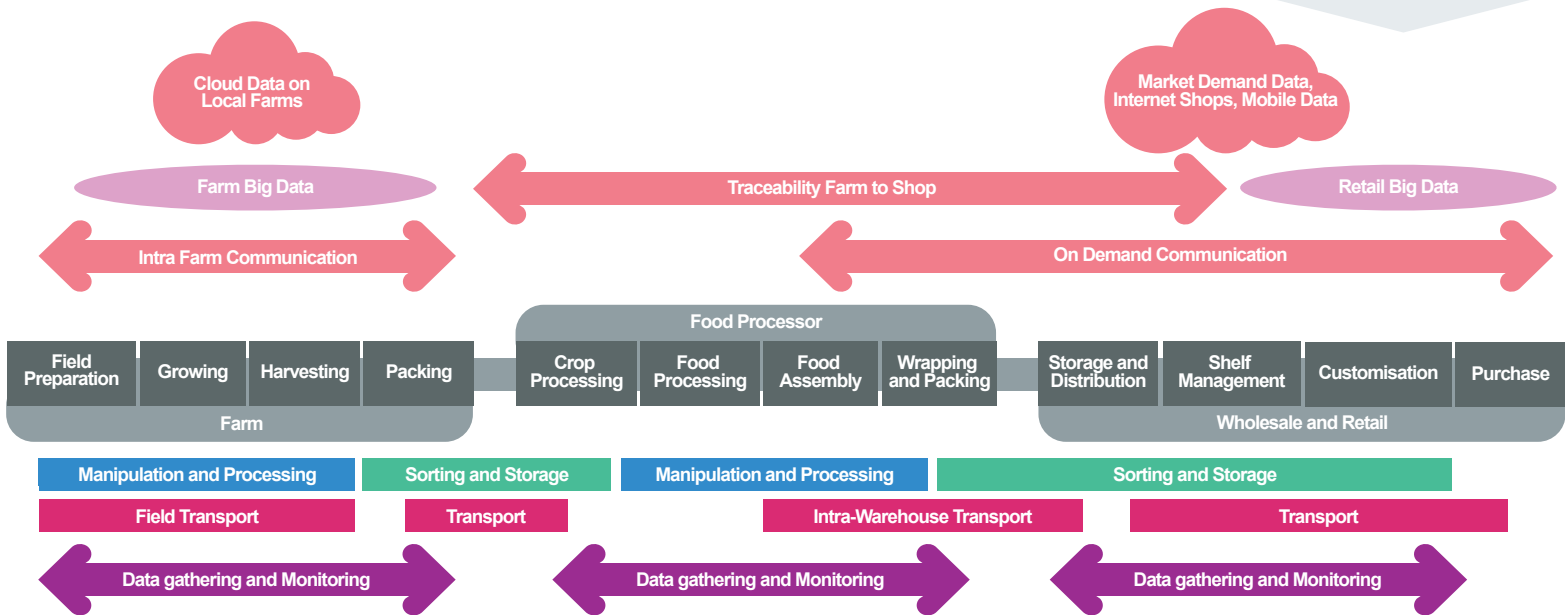
“Pests and disease don't keep to farm boundaries. Local knowledge spread in the Cloud helps everyone”

## Processing and Assembly

Process and assembly operations performed in inert atmospheres, or at cold room temperatures will increase hygiene and reduce waste while extending shelf life.

Allowing on demand production based on up to date market data and raw material supply.

**All these will reduce waste and increase consumer choice.**



## On the Farm

The advantages of RAS on the farm are considerable; reduced pesticide use, less ground compaction, selective fertiliser application, selective weeding, per plant processing, early pest detection, precise crop condition data, selective harvesting at optimal time.

**All these will increase yield and reduce environmental impact while at the same time reducing costs.**

## Disruptive Logistics

RAS based processing on the farm for delivery direct to the consumer. Daily on demand delivery of food means a reduced need for fridges and freezers. Pizza, salads and sandwiches customised at the retail outlet based on customer demand.

In store automated shelf restocking that dynamically responds to demand and the weather.

**RAS will disrupt the agri-food supply chain.**









## Healthcare and Consumer

RAS technology will find multiple applications in healthcare, in clinical and non-clinical services and in altering the method of delivery. Its role in capturing and utilising data will be pivotal to the improvement of services.

RAS is already deployed in a limited range of surgical applications and is being tested in hospital services and in rehabilitation.

Changing demographics will place an intense spotlight on the efficiency of healthcare. RAS when properly deployed can impact positively on efficiency.

### Disruptive Technology

RAS has the potential to up-skill routine procedures such as eye injections and endoscopy, and to simplify complex ones by improving dexterity beyond human capability. Operating on the sub-millimetre scale in neuro and vascular surgery has revolutionary potential.

