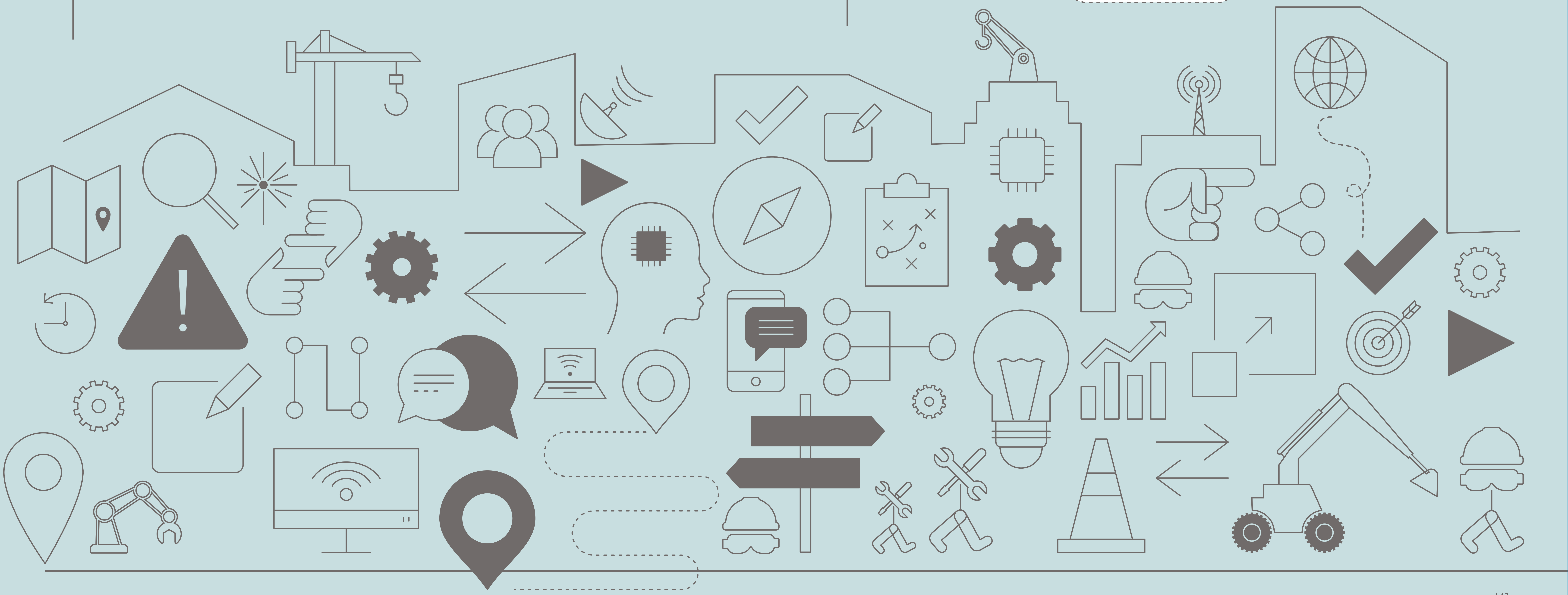
Connected and Autonomous Plant
Roadmap to 2035



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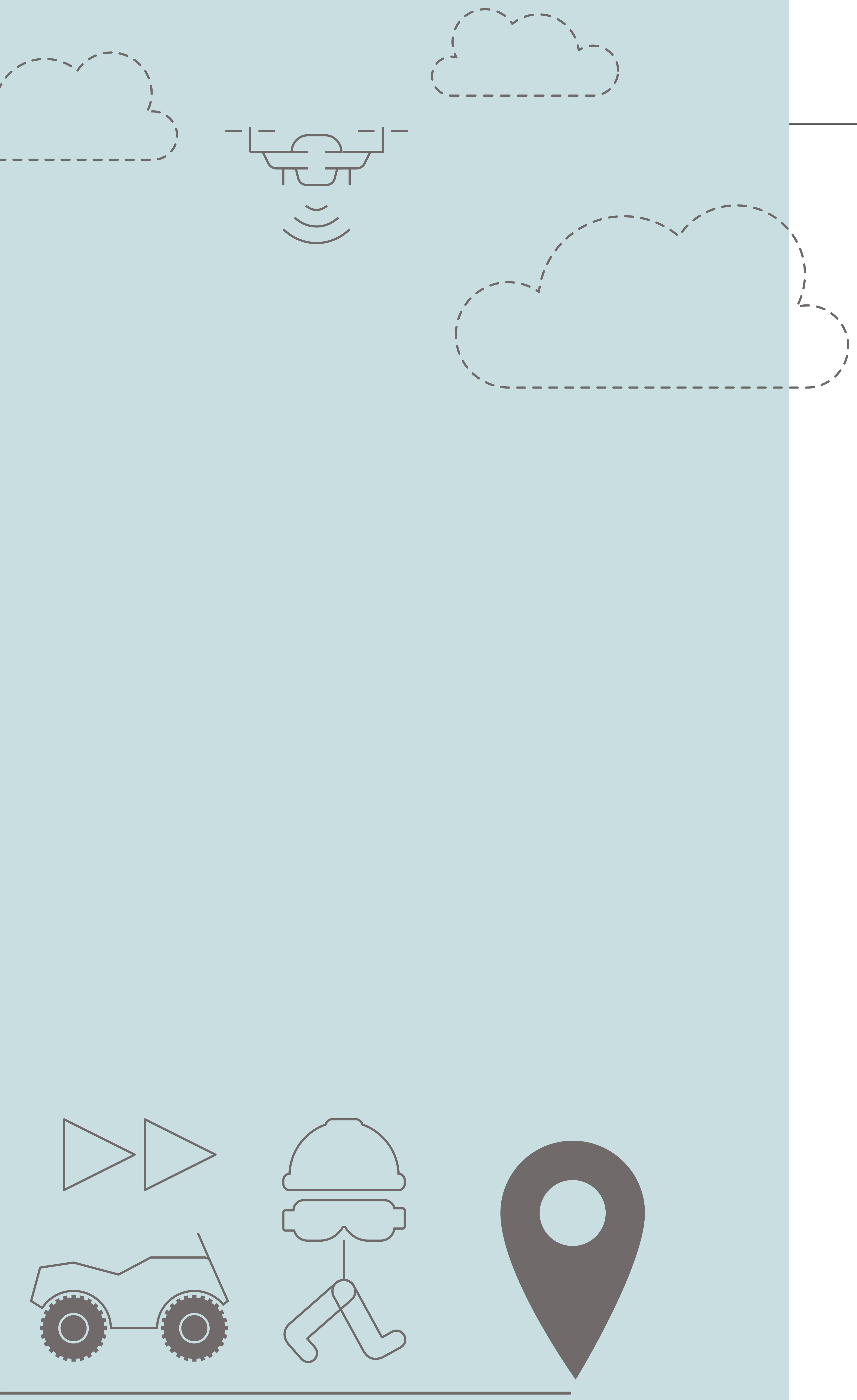


The use of connected and autonomous construction techniques will become the business as usual approach across UK construction.

This Roadmap provides a tool for stakeholders to support their decisions on planning, strategy, and investment.

Indicates interactive elements on the page

Executive Summary

Connected and Autonomous Plant - an opportunity and a challenge

Advances in technology and the introduction of Connected and Autonomous Plant (CAP) are transforming activities across the UK construction sector. CAP offers potential in a wide range of applications, for example: remote collection of data for design; geofencing of plant operation; semi-autonomous extraction and movement of materials; offsite and robotic construction.

However, this transformation presents a challenge to the sector. The introduction of CAP technology lacks a unified approach. Practice differs across construction sites and between clients. As a result, CAP deployment varies significantly across sites and information flow between organisations is slow.

The industry is developing a strong understanding of the potential presented by CAP, with exciting examples of new technology being applied in practice. However, the community is concerned over the pace and practicality of implementing new methods, in context of the current approach to commissioning and delivering construction projects. Because there is no clear direction to encourage the use of CAP, the industry must bear all the risks of investing in new systems. These investments are made in an environment where there's a lack of certainty about the capability of the technology, and a lack of clarity about the risks, liabilities and acceptability of its use.

Why set a vision and develop a Roadmap?

Just as the use of machines and robotics transformed the factory floor, CAP could deliver safe, automated, efficient construction processes, drawing on skilled labour in lower numbers to turn out higher outputs. If the benefits to manufacturing are mirrored in construction, productivity improvements achieved via CAP could exceed £200Bn by 2040.

But without the coordination, strategy and direction proposed in the Roadmap, achieving widespread automation in construction is unlikely. A delay of only five years could reduce the 2040 savings by over 50%. On the other hand, by accelerating the adoption of technology that already exists, we could see significant benefits within five years.

What does the Roadmap describe?

The Roadmap has been developed collaboratively with over 75 organisations. Questionnaires and workshops identified the actions required to overcome technical, business and legislative challenges affecting successful delivery of the vision. The Roadmap brings these together in nine workstreams, each focussing on key areas identified by stakeholders. These workstreams would be delivered in parallel through industry-wide collaboration.

Roadmap workstreams

- **Legislation, regulation and policy.** Legislate and regulate to facilitate CAP. Support testing, approval and certification. Transform contracts to encourage CAP.
- **Finance, business and investment.** Understand the benefits of CAP. Drive investment in autonomous technology and collaboration.
- **CAP training framework.** Understand the skills gap and how to fill it. Establish training and engage with society to deliver a skilled workforce.
- **Ubiquitous connectivity.** Deliver the communications standards and infrastructure that will meet the demands of CAP.
- **Remote survey and operation.** Develop technologies that will support live digital twins and the remote operation of plant.
- **Autonomous plant.** Establish capability levels for autonomous plant. Drive a technology development programme to deliver these capabilities.
- **Algorithms in autonomy.** Deliver the intelligent control systems that enable autonomous operation. Develop and implement virtual validation capabilities to test them.
- **Interoperable telemetry.** Develop tools and standards to share the telemetry data required to deliver autonomous and cooperative operation.
- **Common Data Platform.** Establish and populate the national asset registers that will support data sharing, automated design and construction.

Delivering the vision

The delivery of the vision within the Roadmap now becomes the responsibility of the sector. I3P will play a key role in bringing the community together, but stakeholders must identify and target the areas within the workstreams over which they have capability and influence and lead their delivery.

Key stakeholders—Next steps

- **i3P:** Drive industry collaboration. Establish community agreement on the first steps and on a collaborative investment programme.
- **Government and standards/legislative bodies:** Lead the development of the levels that define CAP capability and use these as a basis to develop R&D programmes.
- **Government and standards/legislative bodies.** Initiate work to establish the legal and standards frameworks that will enable CAP to thrive.
- **Infrastructure owner/client bodies:** Commence work on the enabling activities that will help the industry to deliver CAP - such as developing and delivering testbeds and setting performance requirements.
- **Infrastructure owner/client bodies:** Review business models/contracts and identify the changes that are required to encourage the use of CAP.
- **Manufacturers:** Invest internally, with SMEs and with academia, in the collaborative development of technology. Support the development of interoperable standards and training solutions.
- **Contractors:** Advise, support and assist clients in the delivery of the changes required. Participate in upskilling strategies and communicate and promote best practice across the industry.

Call for collaboration:

By working collaboratively, government, clients and the plant and technology industry can optimise the implementation of autonomous construction technologies, and deliver the 2035 vision.

Foreword

Welcome to the Connected and Autonomous Plant Roadmap to 2035. We have developed the roadmap as a tool for the construction sector to support decisions on planning, strategy and investment in automated construction technologies.

At Highways England, we have three imperatives that guide everything we do: improving safety for all, providing a better service to customers and delivering our construction and maintenance projects effectively and efficiently. Revolutionising technology on our construction sites can move the dial on all three.

Construction sites remain one of the most dangerous workplaces in the UK. While injuries from construction plant are not the most frequent, when they occur they are serious and often fatal. If we can remove people from harm's way, we save lives and we improve the well-being of all. Much technology to improve safety already exists, but we do not yet routinely see it on site.

Productivity remains a challenge for the construction industry. While retail and manufacturing sectors have seen significant and sustained improvement in productivity through better processes and technology, construction has stalled. Other site-based industries such as mining and farming have made strides towards greater automation over recent years. We asked the question, why not construction? This roadmap sets out how we, as an industry, can work together to create an environment for the technology to flourish and be embedded from the design stages onwards.

We recognise that to achieve real improvement through a complex supply chain, we have to act as one. Additionally, Road Period 2 is a very significant five year investment programme that can provide continuity and support the industry in delivering key elements of the CAP roadmap. That's why we were pleased to work alongside i3P, connecting with stakeholders representing 75 organisations across the breadth of our industry, to produce this first step mapping the journey to connected sites and automated construction activity.

We hope that you find the Roadmap interesting, stimulating and useful, and we look forward to starting the journey with you.

Malcolm Dare
Executive Director, Commercial and Procurement
Highways England

As chair of the Infrastructure Innovation Industry Platform i3P, I am delighted to introduce you to this Connected Autonomous Plant industry roadmap. This work charts an extremely exciting and potentially game changing route as to how we operate our sites when building Britain.

As an industry, we need to embrace innovation and enhance the way we work together to make this exciting future our reality, making our people more efficient and safer than ever. Fundamentally, collaboration is THE key to unlocking the power of innovation. The vision of i3P is simple: we are better together. Through sharing knowledge and acting collaboratively we are greater than the sum of our parts.

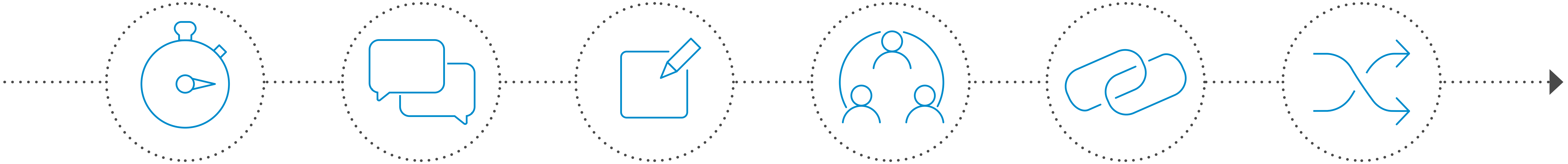
Construction is an industry of many moving parts, companies and complex contracting environments. This makes collaboration no easy feat, and that is why a clear direction and sense of purpose is essential for i3P to drive real change. As clients, we need to pass the baton from project to project making sure we pick up the learnings from one another. This is something I want us to do in HS2, making sure our innovations build on those from our colleagues in Tideway, Network Rail and Highways England. And then we in turn continue to innovate on our programme, ready to pass our learnings into the collective knowledge environment.

This is how our sector will continue to evolve, change and grow and be continually competitive. I3P provides an excellent platform to offer clarity to contractors, designers, engineering companies and also to align policy makers to deliver innovation at industrial scale, whether technical or commercial.

I believe that connected and autonomous plant has tremendous potential to improve safety, productivity and impact on the environment. This work has been supported by i3P as one of our key priority projects that have the greatest potential to benefit from cross industry collaboration.

My challenge to all of us is to take the steps we can take today to improve, and move forward towards the bright future that could be ahead of us, if we keep moving – together.

Mark Thurston
CEO HS2



1. Deliver 2. Encourage 3. Create 4. Collaborate 5. Support 6. Change

Connected and Autonomous Plant will transform the sector by delivering safe, automated, efficient construction processes. The Roadmap sets a vision for CAP to become the business as usual approach by 2035. Government, clients and the plant and technology industry should act now to optimise the development and implementation of this new approach, to deliver the 2035 vision.

1. **Now is the time to create an environment where CAP thrives**
   Help deliver a step change in construction safety, quality and productivity
2. **Provide the encouragement to deliver projects with CAP**
   "Procure for CAP" – set requirements that promote use of this technology
3. **Create a CAP friendly construction ecosystem**
   Establish the communication and data platforms needed to deliver autonomous design and operation
4. **Collaborate now in CAP development**
   Support the R&D programmes that will deliver a transformation in technology
5. **Upskill and support best practice across the industry**
   Encourage everyone to learn and understand this new field
6. **Drive change in your organisations**
   Accept and promote this new approach

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Introduction

The construction industry has seen many developments over the last 100 years. It has transitioned from intensive, labour-based methods to a machine-intensive industry, drawing on new technology to support many aspects of the construction process.

However, according to data from the Office of National Statistics, the construction sector has the lowest labour productivity of all sectors (Office for National Statistics, 2018), and its workers are around 3.5 times more likely to experience injury (Health and Safety Executive, 2019). The industry is falling behind its peers in a number of key areas.

As digital technologies are increasingly introduced in construction, opportunities arise to introduce new techniques, including automating many of the activities that currently require human intervention. The introduction of automation using Connected and Autonomous Plant (CAP) will benefit productivity, quality, safety, welfare and cost. CAP could deliver this in a step change approach.

There are a wide range of emerging technologies that can be described as connected and autonomous plant, and a number of these are already being applied, however, the current approach is piecemeal and uncoordinated.

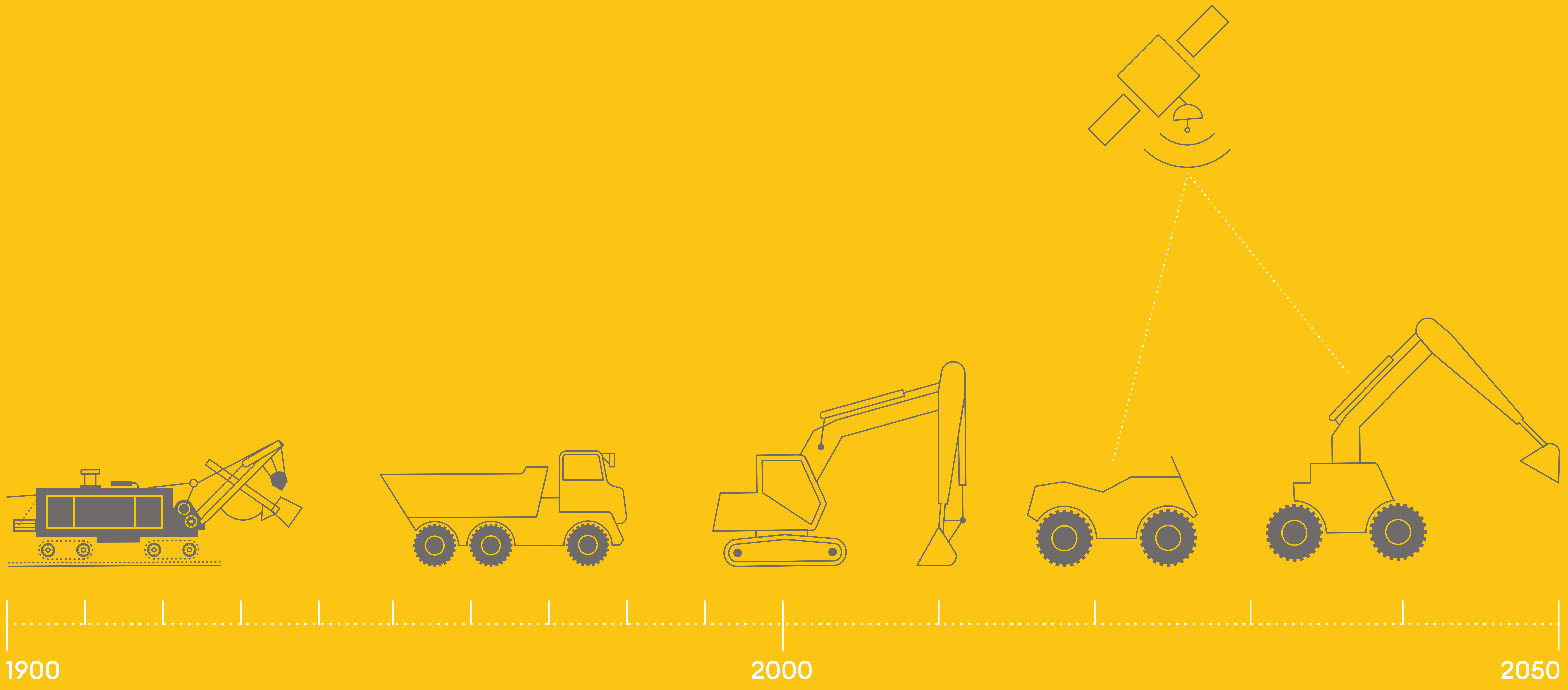
There is little incentive in current procurement processes to encourage the industry to adopt new approaches that may be both more costly and higher risk. This environment, which favours traditional approaches, will tend to constrain the potential benefits offered by new technologies.

Development of this Roadmap has been stimulated by the need to bring the industry together to determine how new technology could best be applied to bring benefits in the construction sector. Its development has been based on a need for a holistic, long-term vision that would ultimately deliver CAP as a business as usual activity across all construction activities. The Roadmap has investigated the legal, technical and social implications of CAP and identified some of the significant challenges that would need to be overcome to realise this vision for the use of CAP.

The project has bought industry partners together to understand how this vision of site autonomy will be achieved. The Roadmap has been produced to disrupt, provoke and accelerate change within the sector.

It is hoped that this first Roadmap for CAP will help stimulate the industry to accelerate progress in implementing new technologies. This will be a living document that can adapt to progress, identifying new challenges and determining how they might be overcome.

Evolution of automation in construction



The challenge in 2020

Rapid progress is being made in the development of technology in the construction sector. These advances offer opportunities across the entire construction process. They include: the remote and automated collection of high resolution digital data to support survey and design; machine-assisted control and geofencing for site excavation; semi-autonomous tools for extraction and movement of materials; off-site construction of building components, and robotic and machine assisted control for on-site construction.

With these advances, why does the construction industry have the lowest level of productivity out of all industrial sectors in the UK?

In 2020, what is preventing a step change in the approach, drive and vision of the sector?

Workshops held during the development of the Roadmap, in collaboration with enterprise innovation incubator i3P, have considered these questions.

> Clients won't pay for adoption of new technology
>
> CAP stakeholder

In your sector, are you using connected or automated construction equipment?