### Key Drivers

- Ageing population and demographic change
- Skill shortages and budget controls
- Greater patient expectation of outcome

### Key Enablers

- Ethical and responsible design
- User and societal acceptance
- A legal framework for autonomy in medicine

### Key Impacts

- Cost effective service delivery
- Improved patient outcomes
- Enabling alternative means of care delivery

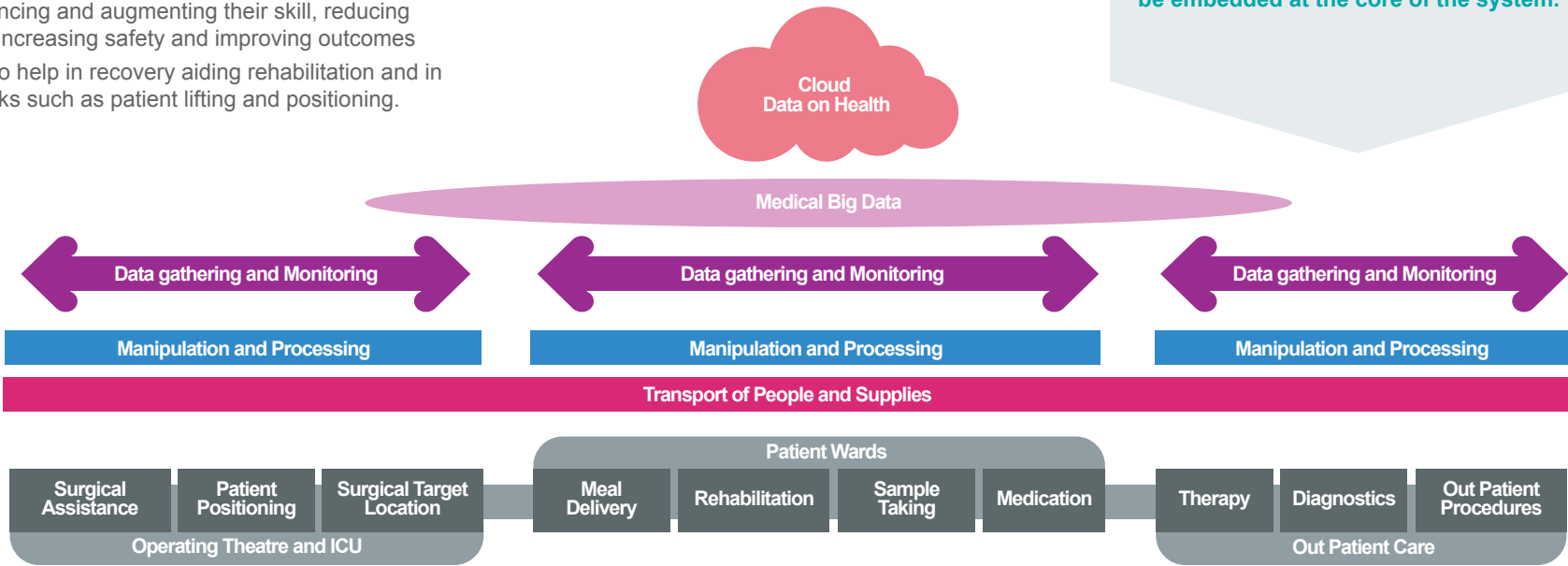
Health Data

The delivery of efficient and effective healthcare depends on accurate and timely data. RAS devices can collect and communicate that data augmenting it with an interpretation of context. They will be an invaluable source for Big Medical Data.

**Ethical data use and privacy will need to be embedded at the core of the system.**

In Hospital

RAS will impact on both surgical and non-surgical procedures. Not by replacing the surgeon or clinician but by enhancing and augmenting their skill, reducing complexity, increasing safety and improving outcomes. RAS will also help in recovery aiding rehabilitation and in auxiliary tasks such as patient lifting and positioning.



Surgical Tools

A new generation of surgical tools can ensure consistency in surgical procedures and integrate physical information during complex operations to guide the surgeon's hand.

Adaptive surgical tools, micro surgery, reduced trauma and realistic training systems will all improve accuracy and outcomes

**Robotics assisted tools are a paradigm shift for surgeons.**

Rehabilitation

Post stroke rehabilitation requires repetitive stimulation to be successful. Patient's expectations of recovery are growing. There is a need for home-based services where users have a large incentive to self-treat.

Better monitoring of progress, progressive exercise that combines physical and cognitive stimulation. Maximising outcomes for 100,000 new stroke cases per annum.

**RAS will have a significant impact on recovery.**

Routine Procedures

There are numerous minor procedures that are carried out every day, from taking blood samples to administering eye injections. Many of these repetitive procedures can be partly automated. For example through site identification, or by sensory extension such as the overlay of blood flow data, or faster more accurate actuation than is humanly possible.