Buildings (Housing)	67%
Buildings (Commercial)	62%
Maritime	60%
Other	60%
Telecommunications	56%
Rail	43%
Roads	42%
Aviation	41%
Environment	39%
Water	38%
Research	38%
Energy	36%

Regardless of the sector (aviation, road, rail, maritime) the consultation found widespread understanding of the potential for CAP. It found example applications of the new technology in areas such as design, survey and construction (see Appendix A.) however, the current approach is to focus on specific application areas, with a lack of underlying strategy. **The industry has been clear in expressing its desire for change,** but it has concerns about the ability to implement these new methods, and the rate at which this can be achieved.

The development of new technologies is expensive and currently must be borne by the contractors and operators using the equipment, even though the benefits are passed to clients. While innovators and early adopters are seeing the benefits of the new methods, finance will have a large influence on the rate of development and take-up. If financial incentives are not clear, decision makers will not select or develop new methods, and delay will be the inevitable consequence.

Procurement processes are typically founded on the application of standard, well understood techniques, with minimum risk and cost. This approach can conflict with the introduction of technologies where there is little experience. Having invested in new technology, providers can be at a disadvantage when competing for work, even if their approach has the potential to deliver better quality, improved safety or reliability. The industry has called for support for innovation and the uptake of new methods.

Conventional methods bring the security of established legislation, an understanding of liability and insurance issues, and well-defined processes for safe operation. Autonomous technologies are seen to bring a new wave of challenges to the industry in the protection of its workforce, management of its liabilities and understanding of the risks.

Whilst developers, providers and users of plant can provide insight and guidance to overcome these issues, legislation and standards must be driven centrally.

Although there have been breakthroughs, and many claims are made about the technology, there are still concerns over the capability of current developments, and the challenges to overcome. Significant work lies ahead to develop technologies that can be applied with confidence across construction activities.

In bringing these 2020 challenges together, stakeholders made a clear call for a central, co-ordinated drive to deliver CAP, via **“the formation of a coalition to govern the technical aspects, provide oversight and influence law, financing options and commercial risks.”**

Liability. In the event of an incident who does it sit with?

CAP stakeholder

We lack a single controlling mind to determine the direction of automation

CAP stakeholder

Public procurement processes stop adoption of new technology

CAP stakeholder

Autonomous technology is not as advanced as people are led to believe

CAP stakeholder

A vision for 2035

In 2035, the use of connected and autonomous construction techniques will be a business as usual activity in the UK. Construction sites will be connected and digitised. The autonomous operation of plant will have delivered a step change in the safety and productivity of construction. The UK will have a highly skilled workforce proficient in autonomous and digitised construction.

In 2035, autonomous methods will affect all areas of construction - from design through to delivery. National asset registers and digital twins will provide models for design that will be updated using remote, automated surveys. Design processes will use artificial intelligence (AI) to deliver outline designs. Autonomous options analyses will support the selection of the final design, which will be optimised for construction using automated devices and off-site methods. Designs will maximise the use of sustainable resources and minimise energy consumption.

On site, machines will operate fully autonomously, minimising the need for manual labour and taking humans out-of-the-loop wherever possible. These machines will measure their own progress, feeding back real-time updates to the digital twin. Resource selection, planning and delivery will draw on comprehensive, accurate, real-time data, ensuring efficiency and timeliness.

On completion of the construction, models to support ongoing management will be populated automatically. These will provide detailed information to support maintenance and replacement of components - which will themselves be modular and designed for cost-effective, sustainable end-of-life recycling.

Key outcomes of the Roadmap to 2035

1. An established legal framework for automated construction activities
2. Procurement processes favour the use of automation in construction
3. Standards in place to support communication and exchange of data
4. National asset data registers established and ready for real time updates
5. Approach is optimised for the use of automated design and construction methods
6. Automation is seen as the prefered approach for safe construction
7. The workforce is skilled in, and engaging with, automation
8. UK is the world leader in CAP, exporting technology and skills

Between now and 2035, the implementation of autonomous construction will deliver incremental benefits as each technological advance is achieved. The benefits to society will be financial, social and environmental.

Appendix B discusses benefits as case study examples. We can make an estimate of the extent of the benefits offered by CAP by considering its potential influence on productivity. The use of machines and robotics has transformed the factory floor from a labour-intensive activity to a robotised, efficient process that draws on lower numbers of skilled workers turning out higher outputs.

Manufacturing has delivered year on year productivity improvements that have placed it 40% ahead of construction.

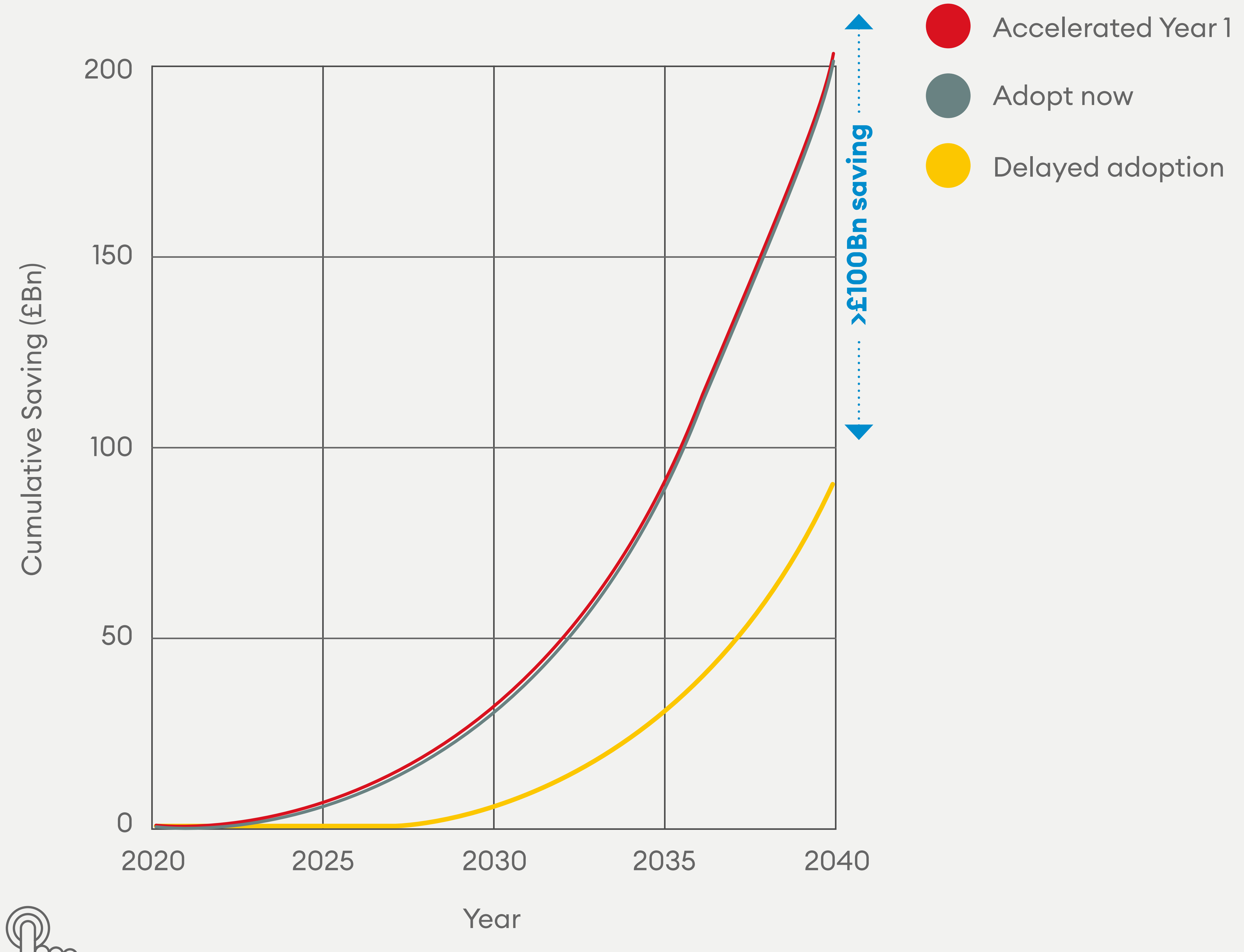
With an annual spend of over £100Bn, such productivity improvements could deliver huge savings to the construction sector. **A staged introduction of CAP technologies from 2020 to 2035, leading to improvements in productivity that are only half of those achieved in manufacturing, could deliver up to £200Bn of benefit, in today's value, by 2040.**

Without co-ordination, strategy, requirements, and direction, the likelihood of achieving widespread automation in construction will be reduced along with the benefits. A delay of only five years could reduce the potential 2040 savings by more than 50%.

In contrast, if adoption of existing technology was accelerated so that there was greater implementation of current CAP capability within the next year, then by 2025 this could deliver over £1Bn of benefits.

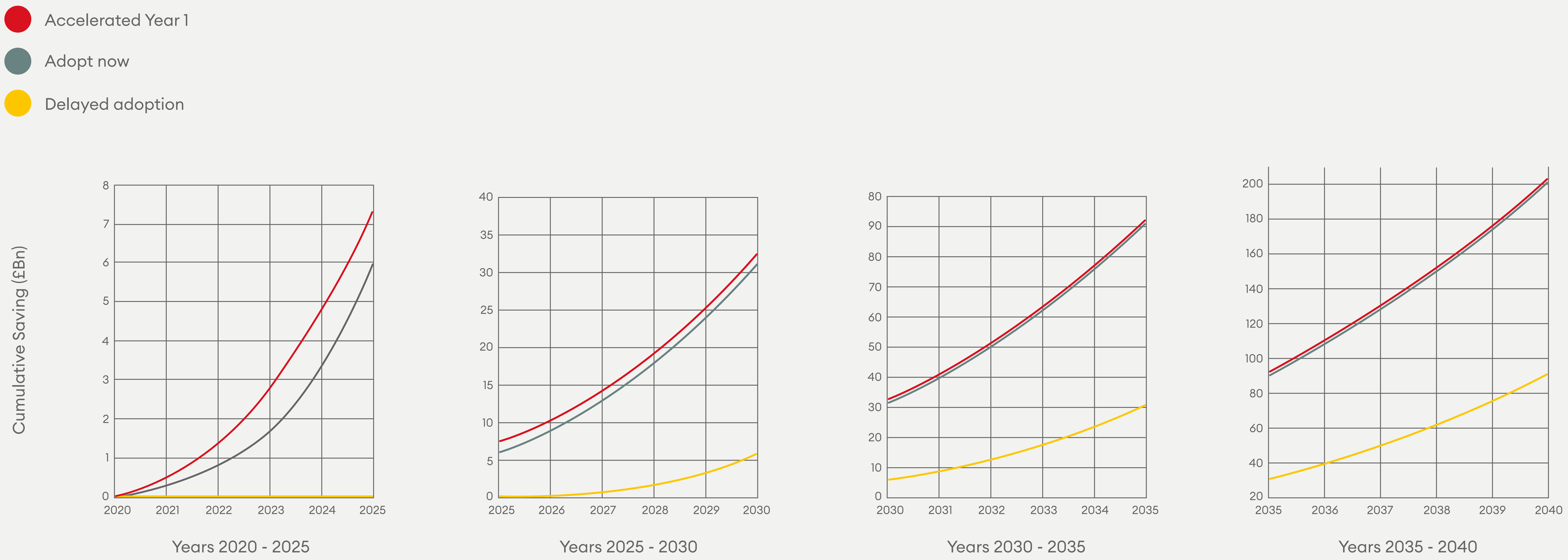
The Roadmap supports the delivery of these savings. It defines the activities that will need to be undertaken to deliver the key outcomes. It addresses the impacts for people, society, technology, hardware, and digital techniques. It is hoped that it will stimulate proactive collaboration across government, client and industry bodies.

Potential benefits of accelerated adoption



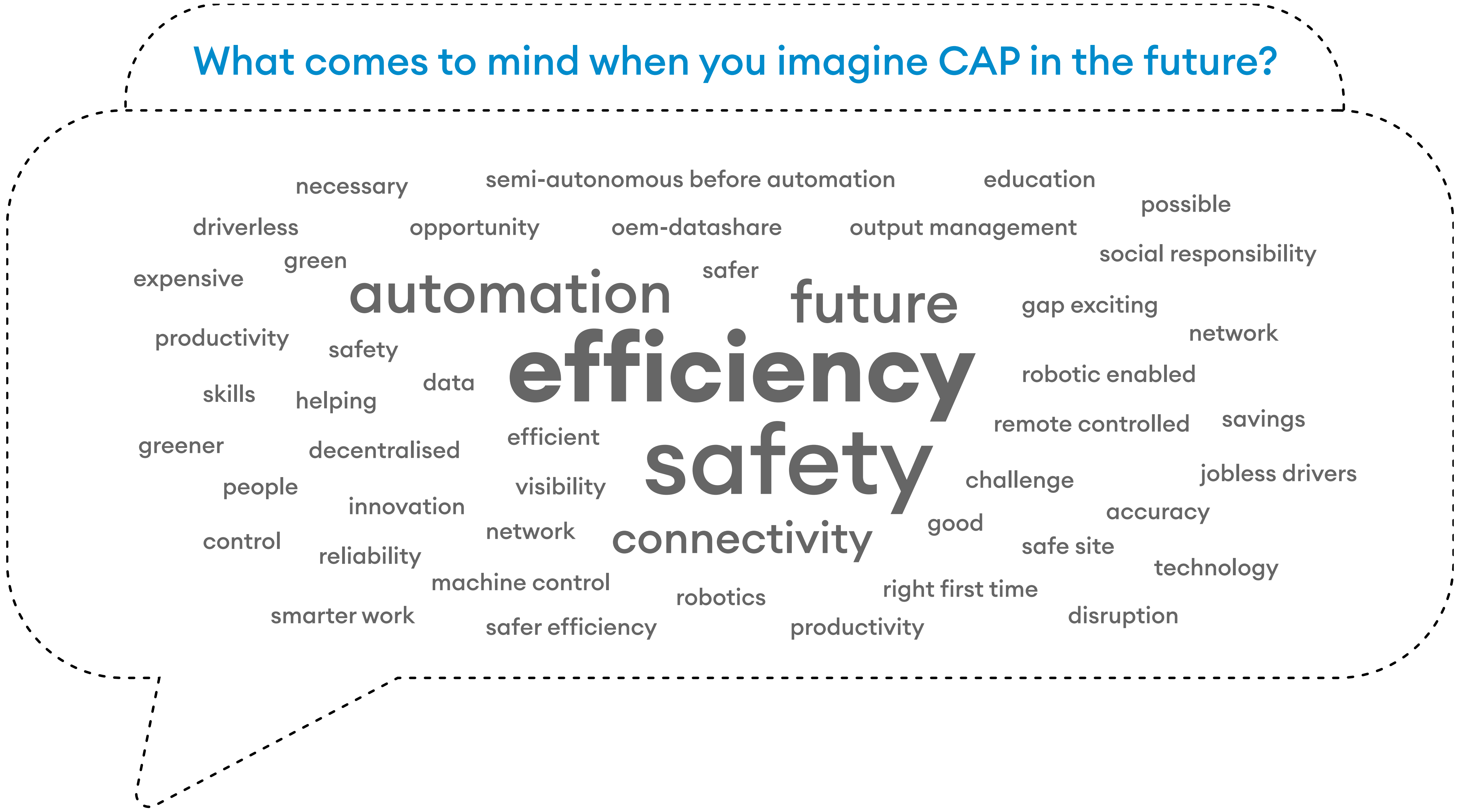
Rollover years to view detail

Potential benefits of accelerated adoption detail



Development of the Roadmap: Barriers to overcome

Questionnaires and workshops for industry stakeholders have explored the understanding, status and use of CAP in construction operations. As noted above, there is already an awareness of CAP technologies across the sector. Its application is most widespread in building and maritime. Although adoption in road and rail transportation and utilities is lower, there is still a strong awareness of automation and an appetite for wider adoption in these sectors. However, when stakeholders were invited to discuss their views on the requirements for widescale implementation of CAP in the short (5 years), medium (10 years), and long (15+ years) terms, they identified a wide range of barriers.

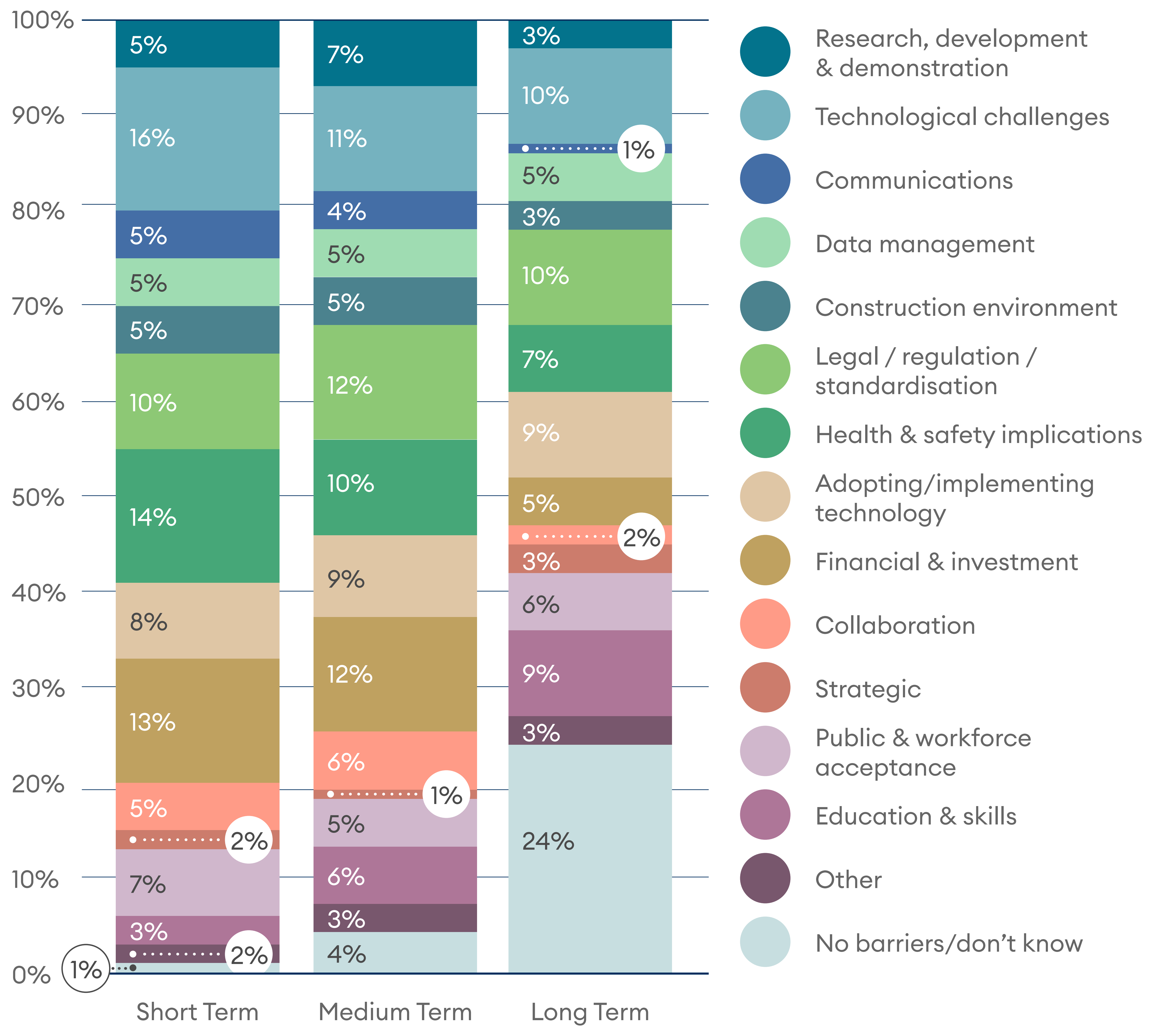


The charts on the next page summarise the broad range of views expressed by the industry. Noteworthy concerns have been raised over barriers such as:

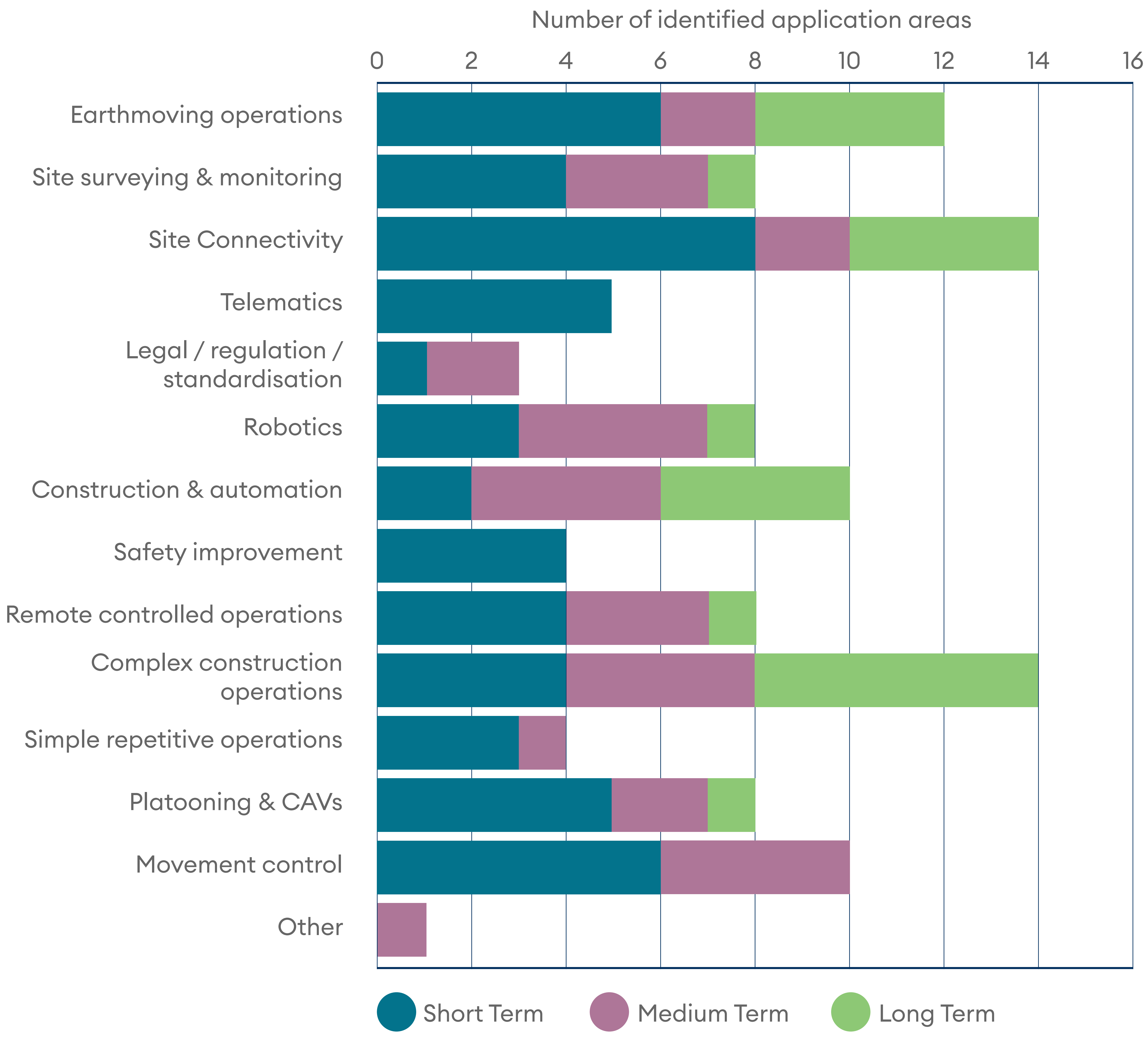
- The need for **legislation and regulation** that permit the use of CAP
- The need for **standards**
- The need for the **benefits to be clearly realised and demonstrated**
- The need for **financial investment** for the development and adoption of CAP
- The need for **contractual incentives** for the use of CAP
- The difficulty in developing the **technology for autonomy and connectivity** across the wide variety of plant
- A strong need and desire for **collaboration** across the industry

The need to overcome these barriers has stimulated and informed the development and the content of the Roadmap.