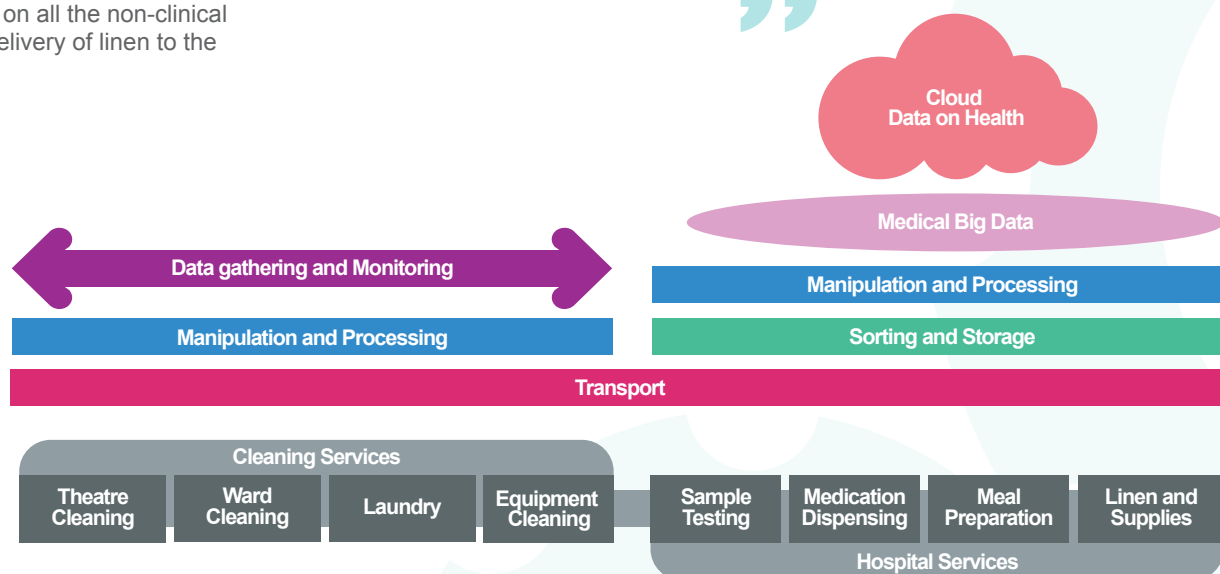
**RAS can provide clinical tools that incrementally improve outcomes.**



## Smart Hospitals

Hospitals are complex distributed organisations where critical decisions are made every day. Information accuracy and efficiency in service delivery underlie good decision making. RAS will impact on all the non-clinical functions in a hospital, from the delivery of linen to the testing and delivery of samples.

“ In time we will see robots in hospitals as the everyday sign of a good hospital ”



### Hospital Logistics

Efficient logistics for supply delivery is a key part of the smooth running of any large hospital. RAS can improve service delivery as well as hygiene with standard cleaning regimes, on demand supply and dispensing services to wards.

Clinical services including assisted patient lifting and positioning, sample taking and analysis and portering will all be impacted by RAS.

**RAS will impact on the efficiency of hospital services.**

### Cleaning Services

Infection rates within hospitals are a key performance indicator. Automated cleaning of both staff, patients and equipment has the potential to reduce cross infection. Combined with smart sensors and touch free systems able to sense and clean.

**RAS will impact on key performance indicators.**

### Sample Testing

Managing the flow of samples to a central testing laboratory and their sequencing within it is a complex logistics problem. Greater levels of automation in both delivery and testing will result in more efficient and timely services.

**RAS can improve the timely delivery of testing results.**

# Care at Home

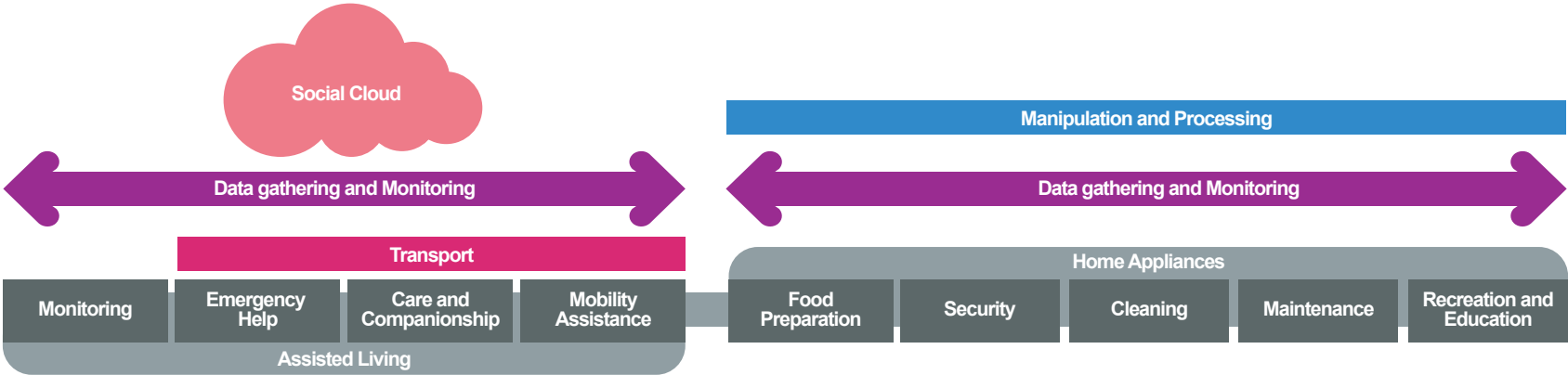
Everyone will benefit from the impact of RAS on everyday chores such as cleaning and laundry.