Barriers to implementation



Application areas



Development of the Roadmap: The process

> Connected and Autonomous Plant technologies will transform construction safety, resilience, efficiency, productivity and performance via communication, connectivity and autonomous operation.
>
> CAP Ecosystem Mapping Workshop

Over 75 organisations from across the sector have contributed to the Roadmap, including government, construction, academia, research, OEM, consultancy, SMEs from the UK and road administrations from Europe. Its development drew on outputs from questionnaires and workshops to seek views on the actions required to overcome the technical, business, social and legislative challenges discussed above.

This commenced with the development of a working definition for CAP. The definition recognises that autonomous construction will not be limited to the transition of plant into self-operating machines. It will deliver a transformation of the construction industry into a new, digitised environment taking full advantage of new technology. This complements Connected Autonomous Vehicles, which will deliver new solutions for overall mobility, not just automated vehicle operation.

The Roadmap contributors proceeded to consider in detail the challenges and barriers to development and adoption and potential routes to overcome them. This began with asking key questions to identify five priority trends and drivers that would influence the direction of the Roadmap. These were considered in detail, exploring the current situation and the future vision that could be realised through the delivery of the Roadmap. The five priority trends and drivers are shown on the next few pages.

A set of three themes, each comprised of three workstreams, was proposed to support the delivery of the vision. These workstreams were developed and refined and a roadmap created for each to describe the pathway to achieving each outcome. A set of business cases was drafted for each workstream which considered the strategic context and business need for each workstream and the benefits and risks associated with it. Each workstream was then assessed and scored in terms of the scale of the opportunity presented and the feasibility of achieving the desired outcomes.

A strategic overview of the three themes and nine workstreams is presented in the following pages. Detailed descriptions of each workstream are given in the Workstreams section, along with the feasibility and opportunity scores.

Questions for a Roadmap

What is driving the delivery of automation?
How will a Roadmap influence these?
What outcomes will this achieve?

Response

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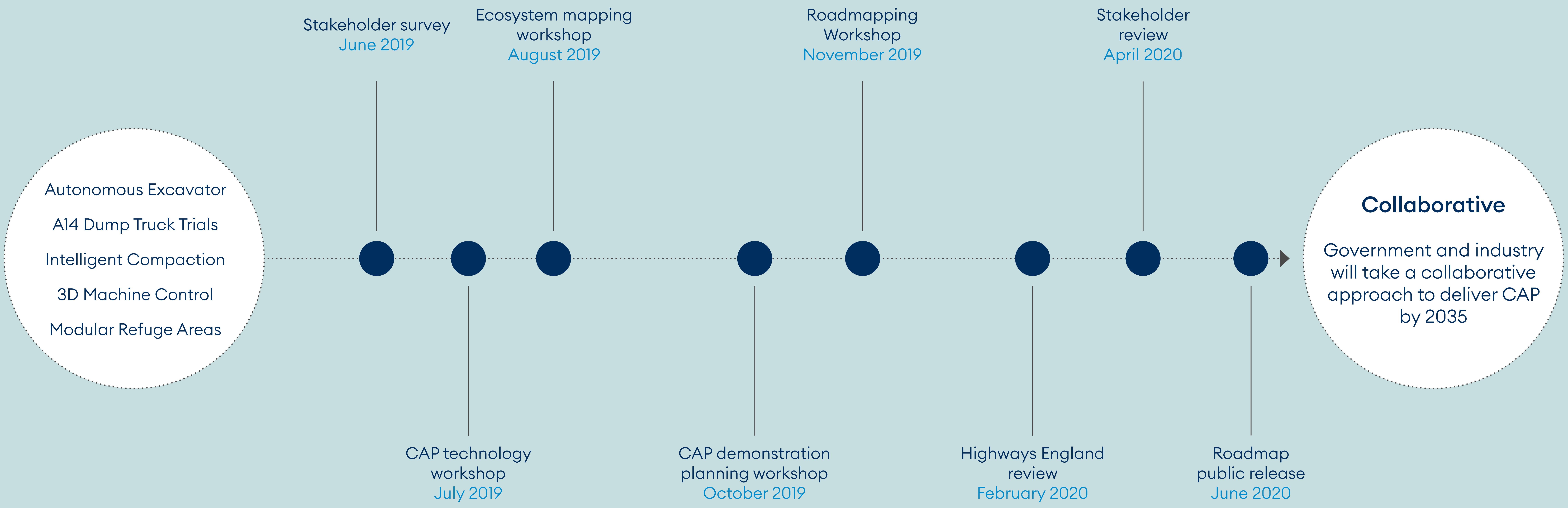
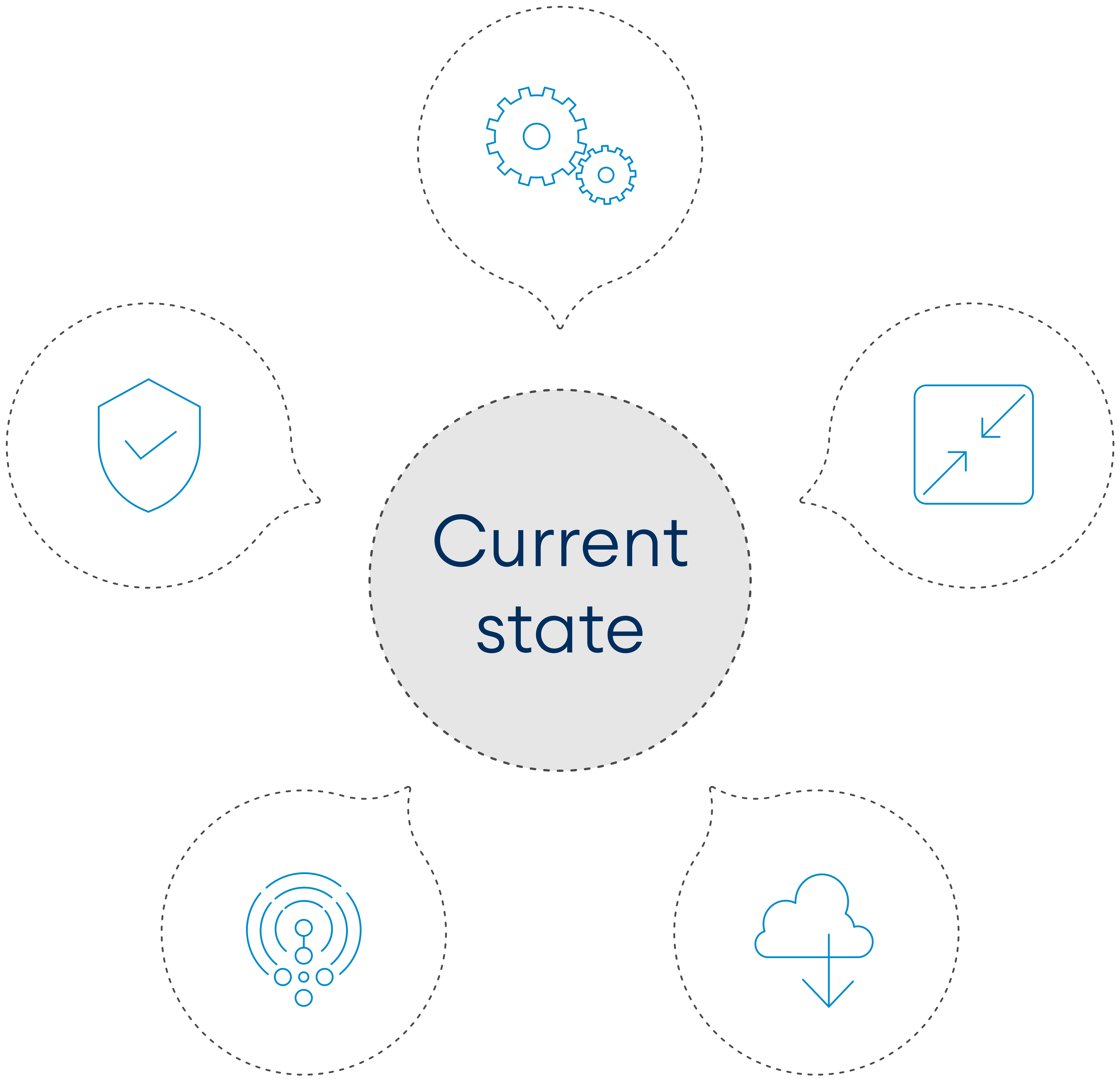
- Workstreams page 29
- Key milestones page 26



Timeline of the Roadmap development

Development of the Roadmap: Trends, drivers & themes



Safety

Improving the safety of construction is a key driving force for the industry. Substantial effort has been directed to this over the last 50 years. The safety record of the industry is plateauing. A step-change is needed to achieve further improvements.

Productivity

UK construction consistently holds the lowest recorded productivity within the economy. There has been no “digital revolution” in construction. Construction uses traditional methods which do not take full advantage of the technology available.

Reducing disruption

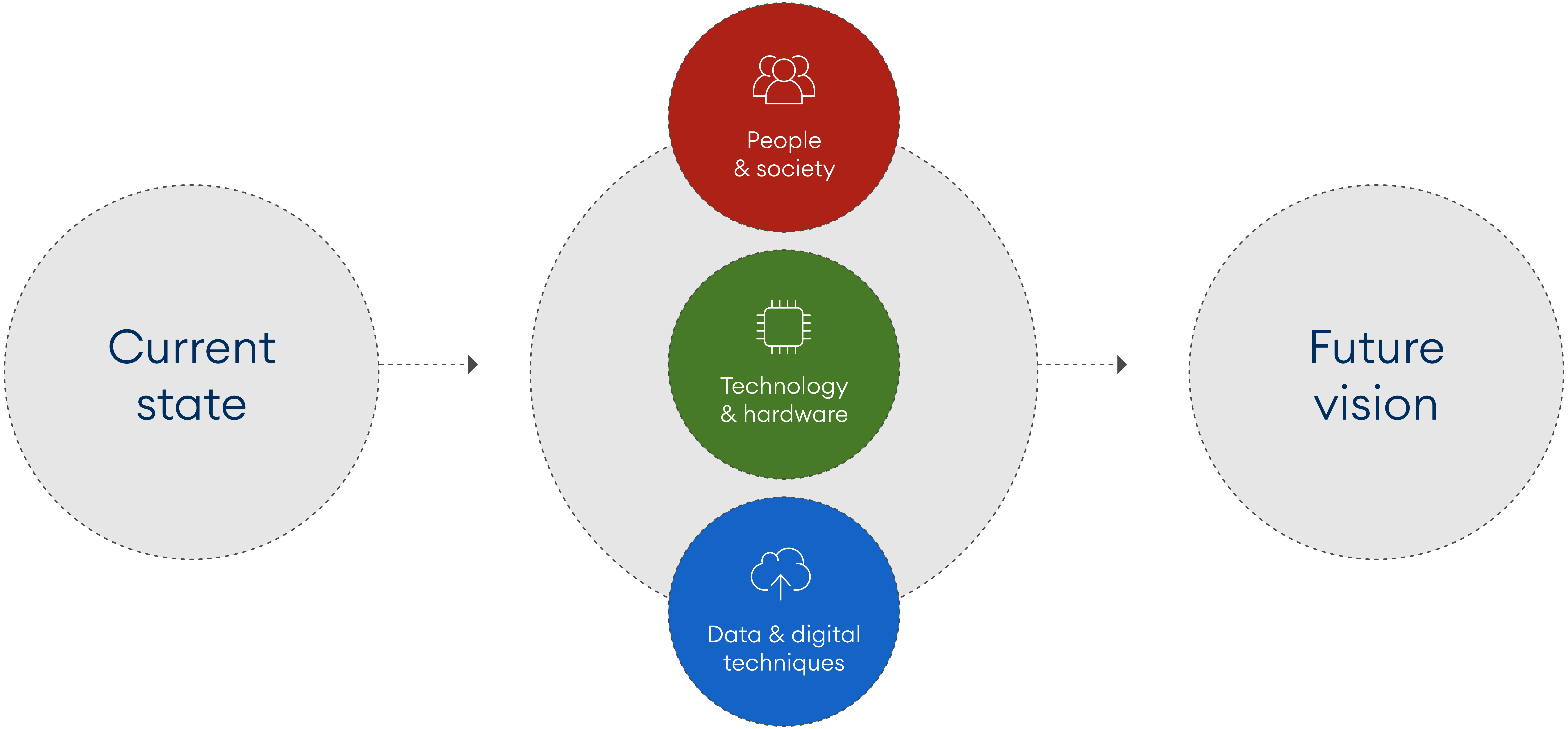
We need to reduce the impact of construction on the day-to-day lives of the UK public. Construction should be performed quietly, with minimum disruption, completed quickly, and right, first time.

Reducing CO2

There is a significant and urgent need to reduce the impact of construction on the environment, as a source of carbon emissions and a consumer of non-renewable resources.

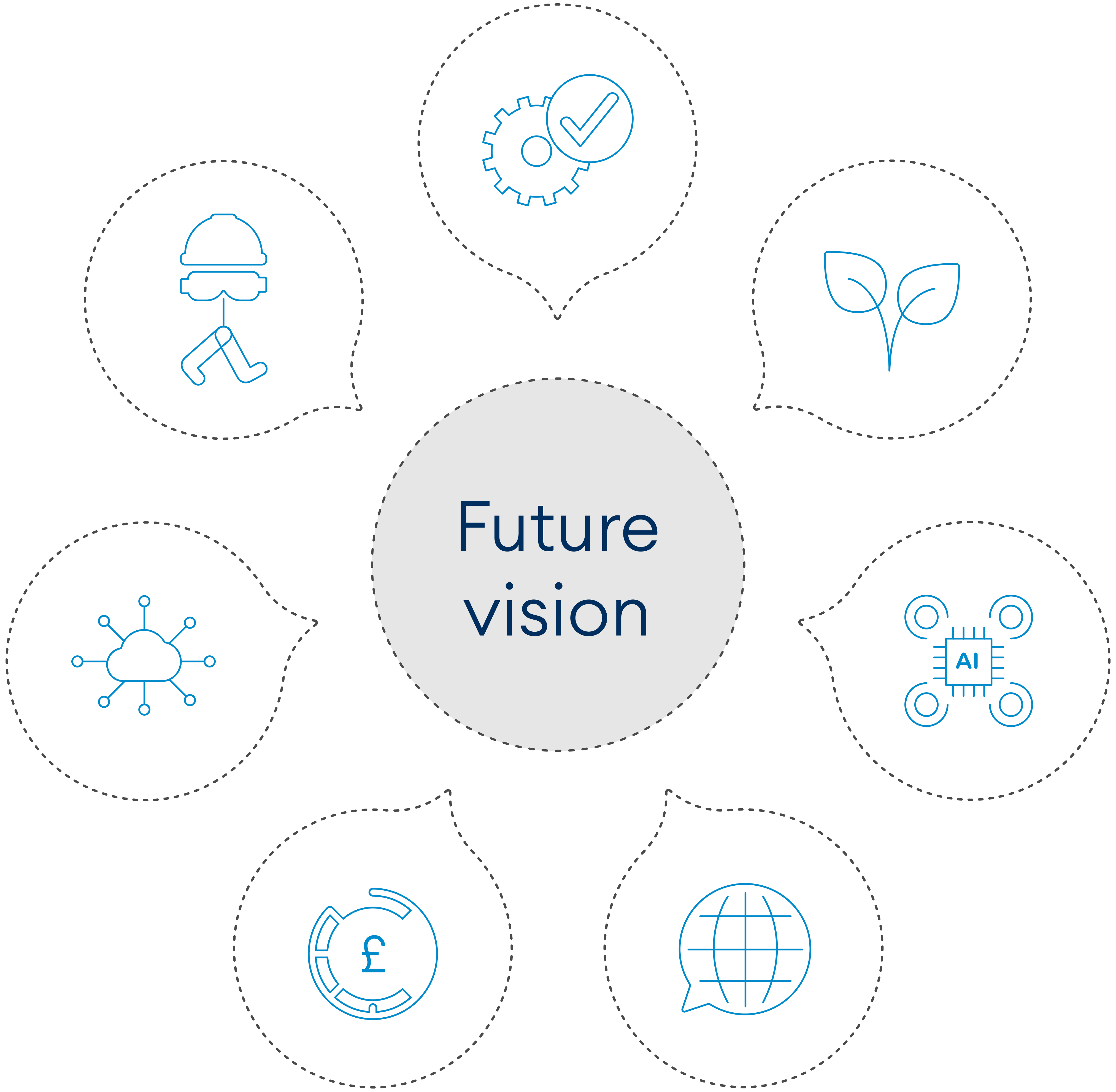
Societal impact

Automation and autonomy will bring about substantial changes to how our society and economy function, however there is uncertainty over the form and the magnitude of these changes.



Themes

The transition from the **current state** to the **future vision**, via these **key themes**, has driven the development and the content of the Roadmap



Safer people-plant interface

Remote control and hazard detection capabilities in the plant signicantly reduce the danger associated with proximity to heavy machinery, avoiding accidents.

CAP as industry standard

The use of autonomous equipment is the norm, further supported by remote control operation for tasks which are not suited to autonomous machine control.

Sustainable construction

CAP delivers a signicant reduction in the resources required for construction, and facilitates sustainable designs that could not have been delivered by humans.

Digitalised construction culture

Construction makes use of sophisticated digital techniques throughout the design, implementation, and maintenance phases. The culture recognises, and makes widespread use of, the benefits associated with digitisation.

The business, productivity, societal and environmental benefits of digitised construction strongly influence option analyses. Standards,contracts and legislation embrace digitisation and encourage the use of new techniques to deliver construction projects.

World leader in CAP training

The UK is recognised for it's world leading training and upskilling programmes that enable the widespread adoption and ongoing use of CAP throughout the industry.

Optimised whole life cycle costs

Increased build quality, coupled with intelligent asset information, enables optimal maintenance cycles to be designed, reducing the whole-life cost of construction.

Ubiquitous connectivity

Pervasive high bandwidth and low latency connectivity across the UK enables fully interconnected systems to be employed across construction sites.

The Roadmap

The strategic summary presents an overview of the Roadmap. For visualisation, some dates and durations have been shifted or truncated.

The Roadmap brings together nine workstreams across the three themes to be delivered in parallel through industry-wide collaboration.

The workstreams each focus on specific areas that stakeholders identified as key to the delivery of CAP:

Legislation, regulation and policy. Establishing the revisions to legislation and regulation that will facilitate the introduction of CAP. Putting the processes in place to enable providers to test, approve and certify CAP. Initiating changes to contractual processes to encourage use of autonomous technology.

Finance business and investment. Understanding where and how CAP will deliver benefits. Driving investment in the development of autonomous technology and cross-industry collaboration.

CAP training framework. Understanding the skills gap and how to fill it. Establishing the training, qualifications and social engagement required to deliver a skilled workforce.

Ubiquitous connectivity. Understanding the demands that CAP will place on communications systems, establishing solutions (including the required standards) and supporting the development and implementation of communication infrastructure.

Remote survey and operation. Developing the sensor and data delivery technologies to provide the data required for the creation of live as-built registers (digital twins.) Developing the technologies for the remote operation of plant.

Autonomous plant. Establishing levels of capability for autonomous plant in specific construction applications. Prioritising, implementing and delivering a technology (hardware) development programme.

Algorithms in autonomy. In harmony with the development of the plant, delivering the intelligent control systems that enable autonomous operation. Developing and implementing virtual validation capabilities for CAP.

Interoperable telemetry. Developing tools and standards to share and use telemetry data across plant, to provide plant with an understanding of its environment and to support autonomous and co-operative operation.

Common data platform. Establishing and populating the national asset registers that will support automated design and construction and developing the data-sharing mechanisms required.

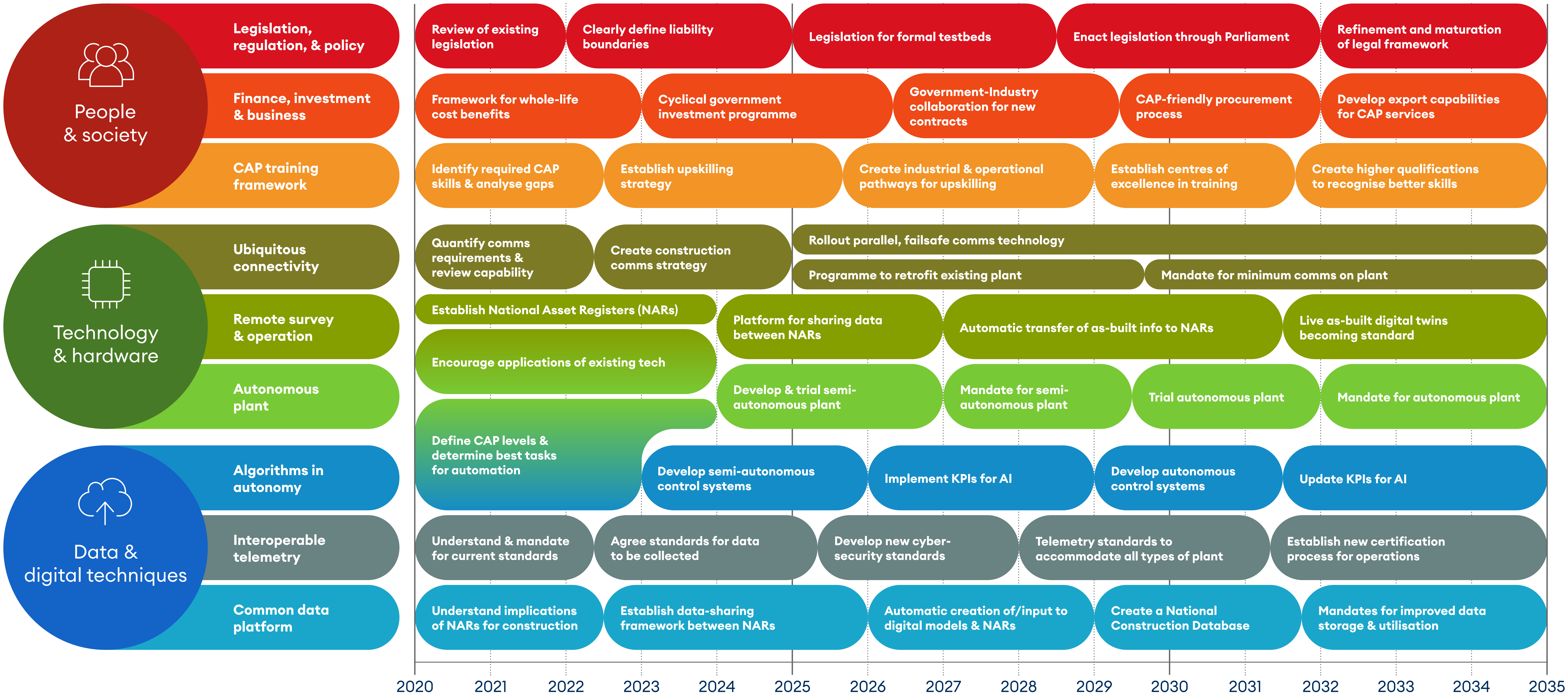
The Roadmap does not show a single path or route, due to the parallel and overlapping workstreams. Progression along the Roadmap will achieve milestones that mark turning-points or are enablers for the next stage. Example key milestones are shown on the following pages. Progress along the Roadmap will also deliver incremental benefits, as highlighted on the Milestone chart.

Detailed workstream-level Roadmaps are presented in the following sections. Activities within the workstreams that directly relate to the strategic summary are highlighted in each workstream.

The workstream Roadmaps have been produced to be relatively independent, to help organisations (including clients, governments and plant developers) understand the overall pathway to CAP adoption in the workstream, as relevant to their area. As a result, there are some duplications in the activities shown between the workstreams.

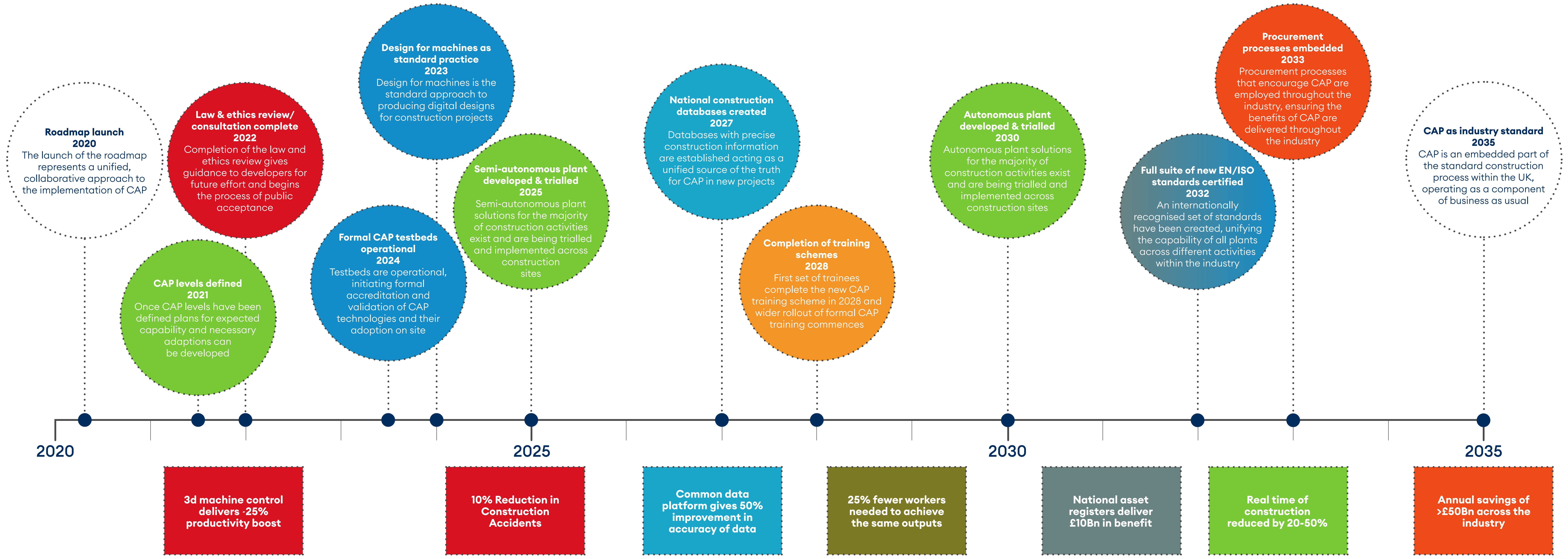
In combination with this report, an interactive roadmap has been developed. The interactive Roadmap shows more detail about the links between workstream activities.

Strategic summary



Key milestones

Each milestone marks a turning point in the Roadmap, or the establishment of a key enabler that unlocks the next stage



Delivering the vision

The need for collaboration

The Roadmap shows many activities that would be undertaken in parallel across the nine workstreams to deliver the 2035 vision.

The Roadmap does not define a single path or route for individuals - it would not be appropriate for an individual organisation to take forward and attempt to deliver the Roadmap.

Some stakeholders will be in a stronger position to influence specific Roadmap activities. For example, activities in the legislation and policy workstream are likely to be areas in which government bodies have greater influence than manufacturers.

However, the activities delivered in the legislation and policy workstream will provide enablers, such as the testbeds, on which other workstreams (such as Autonomous Plant) will draw.

The many stakeholders in the construction community - including government (including the DfT), clients and owners (including Highways England, HS2, Network Rail), construction providers, plant manufacturers, contractors and academia will all make a contribution to the delivery of each Roadmap activity.

Actions

With the Roadmap in place, the first action should be to facilitate collaboration. Enterprise and innovation incubator i3P is in a strong position to provide direction. By bringing the community together, i3P can establish agreement on the key stakeholders that should influence and lead each activity. This would be the first stage in stimulating action along each workstream. A workstream programme for each stakeholder could be developed, drawing on the activities proposed in the Roadmap.

What would this mean for stakeholders?

i3P: Bring the industry together to collaborate to deliver the vision. Establish the Roadmap as a living document. Confirm the key milestones and timetable. Achieve agreement on the activities to commence now, and establish collaborative investment.

Government and standards/legislative bodies:

Define the levels for CAP capability, to guide the focus of R&D and hence establish R&D programmes (such as EPSRC and IUK – part-funded by industry as appropriate.) Support relevant bodies to establish legal and standards frameworks to enable CAP to thrive.

Infrastructure owner/client bodies:

Support the delivery of the enablers that will help the industry to deliver CAP. This would include developing and delivering testbeds and setting CAP performance requirements. Determine the business models and contractual changes required to encourage providers to use CAP.

For manufacturers:

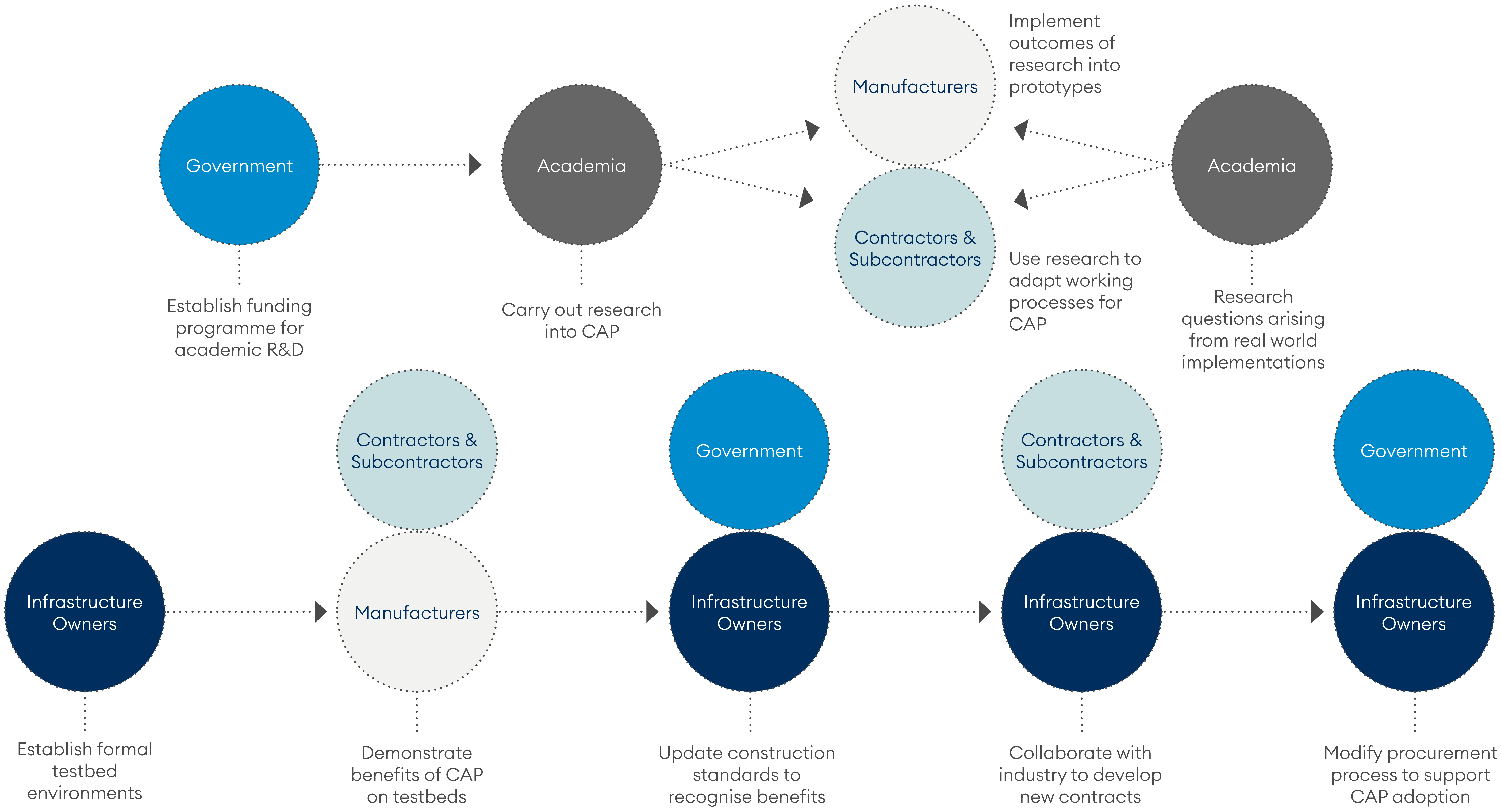
Invest internally and with SMEs and academia in the collaborative development of technology. Support the development of interoperable standards and training solutions.

For contractors:

Advise, support and assist clients in the delivery of the changes required. Participate in upskilling strategies and communicate best practice across the industry.

Only via cross-sector collaboration will timely and efficient and progress be made to deliver the Roadmap vision by 2035.

Collaborative delivery of activities - examples



The Workstreams

Notes on the workstreams

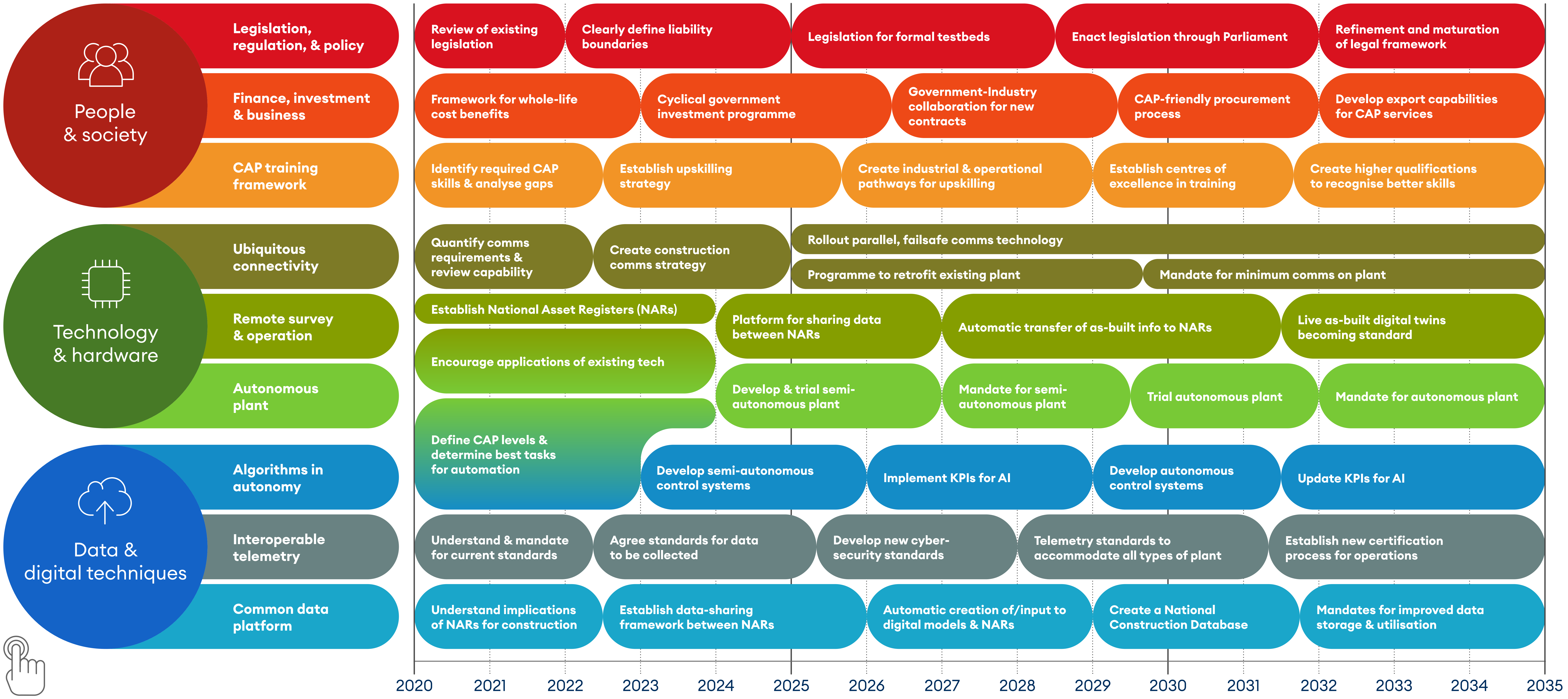
- Each workstream has been designed to be viewed independently. Hence some repetition of activities occurs across the workstreams. There are minor variations in timetables due the particular layout of each workstream plan.
- Activities shown with an outline are linked to those shown in the strategic summary.
- The start dates and duration of activities used are indicative of when substantial effort across the industry is expected to be undertaken. It is recognised that organisations will begin implementing some aspects of the activities shown before and after the indicated time.
- Where phrases such as “establish a new” or “create” are used they can be interpreted to mean both the formation of a new group/technology/standard or an expansion in responsibility of an existing group or a reapplication of an existing product.
- Details on the benefits given as examples can befound in the case.

Key

The **blue outline** indicates that the item is in the strategic summary as well as the detailed Roadmap

Indicates interactive elements on the page

Strategic summary



People & society: Legislation, regulation, & policy

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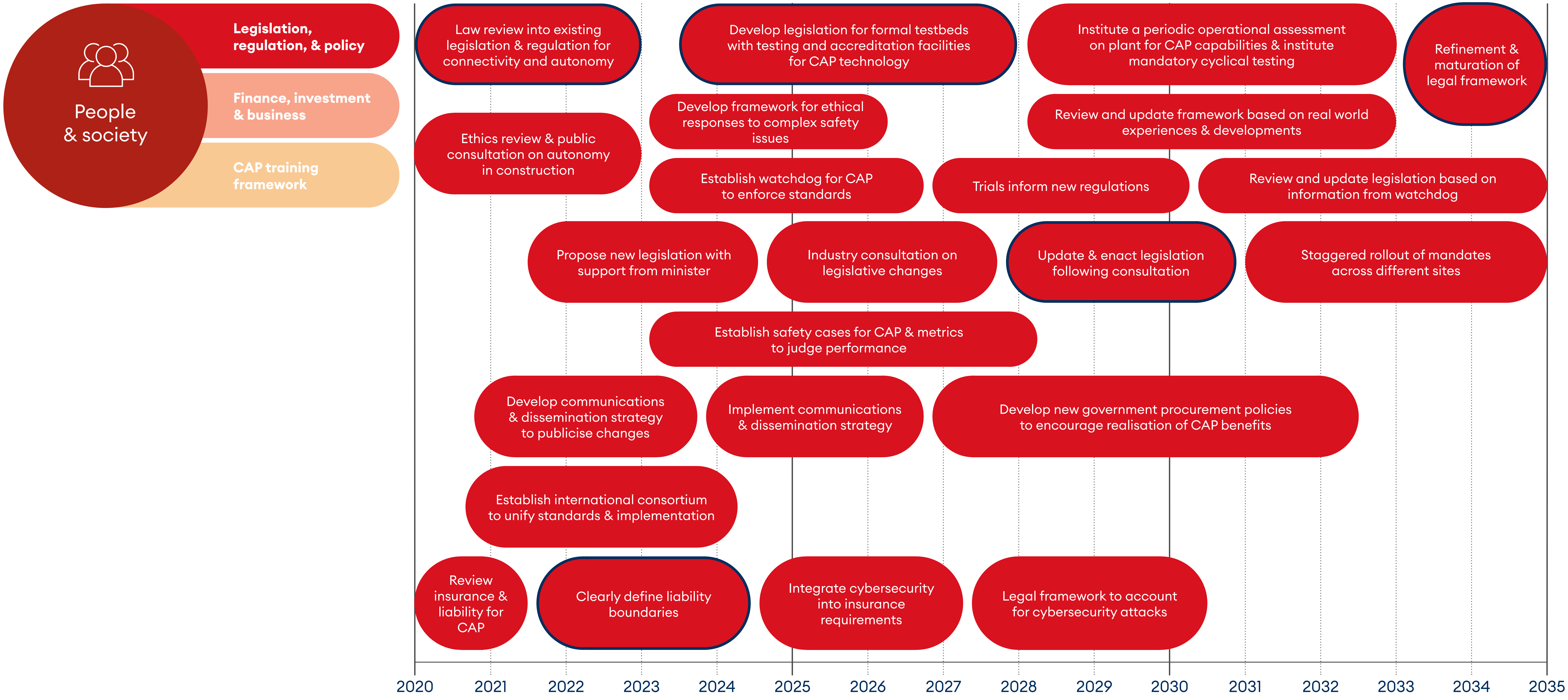

People & society: Legislation, regulation, & policy

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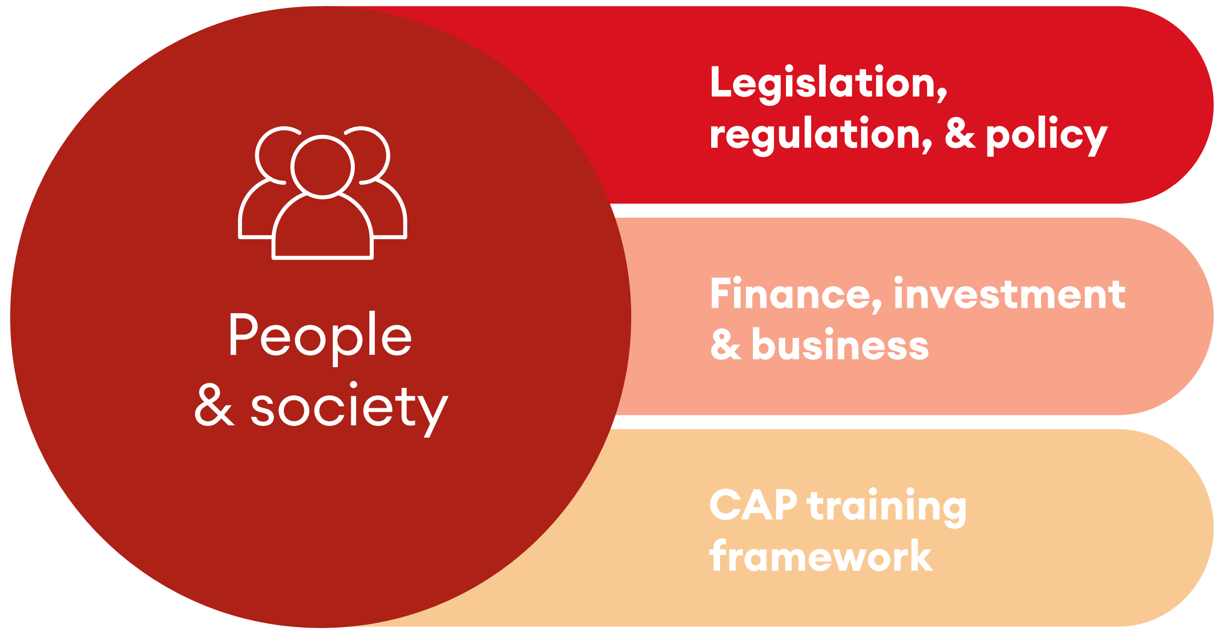