For the elderly and infirm these services will become a life-line to living longer at home and living well.

RAS will also enable greater levels of personal care, mobility assistance and improved social interaction and communication.

In time it will also deliver cognitive assistance.

“RAS will allow the elderly to do more”



## Extended Mobility

As the population ages, mobility and physical capability reduce. Injury becomes more common. Assistive mobility can help to reduce injury but also to amplify capability. Allowing an aging population to contribute to the economy for longer.

**For the elderly, RAS enhanced mobility will become the norm.**

## Personal Companions

The demand for care is increasing and will continue to increase. The supply of carers is reducing. There are severe economic constraints. RAS can assist people to live longer at home, increase their independence, enhance the role of carers, detect if a person is unwell and deliver improved social interaction and communication.

**This requires user centric design, engagement from the care professions and responsible ethical design and innovation processes.**

## Home Treatment

Hospital visits can be reduced by RAS technology applied to monitoring and home treatment. For rehabilitation and self-medication RAS can automate routine procedures that currently need an outpatient visit.

RAS can motivate self-recovery while monitoring progress and the effect of medication.

**At home delivery of treatment becomes possible with RAS technology.**







## Transport and Cities

Increasing urbanisation, the management of infrastructure, waste and traffic will benefit from RAS carrying out services in the city. Integrated transport and the maximisation of capacity are goals with clear benefits for people and the environment.

### From Data to Action

Autonomous systems will become significant data generators for Big Data and the agents of action in the Internet of Things.

It is important that communication protocols are developed that account for autonomy. Not only with respect to interconnection between RAS devices and "cloud" services but also to drive actions based on data from the "cloud".

Establishing integrated transport and delivery will critically depend on the bidirectional flow of information between vehicles and the systems of systems that manage traffic and road usage patterns.

### Key Drivers

- Need to deliver greater capacity
- Need to meet environmental and energy usage targets
- Need to reduce accidents

### Key Enablers

- Definition of cross industry regulations and safety validation
- User trust and acceptance
- Legal framework for autonomy and insurance

### Key Impacts

- Improved safety
- Improved infrastructure utilisation
- Reduced travel times

# Transport and Logistics

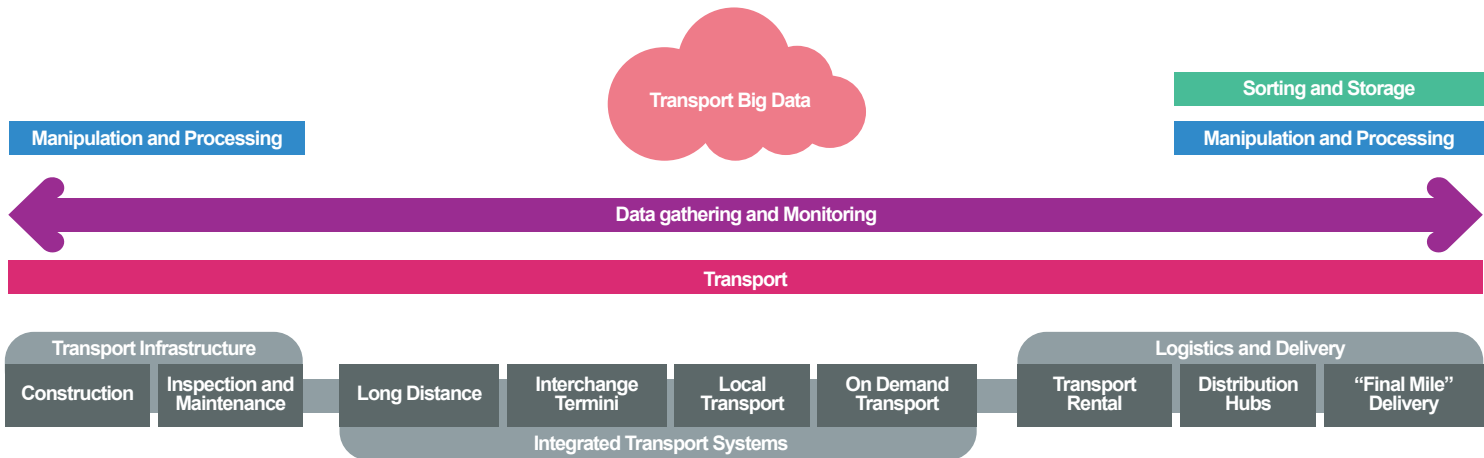
The rush to apply autonomy in transport is well under way, from autonomous driving to automatic parking and enhanced safety systems able to take over in an emergency.