Outcomes

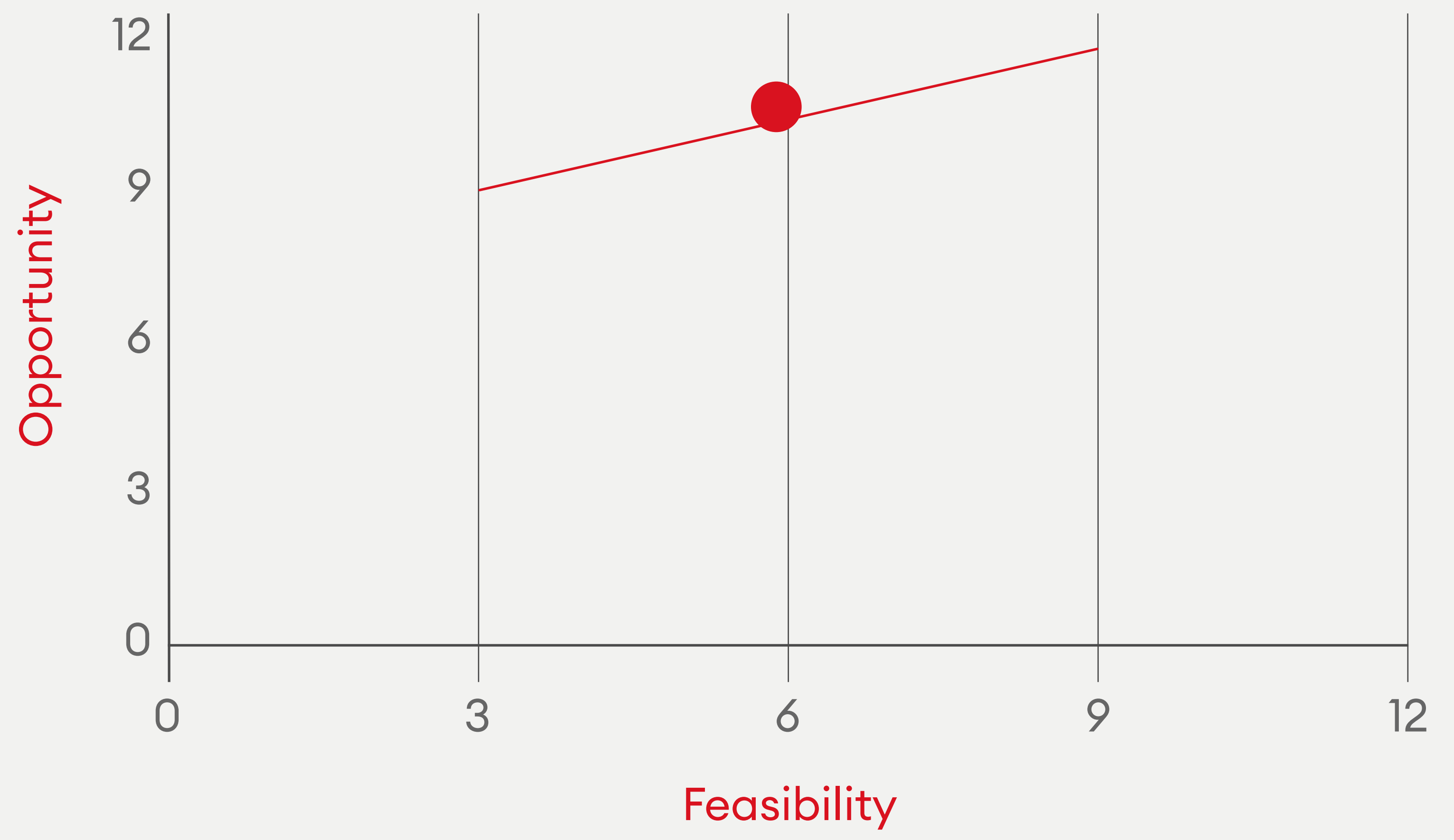
In the initial stages, the Roadmap will provide a legal and policy framework upon which later technical and commercial strategies can build. A process of review and consultation across the CAP ecosystem will establish an understanding of the legal and ethical implications. There will be a need to consider the international implications across the sector. Communication with stakeholders, including industry and the public, will be needed to support acceptance and adoption.

As legal and policy questions are resolved and recognition of CAP matures, opportunities will arise to encourage the application of CAP in construction. The development of procurement policies that facilitate or even mandate the use of specific types of CAP will further accelerate development and take-up. This will be supported by the emerging availability of national test beds, equipment trials, standards and certification.

The establishment of a mature legal framework (supported by a watchdog and standards committees) and CAP being mandated in many areas of construction will combine to further accelerate adoption.

CAP could deliver a **37%** reduction in the number of fatalities within the construction sector.

Opportunity & feasibility



The opportunity-feasibility line suggests there is confidence that this stream will have a potentially high impact, but it will be challenging to implement. It has the capacity to improve safety across the industry, to positively affect the associated whole-lifecycle costs of construction and to support the digital transformation of the industry. It can be readily adopted across a wide range of construction activities.

The legislation and policy stream is key for the overall success of CAP. Initial effort should focus on improving the perceived and actual feasibility of the programme to support its future goals. In particular, there is substantial uncertainty about how difficult it will be to convert existing technology to match new standards or legislation, and how procurement policies can be changed to require compliance with latest specifications. It was felt that the alignment of CAP with existing government strategy was unclear.

People & society: Finance, investment, & business

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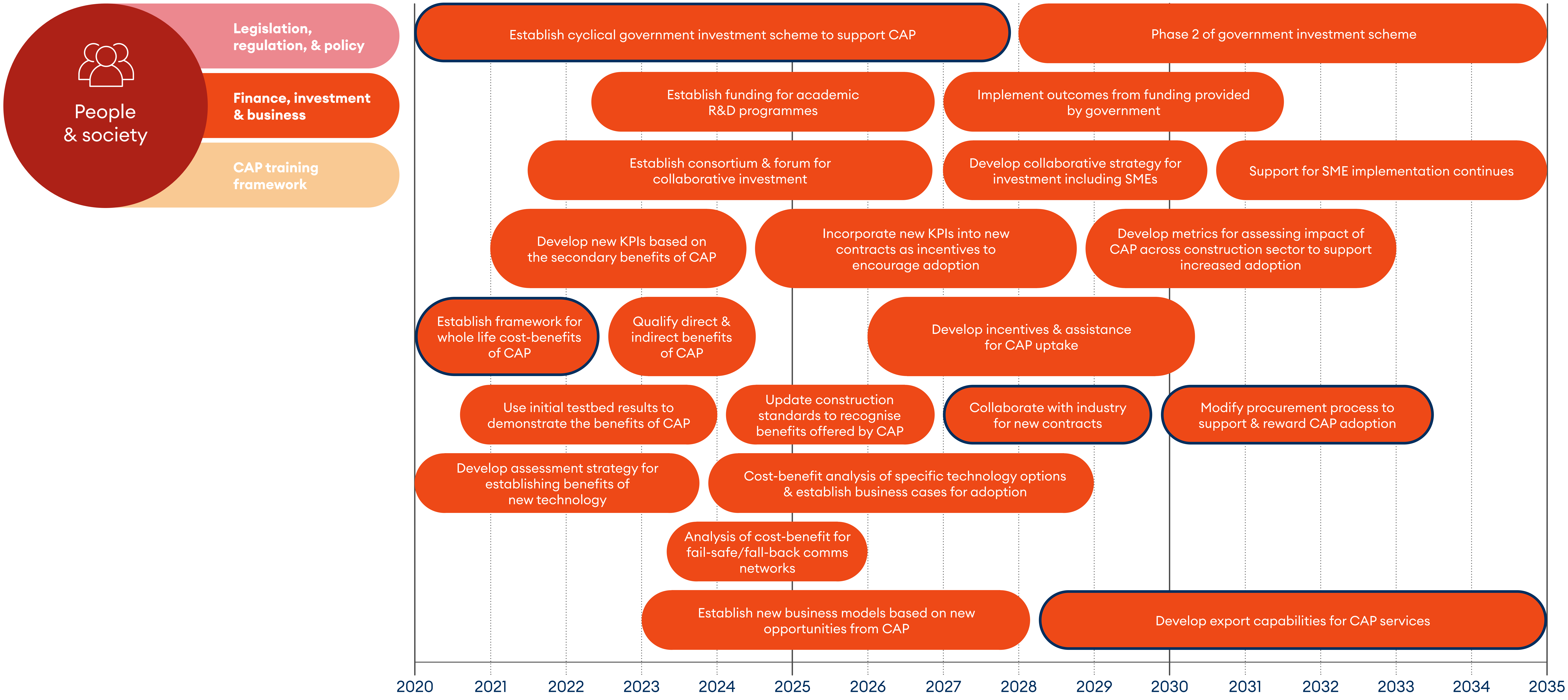

People & society: Finance, investment, & business

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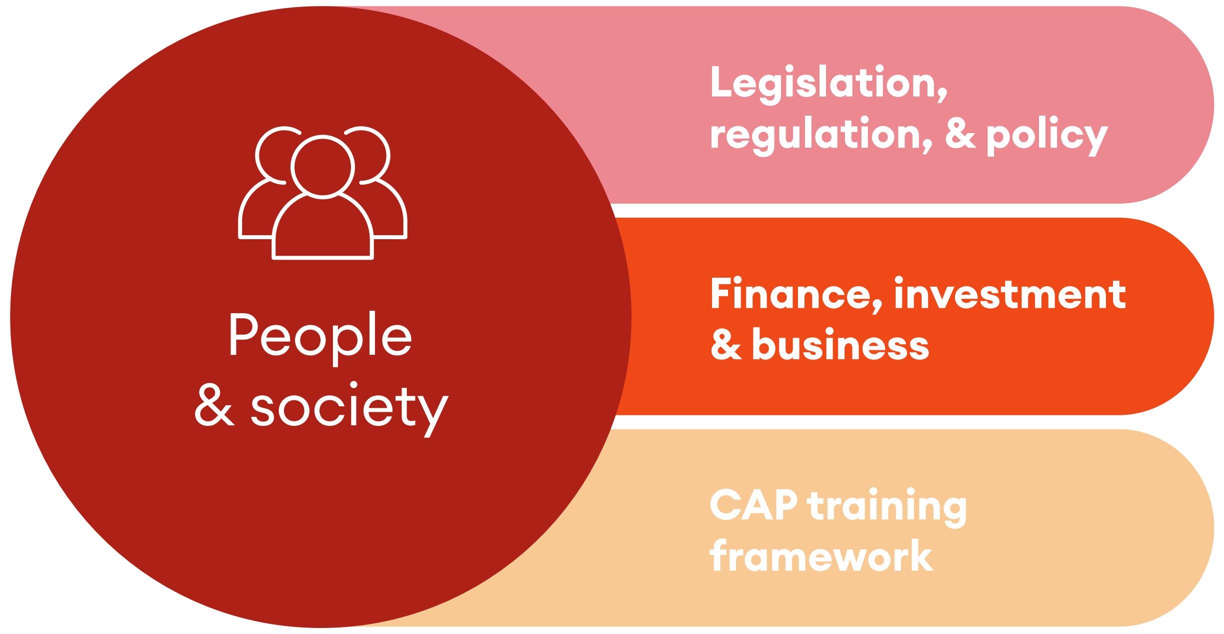


Outcomes

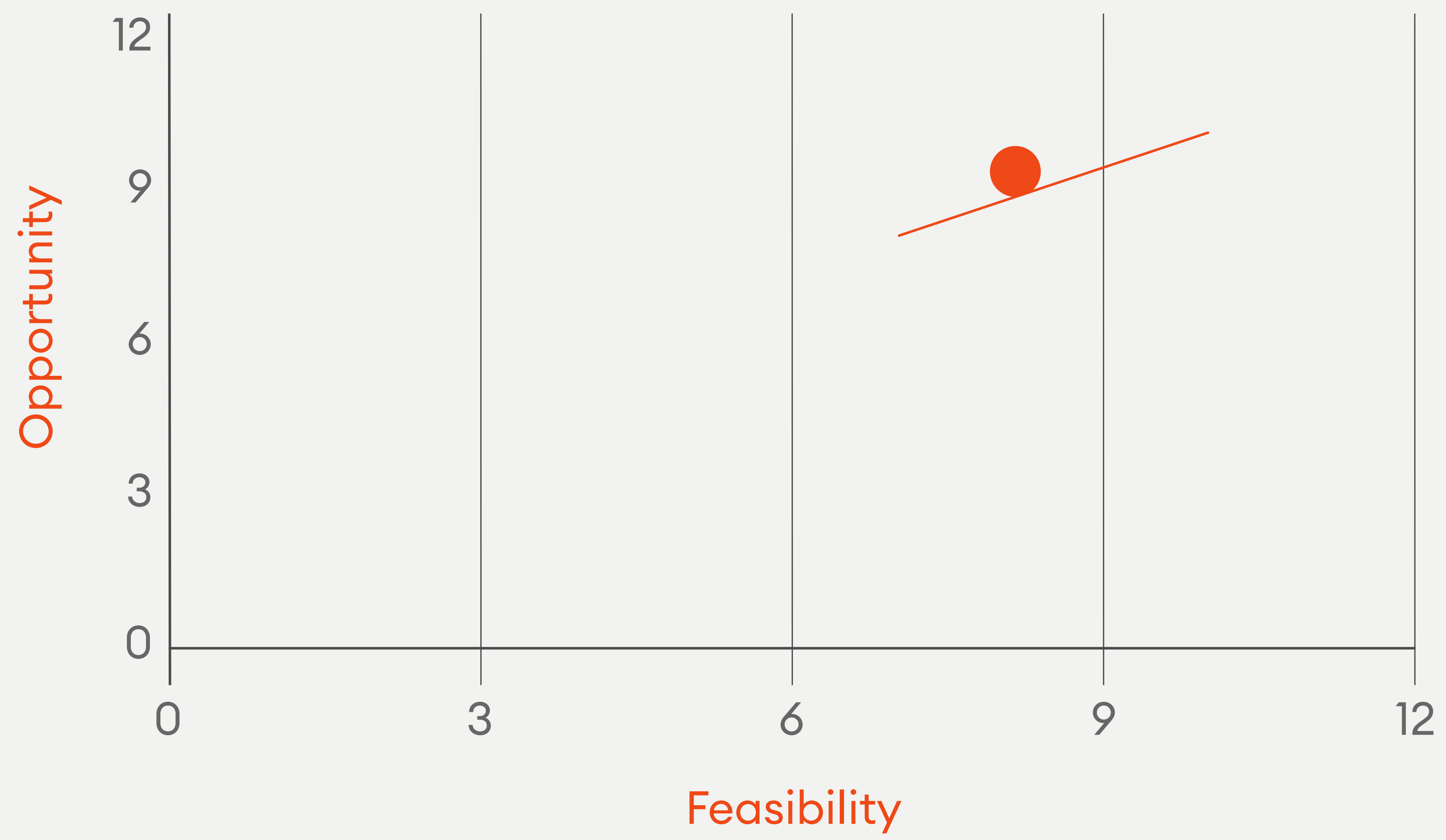
The early objectives of this stream will bring clarity to the industry about the financial and business benefits of automation. This will be important to support progress in other streams. Collaboration across industries will help reveal the benefits to safety, efficiency and the environment. This will support the development of commercial incentives. Establishing a long-term, staged funding programme provided from central sources will stimulate development of all areas of CAP within academia, SMEs and larger industry stakeholders.

Experience, test bed demonstrations and investment in SMEs and academia will establish further business cases. Performance indicators will enable the benefits to be tracked, to provide an objective understanding of the benefits to safety, efficiency the environment and in other key areas. This will support the development of contractual incentives for implementing CAP.

As stimulation funding programmes mature, the publication and implementation of research and development outcomes will support adoption of new techniques across the industry. Export opportunities will grow, facilitated by international collaboration. and the establishment of international standards.

Annual savings of **£53Bn** are possible through CAP across new construction work.

Opportunity & feasibility



The opportunity and feasibility chart applies to only one component of this stream: the development of new business cases for CAP. These represent a significant opportunity for creating value. There is potential to deliver substantial reductions in whole-life costs, which can be adopted across the majority of the industry. New KPIs could incentivise reduction in the number of casualties and reinforce changes to construction.

The development of new business cases for CAP is an achievable goal, as existing technology already offers the potential for different approaches that support industrial and governmental strategy.

However, it will be challenging to implement them, as it is likely that some changes to existing legislation and standards will be needed to accommodate the new models. There is also a risk that new business models will be more complex than existing ones, requiring more oversight and management to implement.

People & society: CAP training framework

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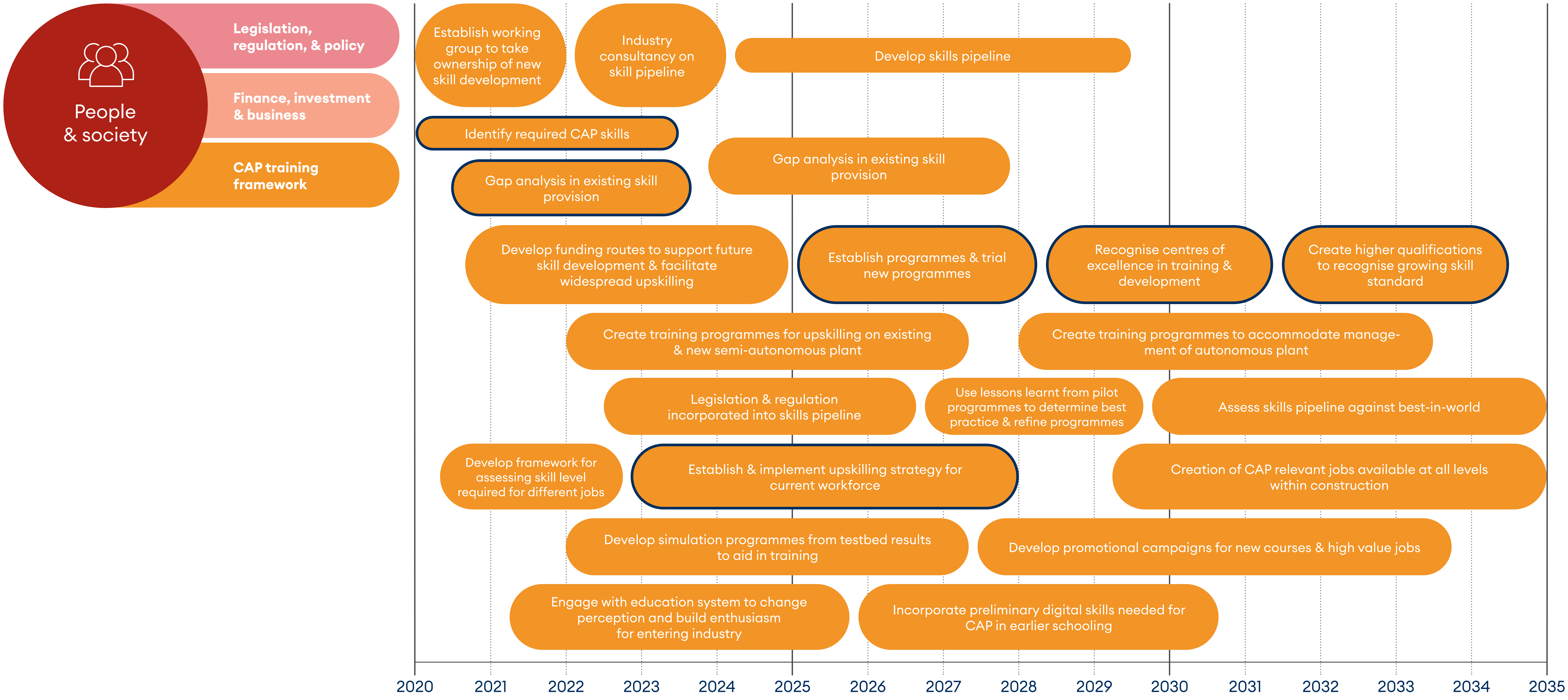

People & society: CAP training framework

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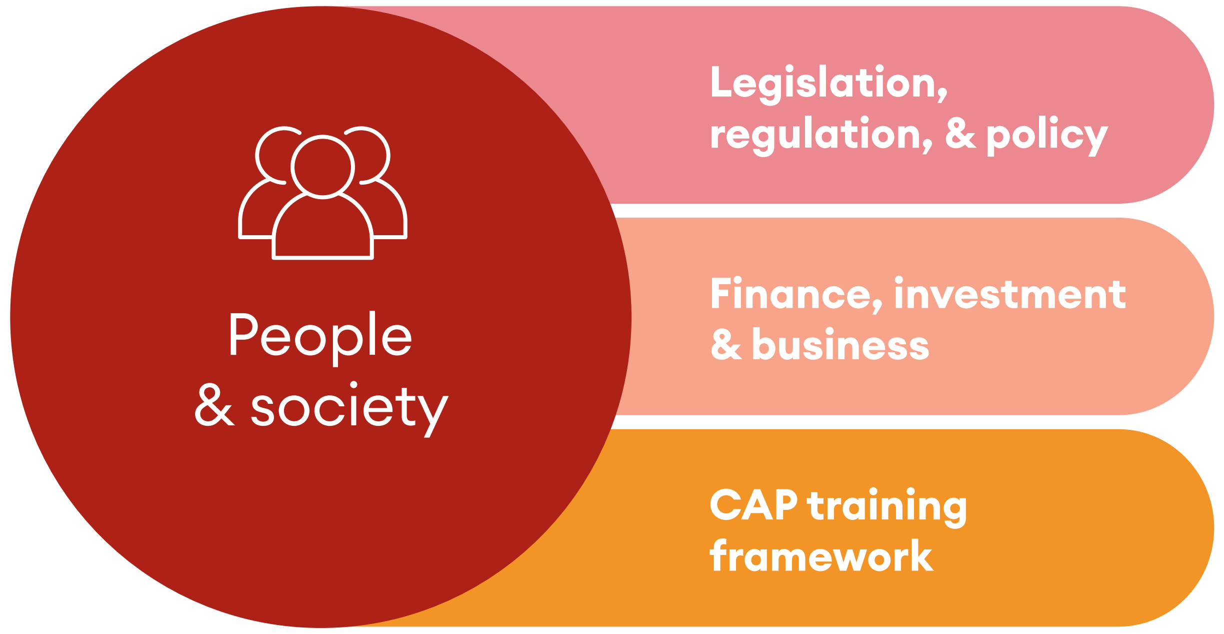