The progression to full autonomy is likely to develop in increments from collision avoidance systems through

autonomous driving on motorways to vehicle convoys doubling flow rates with existing infrastructure.

**This is only the start of a transport revolution. new modes of delivery will enable new business opportunities.**

“RAS will maximise the capacity of existing infrastructure and increase safety”



## Ditching Ownership

Autonomous vehicles will cause new business and service delivery models. Progressive levels of autonomy will enable new transport delivery models where ownership is replaced by more cost effective on-demand services. Reducing the need for parking both in residential areas and in towns and cities.

Non-drivers such as the young and elderly can use individual road transport as needed without the need for qualification.

**With full autonomy comes the opportunity for disruptive business models that swap ownership for on demand services.**

## Safety and Autonomy

Road fatalities and serious injuries have a significant impact on the economy. The introduction of even low levels of autonomy should have a significant impact on accident rates.

Increased autonomy in infrastructure maintenance across both road and rail will directly reduce the risk levels for maintenance workers.

**Applying RAS will progressively lower accident rates.**

## Logistics and the City

On demand delivery over the final mile will alter the pattern of logistics delivery towards the evenings and weekends.

More frequent deliveries will mean perishables such as food can be ordered when needed rather than stored at home.

Mixed load delivery, food and parcels, local and long distance synchronised at the final mile can increase efficiency and reduce costs.

**Autonomous delivery systems will alter how we shop.**



## Smart City Integration

RAS coupled to big data will revolutionise the urban environment both physically and in terms of its utility. Cities are shaped around transport and the flow of people, RAS will change the dynamics.

The efficient use of infrastructure, improved maintenance, synchronised and integrated transport will all result in reduced energy usage, and a better urban environment.

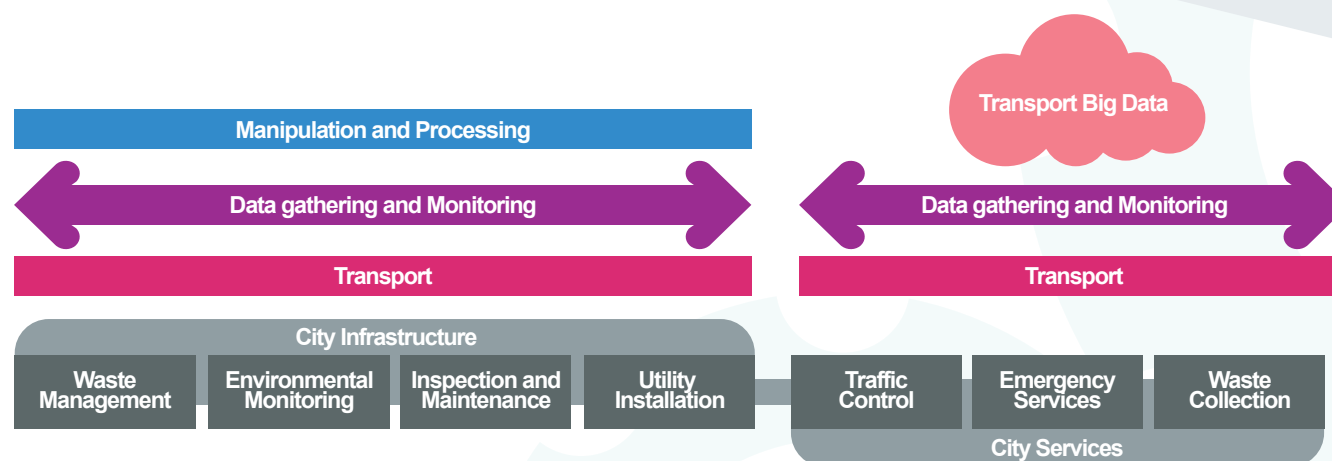
“City data will become a valuable commodity”

## City Scale Transport

Integrating city wide data from transport and using this to dynamically route and prioritise traffic flows will decrease average journey times and optimise the utilisation of capacity and interconnections.

Reduced emissions, better fuel economy and time regained when not driving will all result in lowering the cost of transport and delivery within the city.

**The long term data gathered will inform infrastructure development and set control parameters.**



## Robotised Maintenance

Road closures, bridge closures and highway maintenance significantly reduce operational capacity and put human workers at risk.