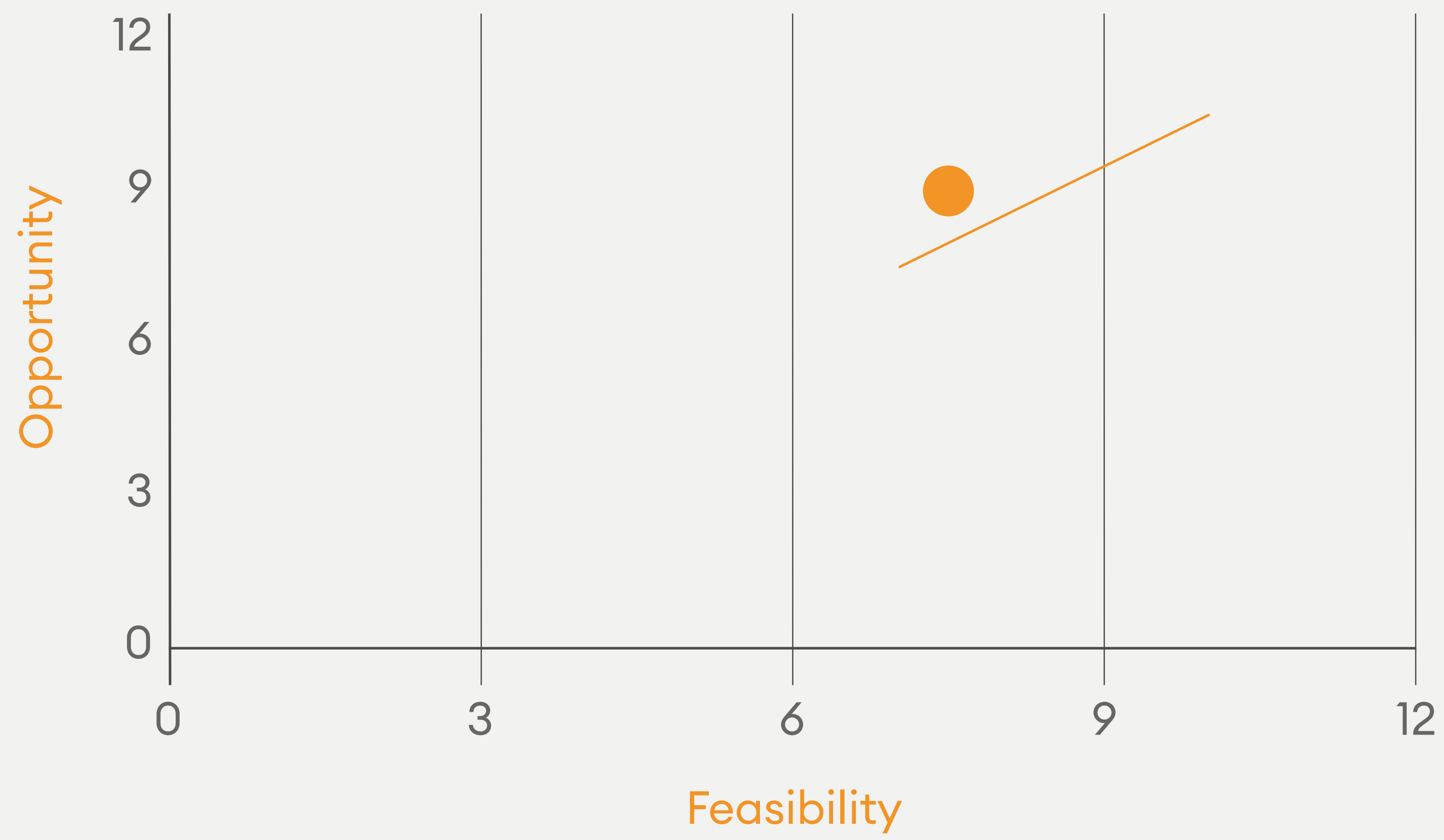
Outcomes

Through a collaborative partnership between industry, education providers and sector bodies, we will fully understand the new skills requirements for CAP and the strengths, weakness, gaps and opportunities of our workforce. We will have established a robust upskilling strategy to address them. Funding sources will be in place to support training and skills development, encouraging academic, practical and vocational training to be established.

As training becomes more widespread, formal skills and qualifications will be established. Take-up will be encouraged via promotional campaigns and the emergence of careers and high value employment associated with CAP. The UK would become a recognised centre of excellence in this field, with a wide and sought-after skills base in the field of automation in construction. It would offer internationally recognised qualifications and roles at all levels.

Autonomous technology can assist with **47%** of construction activities currently performed.

Opportunity & feasibility



The establishment of a new training framework for CAP is a high value, achievable stream - the first steps can readily be taken. A new skills framework will facilitate changes to construction activities, creating a reduction in the number of casualties. The new training framework will be developed across all construction activities.

There may be uncertainty about the economic impact of CAP training, as the courses may be expensive and the increase in skill levels may escalate wage costs. Investigating the cost-benefit of different schemes will be required to reduce this uncertainty.

The development of new training schemes can be based on current standards and legislation, with updates delivered throughout the Roadmap. Indeed, feedback from the schemes can be incorporated into future strategy, influencing the chosen direction. There are questions about how difficult it will be to upskill existing workers, and it's not certain when the technology to enable more advanced training will be available.

Technology & hardware: Ubiquitous connectivity

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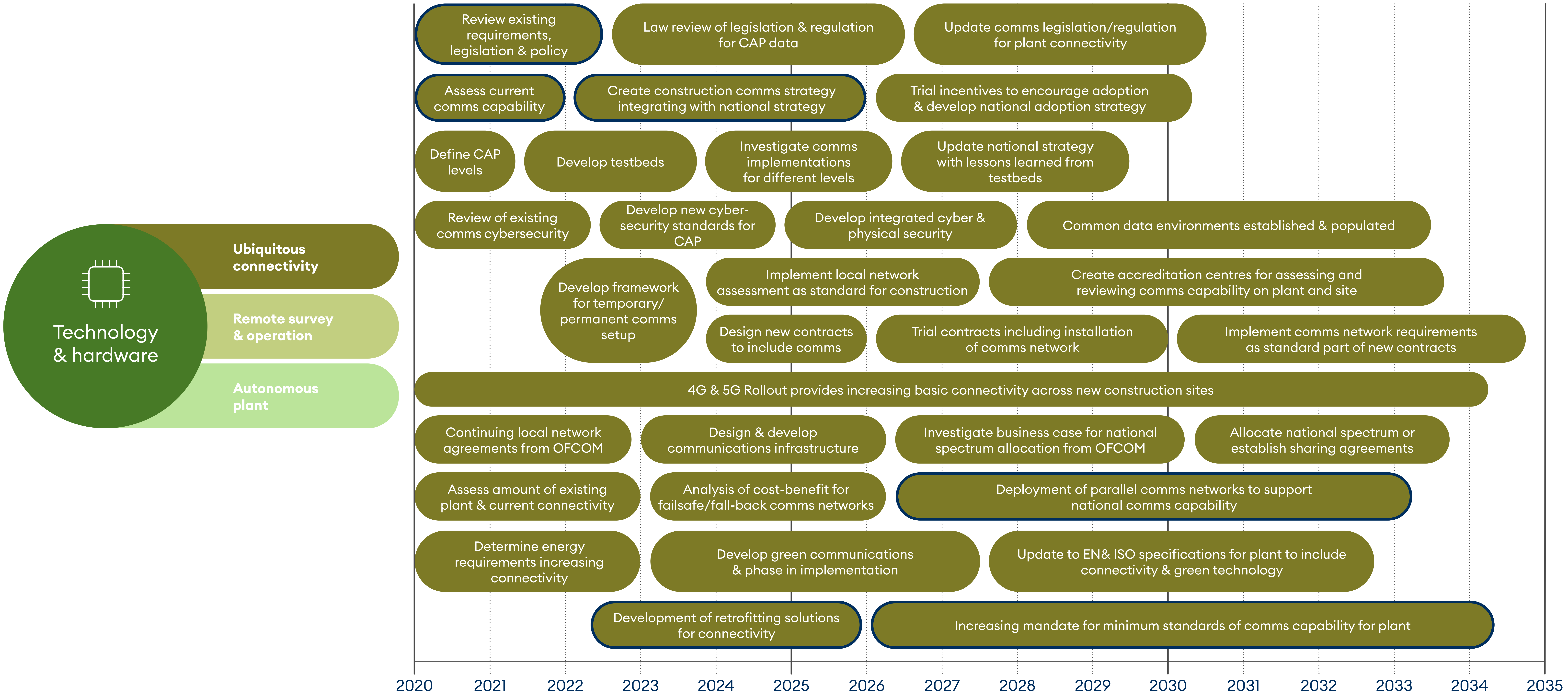

Technology & hardware: Ubiquitous connectivity

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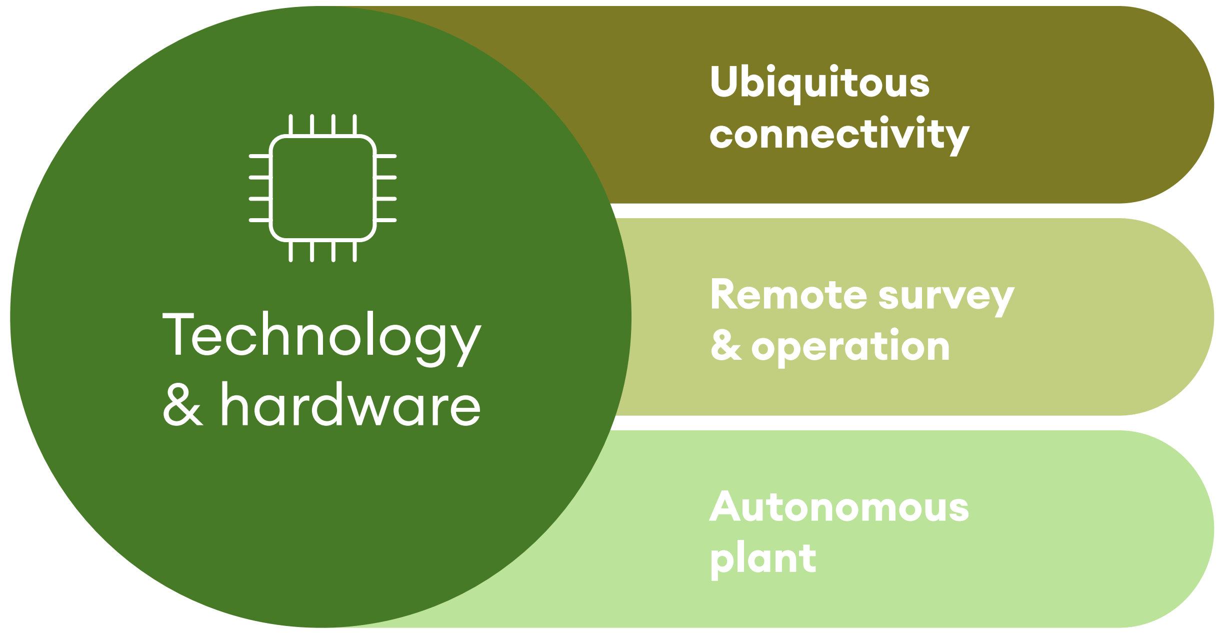


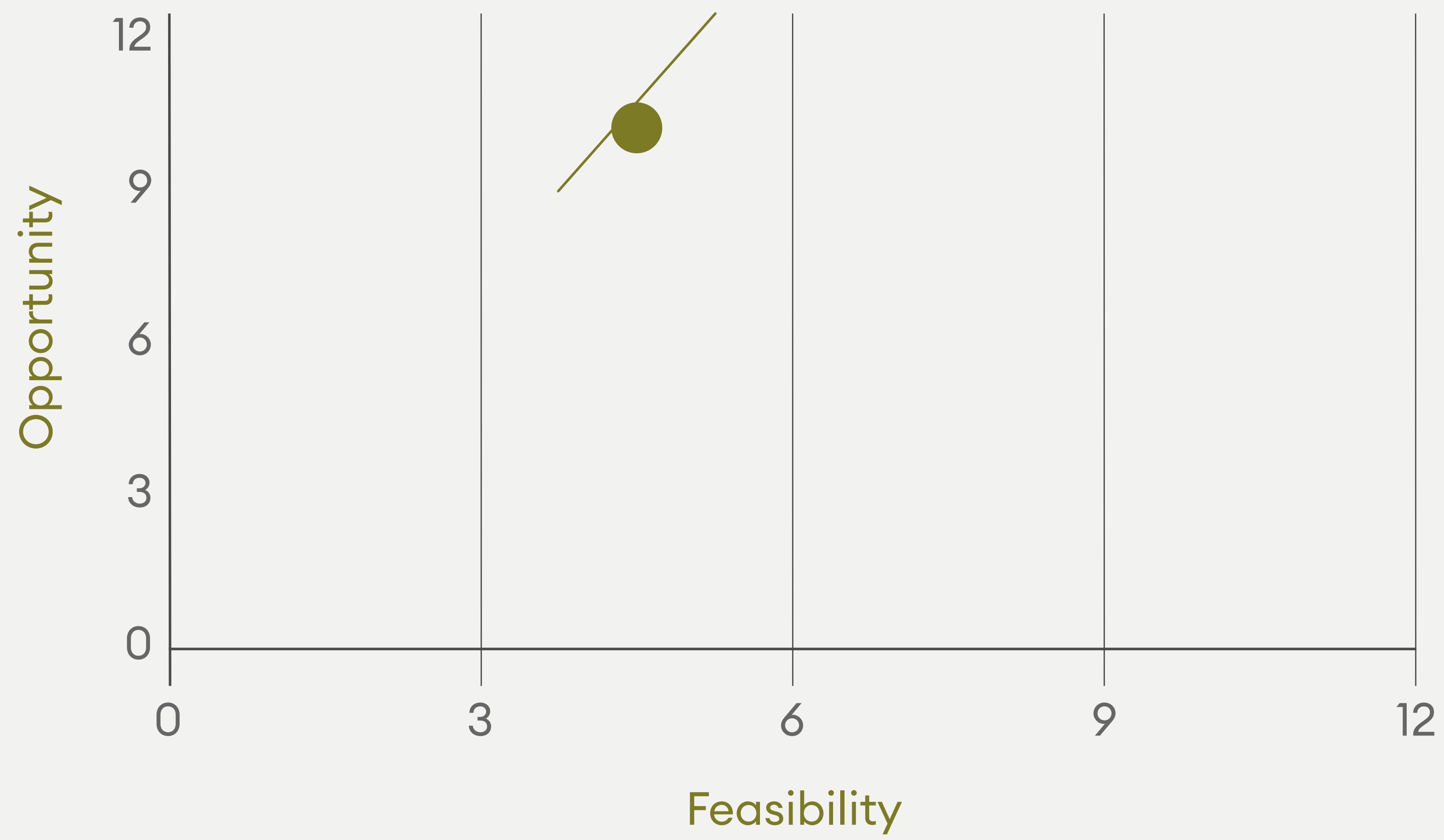
Outcomes

The establishment of robust, ubiquitous communications capability at construction sites will be an essential pillar of CAP. This will begin with defining the current and emerging communication requirements and how existing approaches can deliver these. A programme of retrofitting will accelerate implementation within existing plant.

To complement the development of technical requirements, a review of the implications for legislation and regulation will support the development of standards for connectivity. This will address the cybersecurity issues that must be overcome to achieve robust and secure remote control or autonomous operation. Ultimately, this will deliver EN/ISO specifications for communications. This work will be undertaken in context of the ongoing rollout of 4G and 5G across the country. Local network connectivity is already being established: there could also be a requirement to dedicate part of the transmission spectrum to CAP or to exploit space within evolving windows to accommodate this activity (such as CAV/CAM)

In the longer term, plant will routinely use such connectivity to achieve autonomous or remote operation. Having undertaken a programme of testing to understand the practical, commercial and contractual implications, construction contracts will require deployment of communication technologies.

Opportunity & feasibility



The development of sufficient UK-wide connectivity to enable CAP (and other connected technologies) is a high value proposition – but it is a dependency for the implementation of many of the other streams. It has the capacity to deliver changes to the majority of construction techniques, support the reduction of casualties and reduce the whole-life cost of construction

In contrast to its high potential value, the stream is considered to have low feasibility, despite aligning with government strategy. There were concerns regarding the availability of the necessary technologies, the difficulty in upskilling the workforce to make use of it and in converting existing equipment. Implementation will require an overhaul of existing standards with associated risks.

As this stream is of crucial importance, the initial steps on the Roadmap aimed to establish a common approach to improve the feasibility of implementation.

Technology & hardware: Remote survey & operation

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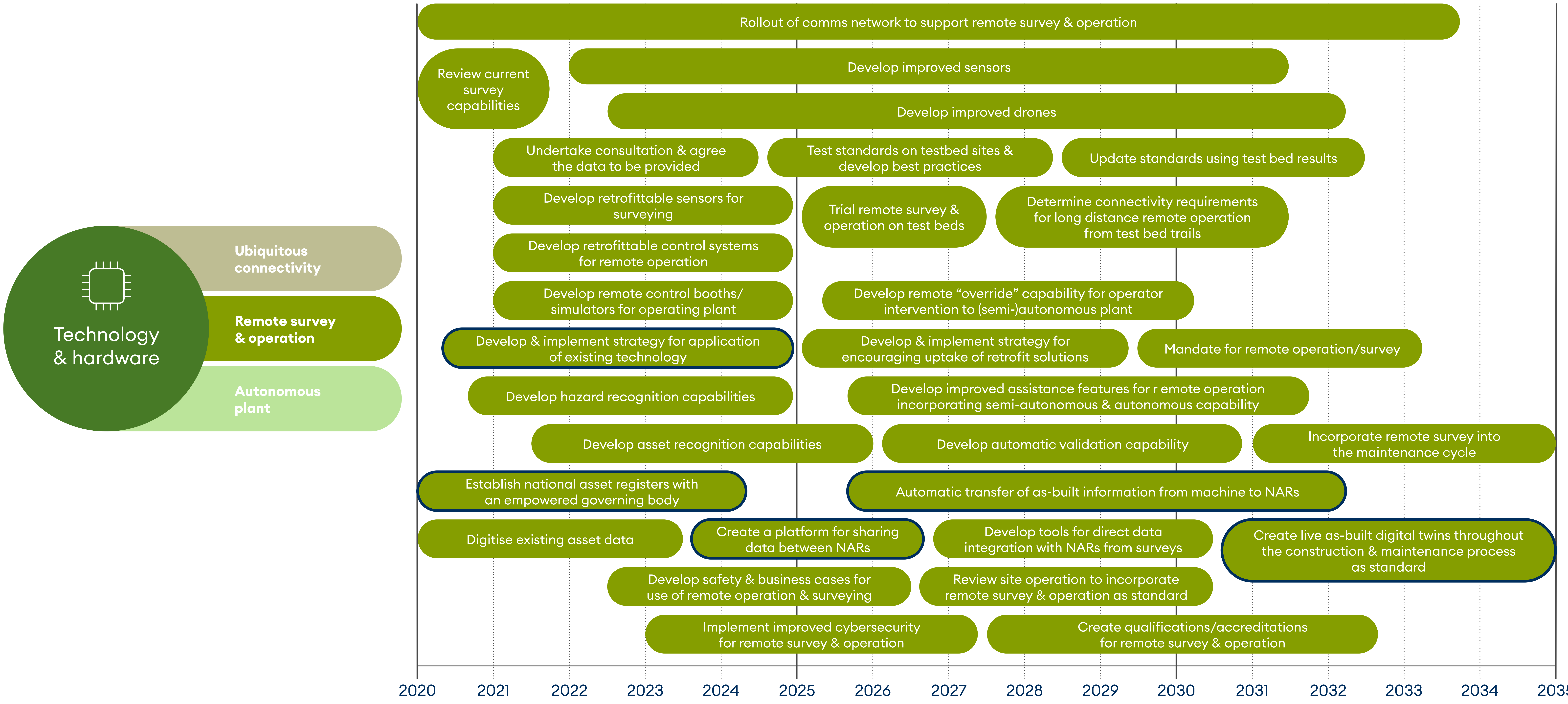

Technology & hardware: Remote survey & operation

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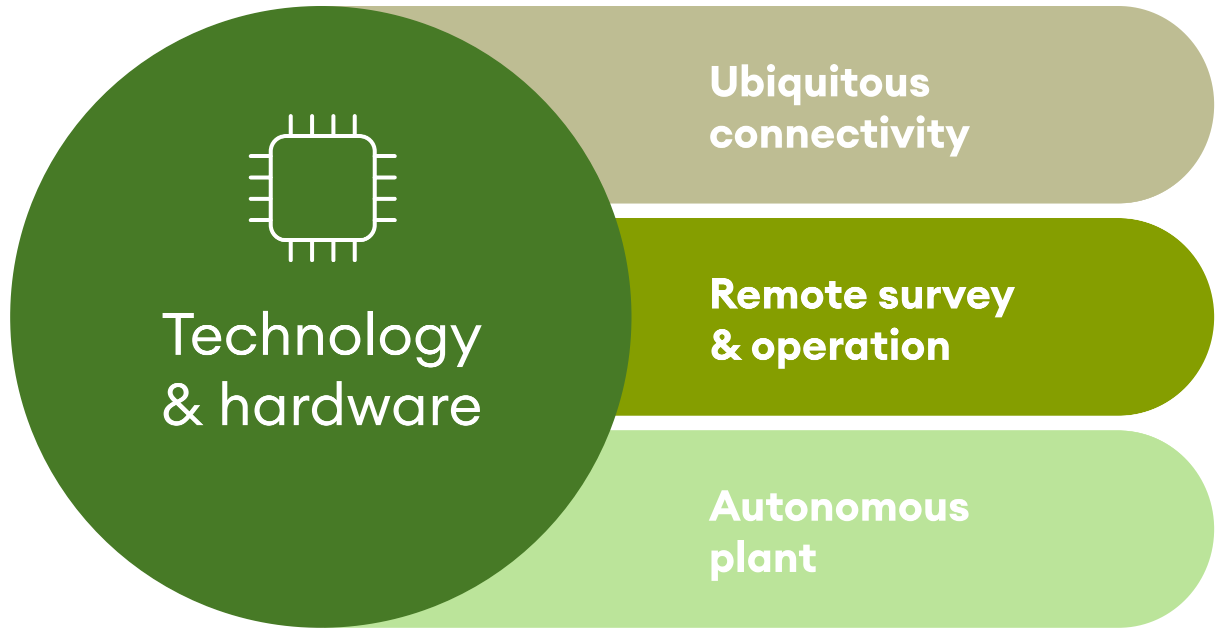


Outcomes

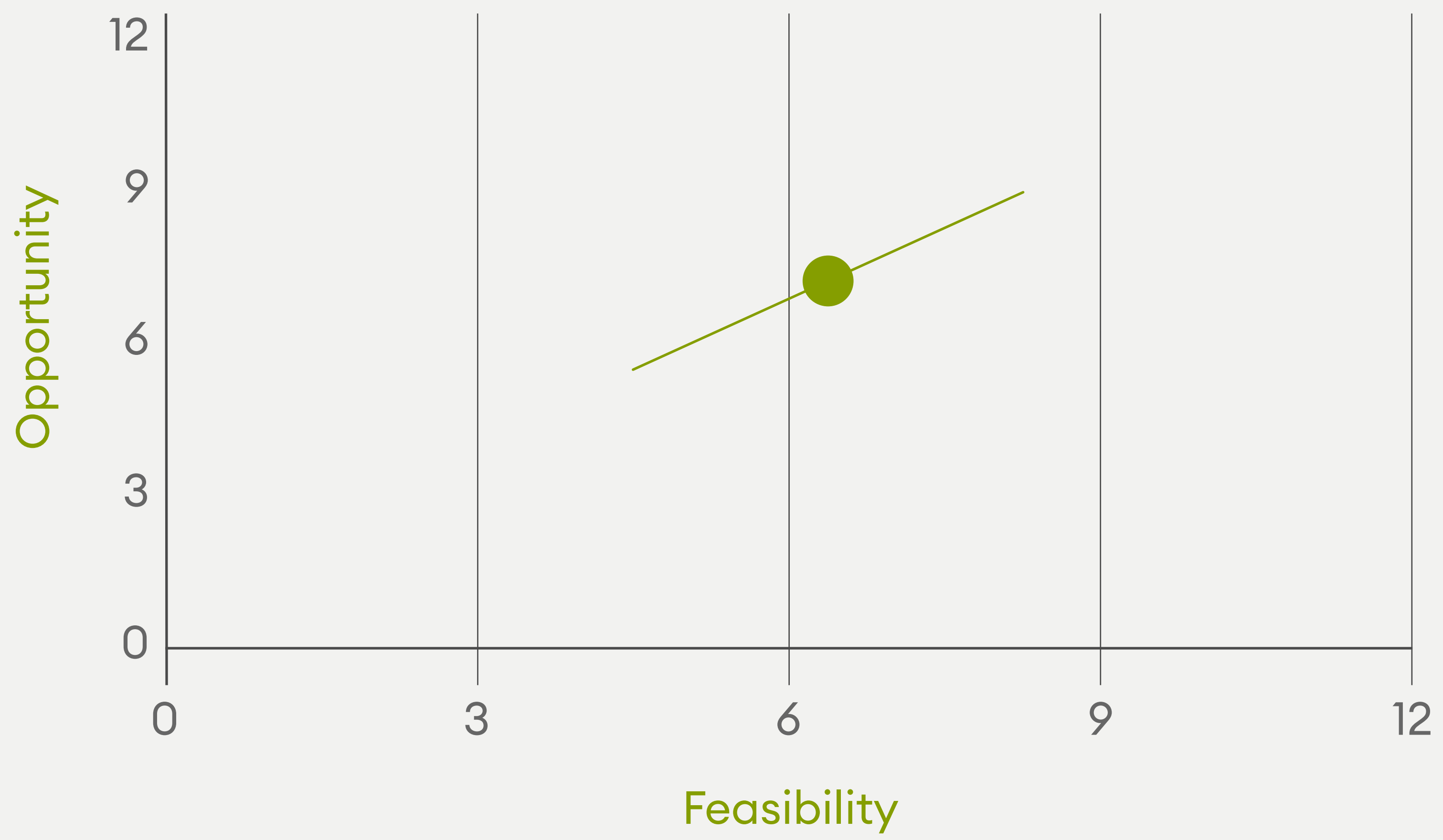
This stream will support the development of the technology required to minimise human involvement in designing and monitoring the evolution of construction sites. Site operations should ultimately automatically monitor and measure progress, so that as-built data is created in real time to support real-time updates to the (automated) design process.

Remote surveys will initially be carried out using dedicated survey systems, and later by using the construction plant itself. This will be linked to the development of improved sensing systems, exploiting communications technologies delivered in other workstreams. Developing automation in the recognition of assets will accelerate the ability to convert sensor data into digital twins. The creation of as-built data in real time will support updates to the (automated) design. This will also support wider introduction of remote plant operation.

Simulation tools will overcome the human-machine interface challenges, leading to the introduction of remote control for basic activities. These will become more advanced as semi-autonomous algorithms are provided to assist the operator.

Design through the rapid engineering model can improve productivity by **80%.**

Opportunity & feasibility



This stream acts as a first step for more ambitious activities. It was considered to have a lower opportunity for developing value. However, remote technology can be applied to a wide range of construction activities, although it is unlikely to deliver transformative change. Remote control was not considered to bring about any improvements in the safety of construction sites.

The feasibility of achieving this stream is middle-ranked, due to uncertainty about when the technology will be available. In part, this is due to the wide range of technology required for sensing different asset types. There was concern over the ability to implement the technology in existing plant, and to retrain existing operators in its use.

The use of remote control is likely to require adjustments to legislation. It raises questions about who is responsible for remotely operated plant. However, this stream is aligned with current government strategy for construction, and so is likely to form an increasing component of future policy.

Technology & hardware: Autonomous plant

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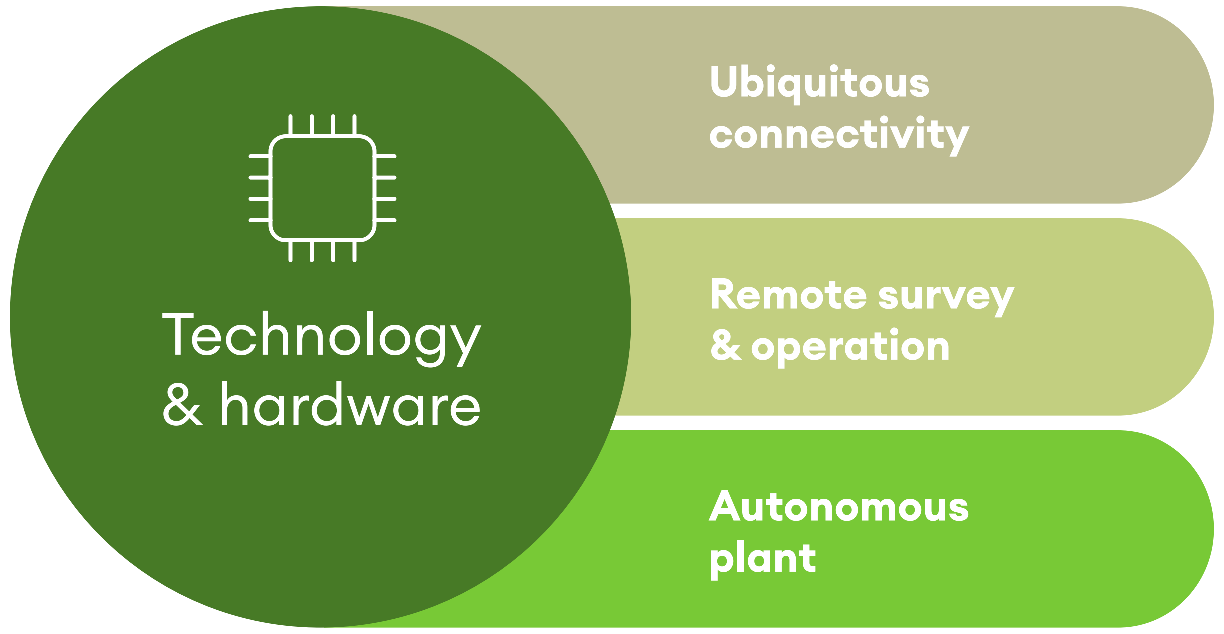

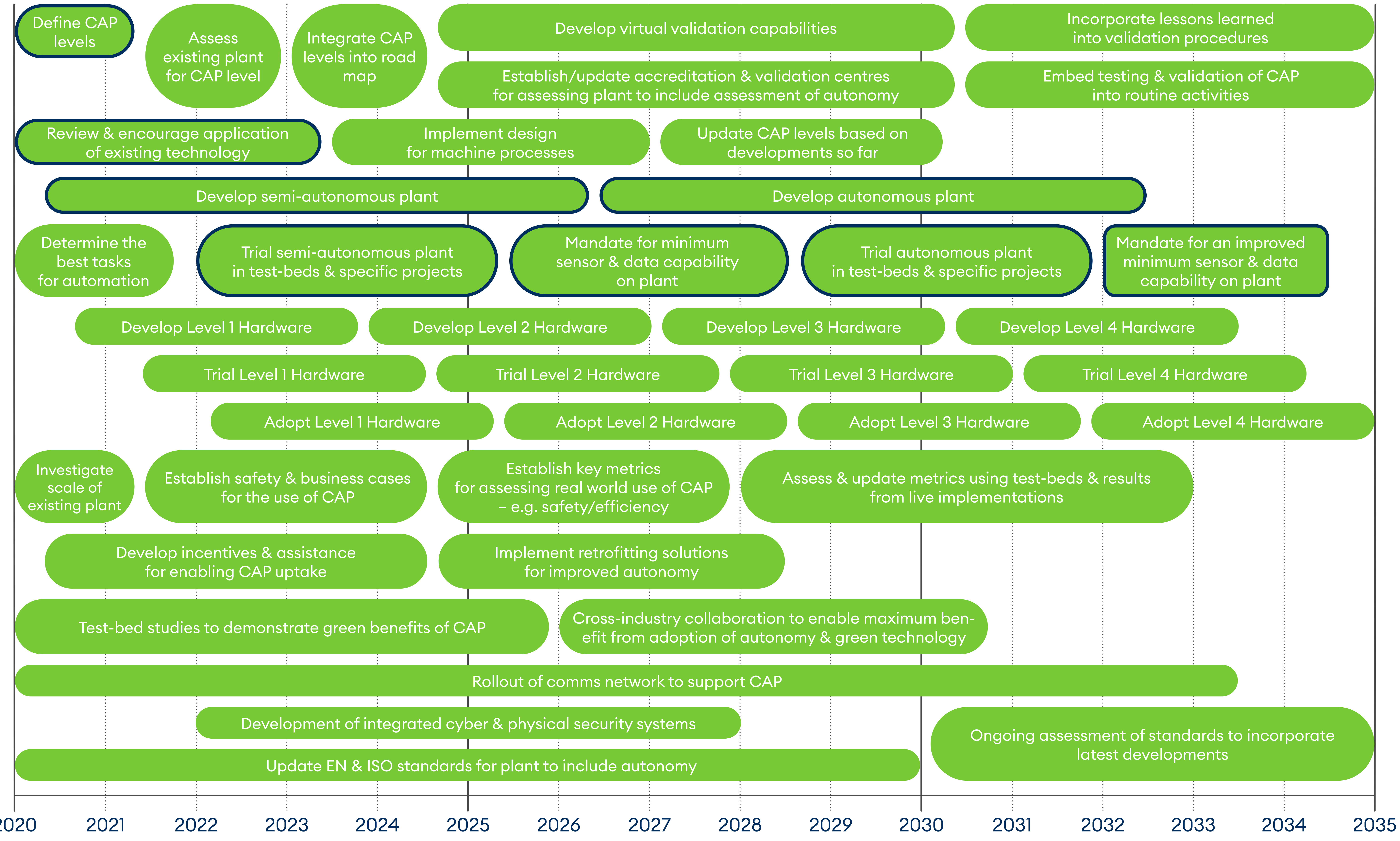

Technology & hardware: Autonomous plant

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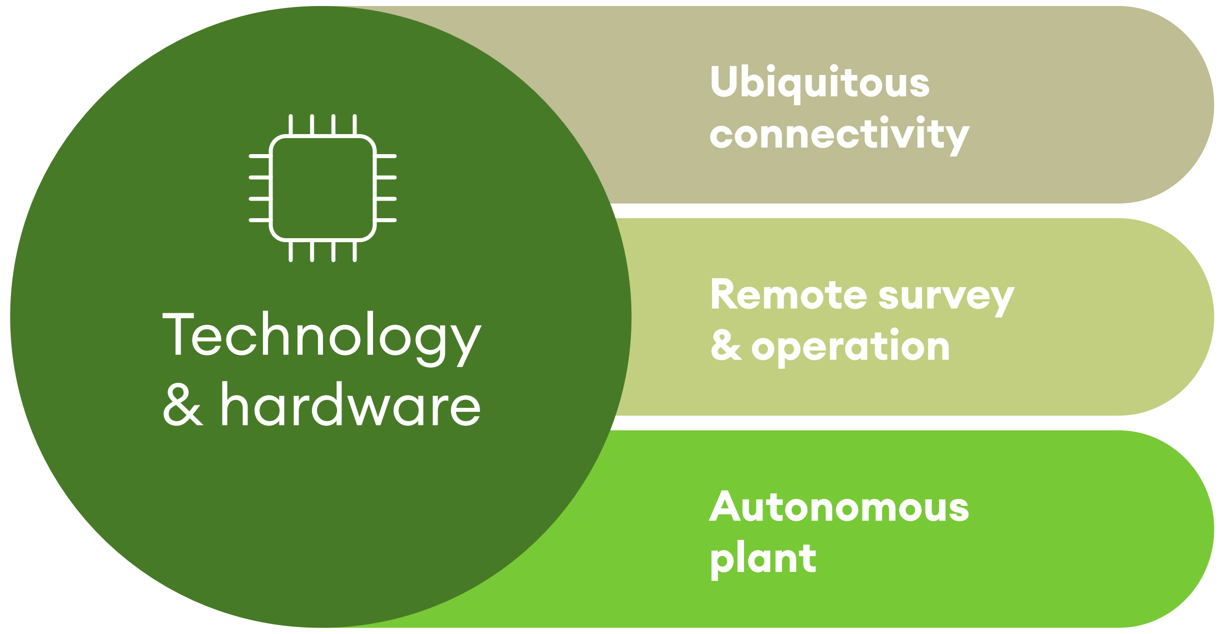


Outcomes

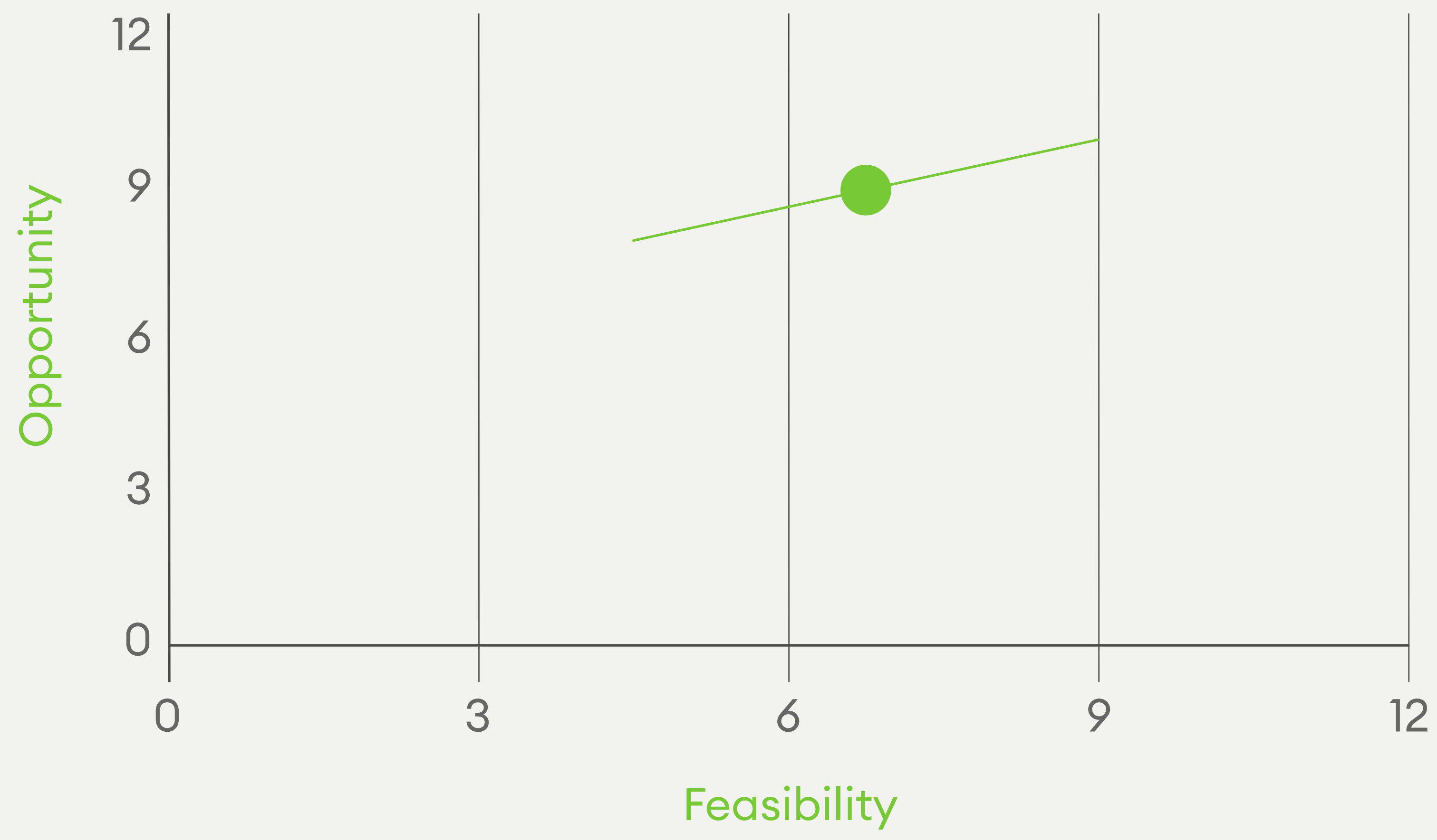
This workstream focuses on the development, testing and implementation of CAP hardware. A key initial activity will establish capability levels for CAP, which will clarify which construction activities have the potential to be undertaken autonomously. They are conceptually similar to those established for connected vehicles and will provide direction for the focused development of solutions. They will be supported by an understanding of the scale of the existing plant ecosystem and the potential range and size of applications.

In the medium term, solutions will work semi-autonomously and/or be remotely operated. Retrofitting could accelerate early implementation in specific applications. Testbeds will help with the development of technology, along with real and virtual validation systems to test, approve and enhance the performance of CAP. Validation will also draw on metrics to quantify the performance of new hardware in areas including safety, efficiency, environmental impact and quality.

Once hardware is in place, standards developed and performance criteria implemented, it will become feasible to mandate the use of CAP in construction activities. Risk management will continue through ongoing validation and accreditation activities, standards development and testing via testbeds.

Machine control in pavement construction could deliver benefits of **>£3Bn** between now and 2035.

Opportunity & feasibility



The development of the hardware for autonomous plant is one of the core streams. It represents a considerable opportunity to bring about a significant improvement in safety within the sector. Autonomous plant can be applied to a broad range of on- site construction activities and can be used to bring about a transformation in how construction is undertaken, offering much reduced whole-life costs for construction.

To completely achieve this stream requires the support of the other streams. Significant legislative overhaul is required and there is much uncertainty over the difficulty of adoption across the sector. However, the technological requirements are favourable, as much development has already occurred, bringing the equipment closer to market. Furthermore, the adoption of autonomous plant is in line with current government policy and this is expected to continue in the future, with autonomous technology becoming an increasing focus for the UK.