Utilising RAS in inspection and maintenance will reduce closures and costs, increase inspection frequency and generate data to drive better maintenance models.

**Infrastructure utilisation will increase and unforeseen closures will reduce.**

## Value Added Services

Interconnecting RAS systems that deliver goods and provide transport that connect to the “cloud” provide unparalleled opportunities for added value services.

Smart phones already impact on transport, adding RAS devices to the mix will enable novel demand driven services and new revenue streams.

**The value added market will grow with RAS.**





## Energy Supply, Utilities and the Environment

RAS is already deployed in a number of areas within the energy supply industry and there is a growing understanding of the potential gain.

RAS can improve the mapping of legacy installations, improve plant condition monitoring by providing early warning of deterioration, and improve the monitoring of widely distributed infrastructure, particularly off-shore.

RAS can be used in the remote handling of legacy waste, for off-shore installation and maintenance and in live power line inspection.

Even in the distribution of domestic utilities RAS can help reduce the impact on roads and pavements, provide faster installation and improved leak detection.

### Down-time

Inspection and maintenance is expensive in the energy and utilities sector because of the need to turn off generators, pumps, and plant in order to safely inspect and repair. Extending “up-time” during maintenance will significantly reduce costs.

RAS technology can reduce the time it takes to inspect infrastructure by not requiring scaffolding. It can reduce the time to repair because multiple autonomous platforms can work together and in conditions no human can endure, for example in relining a furnace while hot.

In some cases RAS can carry out regular inspections while generators and plant are still running, increasing the frequency of inspection. By building Big Data about each plant, RAS can more accurately spot early warning signs that might indicate damage or fatigue. RAS will reduce maintenance down-time.

### Key Drivers

- Increased risk aversion
- Need to maximise natural resources
- Need to reduce energy and maintenance costs

### Key Enablers

- Safety validation in hazardous environments
- Ability to meet key industry standards
- Legal framework for autonomous operation

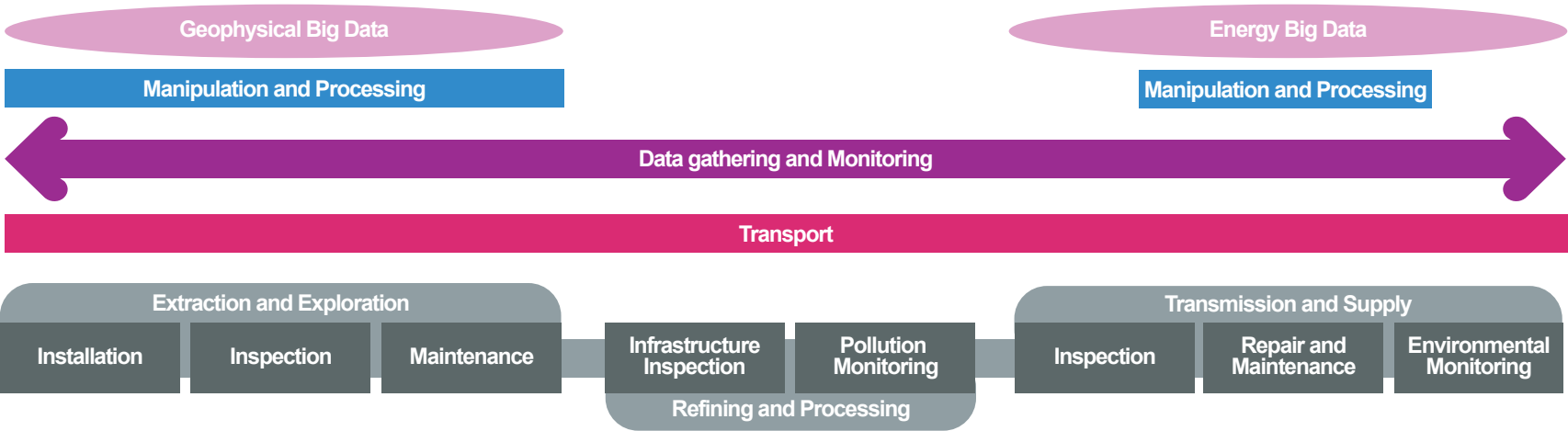
### Key Impacts

- Risk free inspection
- Incremental autonomy in maintenance tasks
- Intuitive Human Computer interaction systems

## Energy Infrastructure

RAS is already being exploited in many parts of the energy supply chain. Most often in hazardous areas providing remotely driven services. However the potential for new applications and opportunities will grow as technical capability extends.

“ Risk and future liability can be reduced by increased inspection ”



### Mineral Extraction

The UK has significant mineral resources that are currently inaccessible using conventional means. Under the sea, in deep mines, in rock structures and in hazardous environments.

Robotic systems will transform mineral extraction, altering the economics and allowing operation in environments too hazardous for humans.

**The potential wealth from this activity will justify significant investment.**

### Managing Infrastructure

The UK has significant energy distribution assets distributed across both land and sea. Inspection and repair to maintain capacity and extend operating life are impacted by RAS.

This is a global problem and UK expertise can supply a global market for technology.

**Fully maintained assets will reduce costs.**

### Environmental Monitoring

RAS can be deployed on long term monitoring of the oceans, rivers, and harbours. Systems able to transition between land, sea and air can track pollution or record plant and animal life.

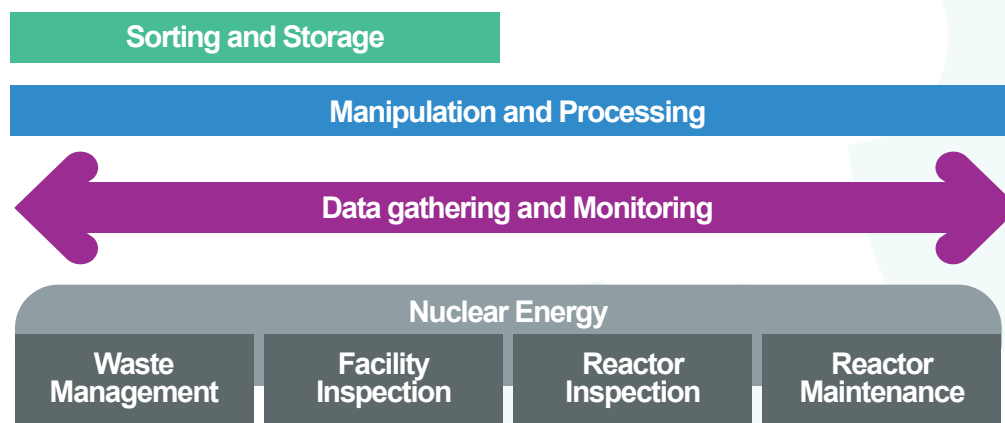
This long-term provision of data will inform decision making across many areas of activity from fishing quotas to pollution targets.

**RAS will deliver better information on the environment.**

## Nuclear Applications

The hazardous aspects of nuclear power generation demand the use of RAS. Waste processing, decommissioning, reactor maintenance and life extension can all use RAS technology to reduce risk and increase efficiency.

“There is a global market for RAS based nuclear decommissioning”



### Hazardous Environments

Operating in hazardous environments under the sea or in nuclear reactors with remotely operated systems. Adding autonomy enhances both inspection and maintenance operations and reduces operator fatigue.

Liability can be reduced simply by mapping and assessing asset condition.

**RAS increases operator safety.**

### Nuclear Maintenance

RAS also has a key role to play in assessing legacy infrastructure to determine condition and decommissioning requirements. RAS offers a means to assess future liability through automated survey and assessment particularly in contaminated spaces.

RAS can be integrated into the design of new build power stations so that maintenance can become embedded.

**RAS can extend reactor life and decrease costs.**

### Decommissioning

RAS can impact along the whole decommissioning value chain. From assessment through to final site decommissioning.

Reducing the risk of cross contamination, increasing processing rates and reducing operator exposure.

**RAS will improve decommissioning costs.**



## Enablers

Robotics and autonomous systems do not work in isolation. They require regulation, standards, innovation, investment, testing facilities, demonstrators and skill development. The Landscape touches on all of these non-technical aspects of RAS and identifies them as equally important as technical progress, indeed in some areas they are a prerequisite for market development. Building this supporting infrastructure will be an essential part of growing UK RAS capability.

“ Investment in demonstrators that prove the market will enable the UK to succeed ”

## Innovation Investment

**The stand out message from the Landscaping process is that innovation funding will be essential if RAS in the UK is to grow.**

This investment must align with UK policy, be cross cutting and joined up across the innovation pathways in the UK.

SMEs are critical to the process of innovation in all sectors, identifying them, engaging them and supporting them must be high on the innovation agenda.

In particular, support for SMEs engaged in manufacturing is seen as a driver of growth and competitiveness.

Supporting the validation of first use, within an application area, by developing live demonstrators is seen as being critical to uptake.

“ Better education directly leads to greater uptake and improved competitiveness ”

## Skills

**The growth of robotics in the UK may be solely limited by the availability of skilled engineers and technicians.**

There is a technical skill shortage in the UK. While this can be solved with immigration there is a pressing need to rebalance STEM uptake in line with a rebalanced economy.

The growth of robotics in the UK may be solely limited by the availability of skilled engineers and technicians.

Existing investment in Universities represents a good start but must be backed up across all levels in the education system from primary schools to in-work training schemes.

Robots will create jobs in the medium term but will also cause displacement. Skills investment must also recognise the need for retraining.

The poor uptake of automation in the UK can be partly blamed on a lack of skills. If the UK is to make the next step deploying robotic co-workers and hybrid manufacturing then boosting skills will be an essential driver of uptake and thus improved competitiveness.

“ Regulation and standards will be the key that opens the UK market ”

## Regulation

**Without users trusting robots and autonomous systems the market cannot grow. Regulation provides the basis of that trust.**

In every sector explored in the Landscape the issue of regulation, standards and certification is recognised as a significant barrier to growth.

In many sectors the opening up of test spaces is essential for product development and first use validation. Regulation that specifically includes autonomous systems is essential.

In healthcare and in particular in the elderly care market ethical and responsible regulation are seen as important prerequisites of a successful service.





# Interacting with RAS

The fundamental change that marks out the new generation of RAS technology is its ability to enable humans to directly and physically interact with robots.

To do so safely and intuitively will require investment in technology, standards and deployment.

In all areas of application this close coupling between robot and human is a key part of the RAS opportunity.

## Interaction and Control

How a robot is controlled by the user will depend on the application. In remote handling or in surgery where moment to moment interaction is essential there will be an immediate mapping of human motion to robot motion.

To this interaction RAS will add safety, dexterity, scaling and an overlay of information to help the user make decisions.

In other applications robots will learn by copying human actions, or will take high level commands about what to do while filling in the operational details.

Where teams of robots are carrying out a task the human user may only need to issue high level mission instructions and wait for the next moment that needs a decision.

**Autonomy is a sliding scale, applications will employ as much or as little as they need.**

## Physical Interaction

Interaction between humans and robots will become increasingly physical. Training a robot will involve showing it what to do, physically guiding it and demonstrating while it watches.

Robots will be able to feedback the shape and texture of the object it is holding to a user as physical sensations. Robots will use our body pose and facial expressions to interpret our intentions and decode our instructions.

**Instructing a robot to carry out a new task will no longer need an expert.**

Extending reach  
Supporting cognition  
Reinforcing safety  
Interacting physically  
Manipulating at a distance  
Commanding a team  
Interpreting intent  
Decoding social cues

# Technology

Underlying the RAS opportunities are advances in key technologies that enable a higher level of capability. As each technology achieves a step in capability new markets will be opened. In turn the market will pull technical development and direct attention to reducing technical deficits in order to enable new markets and business models to succeed.

Each RAS process as detailed in the sector cluster illustrations and shown opposite, depends on specific sets of underlying technologies and these are detailed here. These in turn rely on underlying areas of technology such as communications, energy storage, materials, software engineering and electronics.

## Cross Cutting Technology

Technical developments cut across sectors. For example new technologies for grasping and manipulation in manufacturing can be applied in healthcare and vice versa.

## Cognitive Technologies

Cognitive technologies provide the context, interpretation, recognition, learning and reasoning required to make autonomy smart and effective in a given application.

## Mechatronics

Mechatronics is at the core of every robot, mechanisms, driven by actuators and sensors informing controllers of state, generating responses to stimuli that control motion, grasping, and interaction. Enabling RAS to physically interact with the environment and users.

## Systems Engineering

RAS systems integrate a wide range of technologies from mechanics to complex software in the cloud. Robotics is often seen as the ultimate systems engineering challenge. Integrated design systems, safety led processes, testing and certification all need support from well designed systems engineering tools that manage complexity and speed time to market.

## TRANSPORTATION

### Technology for Transportation

Systems of Systems able to optimise flows, plan routes and navigate in unstructured environments.

Object and obstacle detection, local environment interpretation, integrated safety, motion control, dynamics, motion planning, communications, map generation and adaptive planning.

## SORTING AND STORAGE

### Technology for Sorting and Storage

Optimisation of space and time usage, analysing flows, analysing usage and adapting strategies.

Packing and Unpacking in unstructured spaces, sorting and storing items in warehouses and vehicles.

## DATA GATHERING MONITORING

### Technology for Data Gathering and Monitoring

Sensing the space around the robot and capturing features and data. Monitoring specific characteristics, chemistry, sound, colour, texture, organisms and materials.

Communicating raw data and the interpretation of state, interrogating information in the cloud to make decisions. Adding to knowledge.

## MANIPULATION AND PROCESSING

### Technology for Manipulation and Processing

Picking up, examining rotating, sorting and placing objects without knowing how to handle them in advance.

Object recognition, 3D sensing, grasp planning, actuation, force sensing, proprioception, scene analysis, and the utilisation of affordances.

## INTERACTION

### Technology for Interaction

Intuitive interaction using multiple modes, touch, sound, vision and gestures. Intuiting human intention from social cues, motion and facial expressions.

Modelling human motion to secure safe operation, interfaces that manage complexity, task based command and interactive mission planning.



Word map seeded with text from the outcomes of the first RAS overview workshop

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