Data & digital techniques: Algorithms in autonomy

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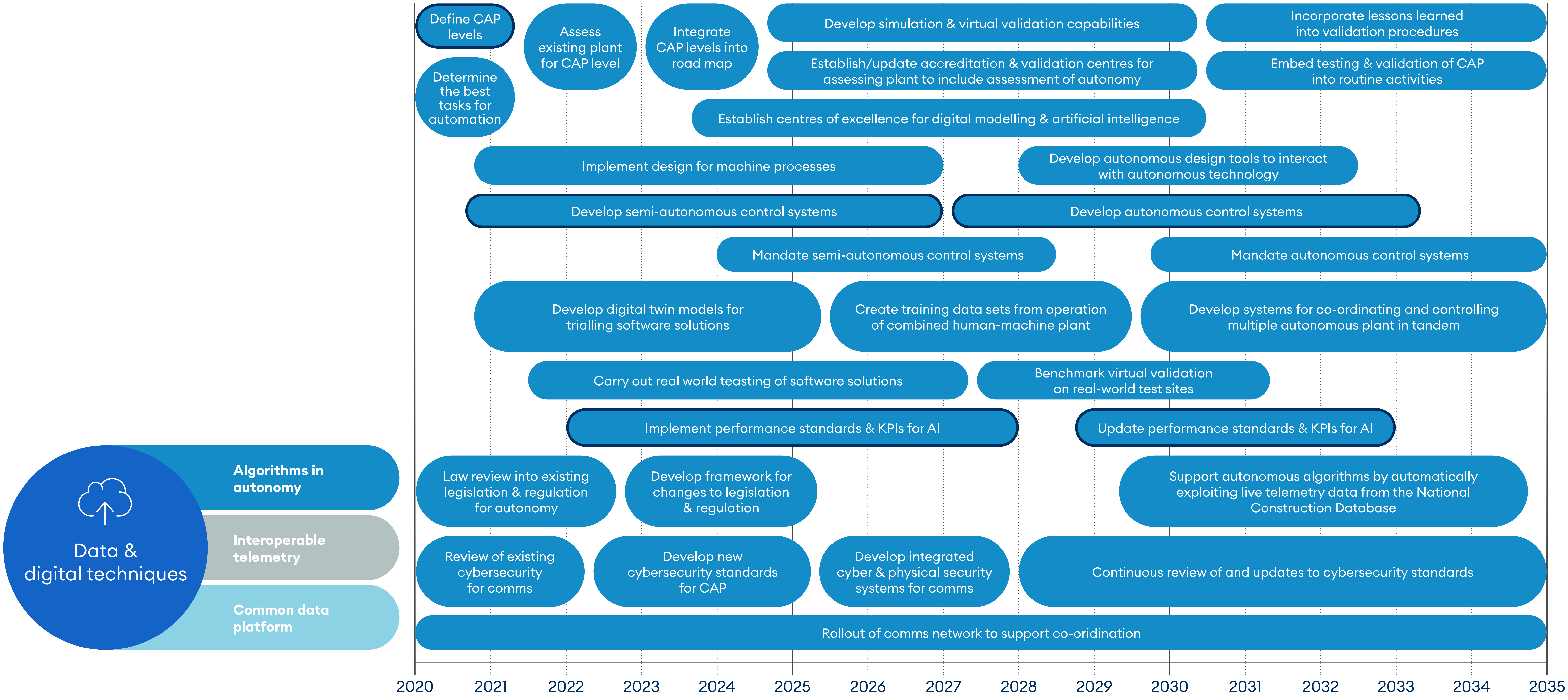

Data & digital techniques: Algorithms in autonomy

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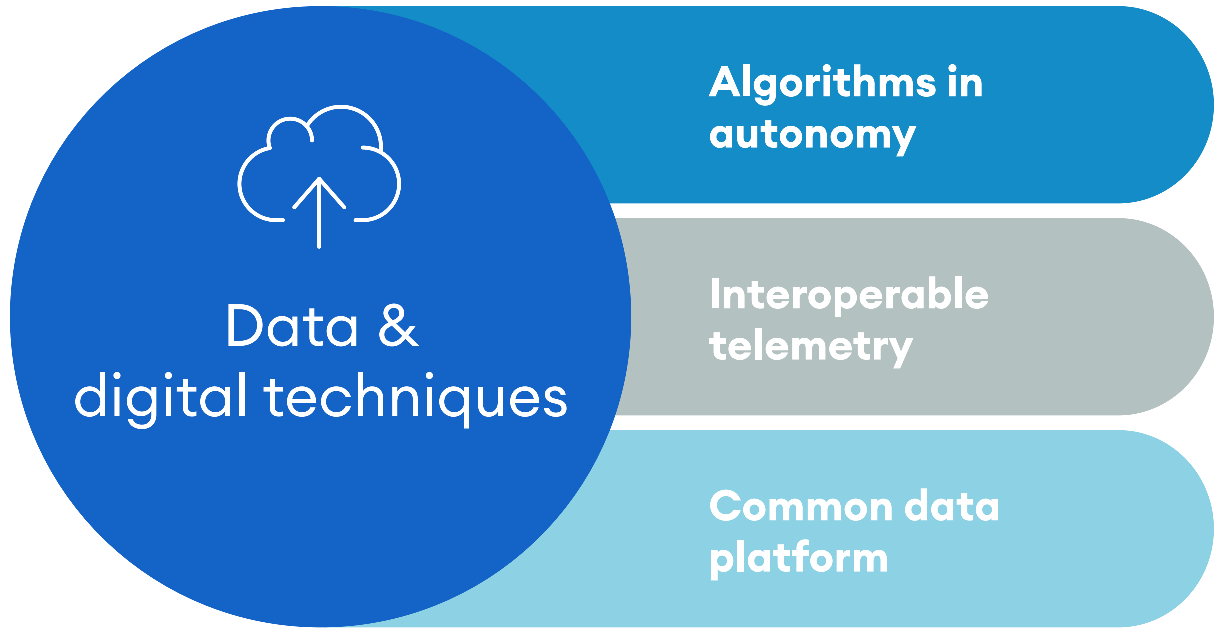


Outcomes

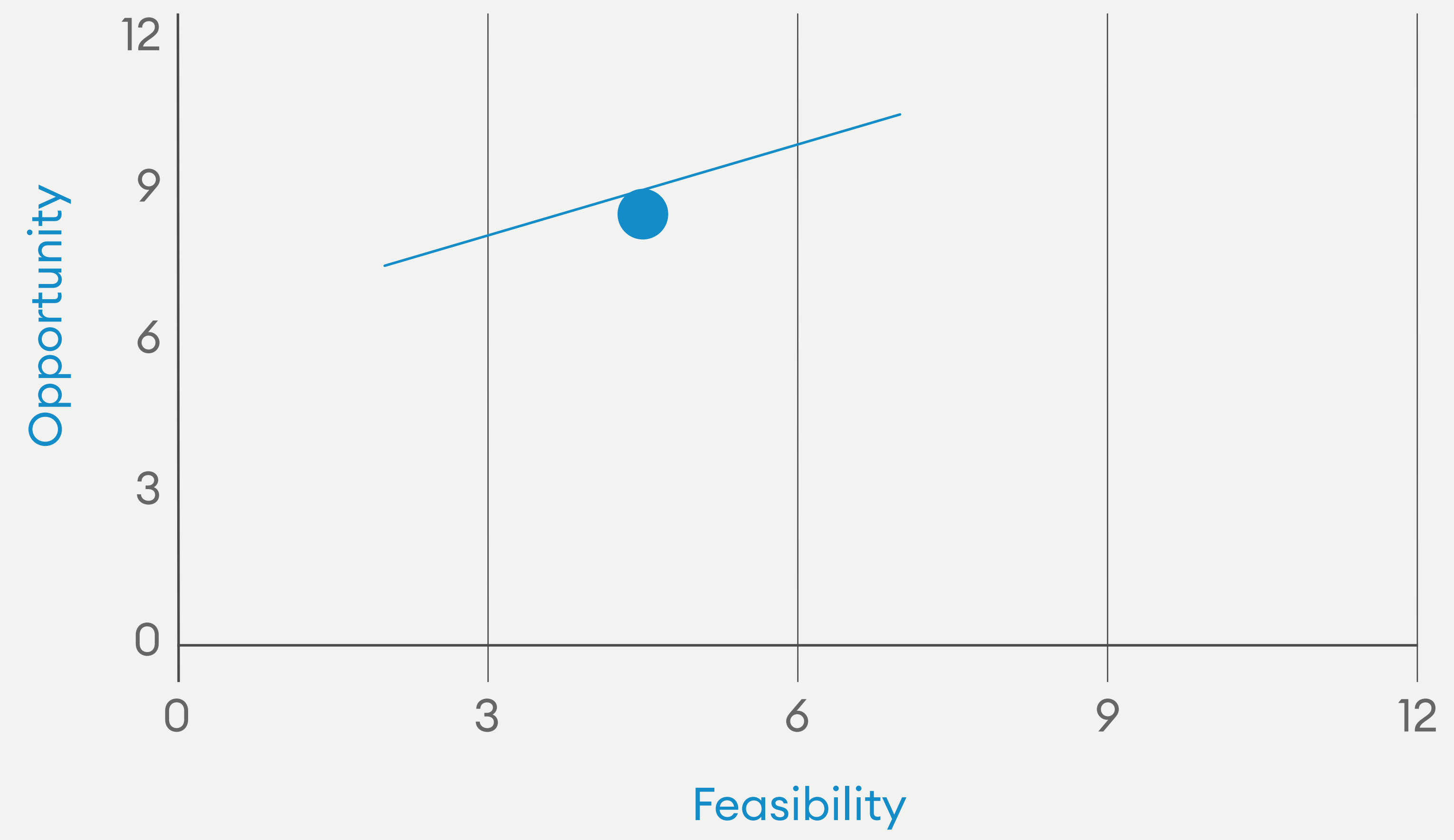
Fully autonomous and semi-autonomous operation will both draw on systems that exploit sophisticated algorithms to control activity. This workstream focuses on the delivery of this capability. It is strongly linked to other streams: in particular, to the definition of CAP capability levels, data, connectivity and telemetry, and legal and ethical requirements. The initial phase of this stream will draw on these to understand and prioritise the tasks for automation. It will address the algorithmic, ethical and data demands as well as the need to convert existing design processes to more machine-suitable solutions. This will include establishing target performance levels for algorithms, to complement or form part of the CAP capability levels.

A focused, collaborative industrial and academic development programme will deliver the algorithms, drawing on rapid improvements in processor performance, telemetry data and AI. The provision of training sets derived from digital twins and real-world construction scenarios will support development, as will the use of testbeds.

As autonomous control evolves, the capability will extend across plant to co-ordinate multiple activities, drawing on connectivity and telemetry data. Standards will be updated to benchmark the expected level of performance using KPIs. Testing and validation capability will mature, with a process for validating updates to algorithms.

Adoption of 3D machine control in earthmoving operations delivers ~**25%** improvement to productivity.

Opportunity & feasibility



Software capable of autonomous decision-making is a key requirement for CAP. This is a high value proposition, but it will be challenging. AI can be employed in place of human operators for significant reductions in casualties and to transform construction. It has potential to be applied across a wide range of activities. However, there is a substantial uncertainty over the cost implications of introducing autonomy.

The development of AI for construction is likely to take a number of years to achieve. There are likely to be significant challenges in converting existing operation: current plant requires a human driver so retrofitting must be possible, but human operators will express concern over automation could mean for their employment. There are significant legislative and legal questions to be resolved before autonomy can be widely adopted.

Autonomy aligns with government strategy currently, and it is likely to have significant influence in the future.

Data & digital techniques: Interoperable telemetry

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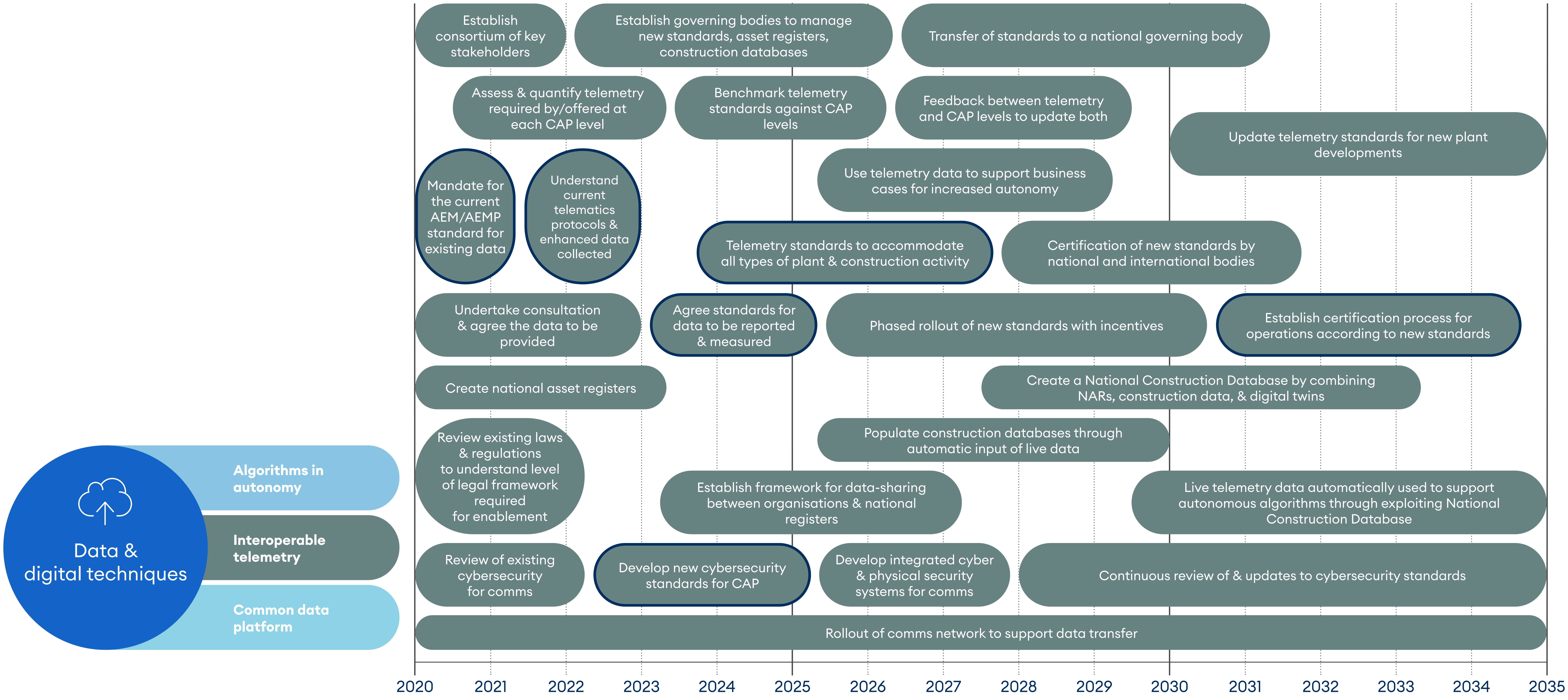

Data & digital techniques: Interoperable telemetry

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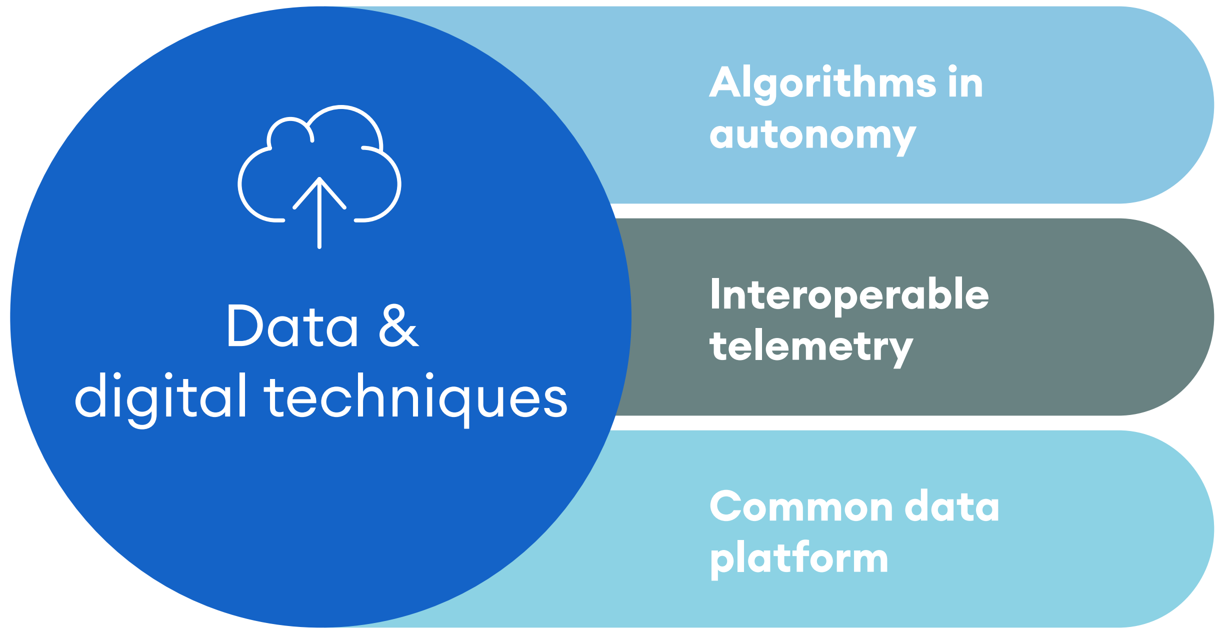


Outcomes

This stream supports the development and implementation of processes, tools and standards to share and use telemetry data. It has a close relationship with the data, connectivity and autonomous algorithm streams.

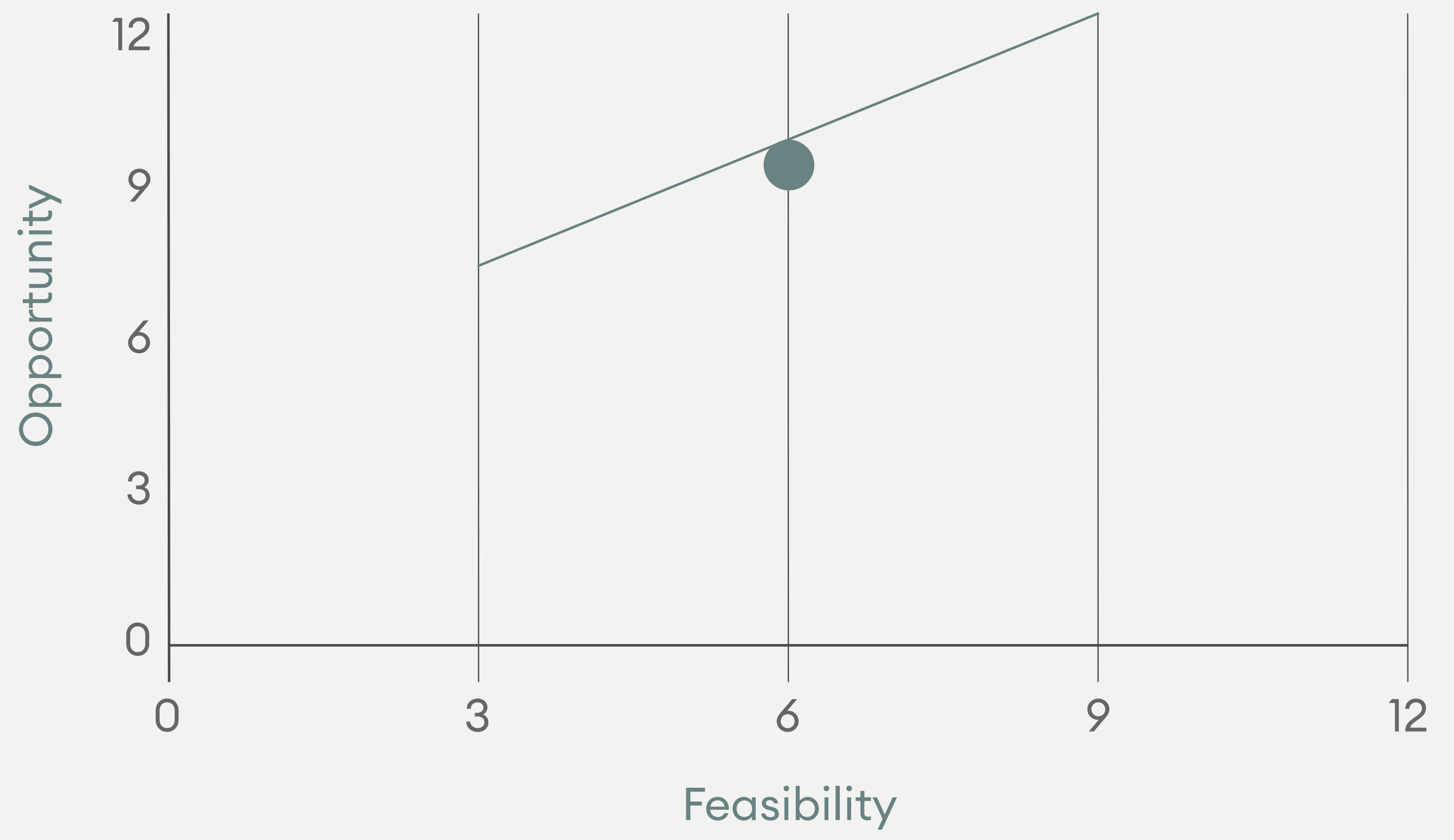
Telemetry data provides plant with an understanding of its environment, the activities and location of surrounding plant and workforce. It supports the connected, co-operative environment. Telemetry data can also be applied to measure the quality of the construction. Collaboration across the industry will define best practice and standards for telematics protocols and data. The establishment of capability levels for telemetry, which support the development of standards, will draw on emerging standards from AEM/AEMP.

An ongoing co-operative programme will extend the standards to accommodate new and emerging telemetry data, supported by the establishment of governing bodies to manage their implementation and development. Roll-out of the standards will accelerate the collection and delivery of telemetry data.

As delivery of telemetry data across the plant environment becomes routine, data will promote the implementation of advanced algorithms for autonomous control. Experience in applying these will support continuous updates to the standards.

Telemetry and geofencing could deliver annual savings **>£25M** through reduced utility strikes.

Opportunity & feasibility



The development and promulgation of interoperable telemetry across the sector is a high value opportunity with broad applicability. It will support significant changes to the methodology and strategy employed in construction. It can be used to bring about a substantial reduction in the whole-life cost of construction and has the potential to improve safety across the sector.

However, there is substantial uncertainty over the feasibility of this stream. Although independent manufacturers offer varying levels of telemetry, having the technology to interact with other plant as standard will only occur later in the roadmap. There is uncertainty about how difficult it will be to fit existing plant in to the telemetry, and to encourage adoption by current operators. There are legislative and legal questions regarding interoperable telemetry, and who is responsible for achieving this. However, autonomy aligns with government strategy, and is likely to have significant influence in the future.

Data & digital techniques: Common data platform

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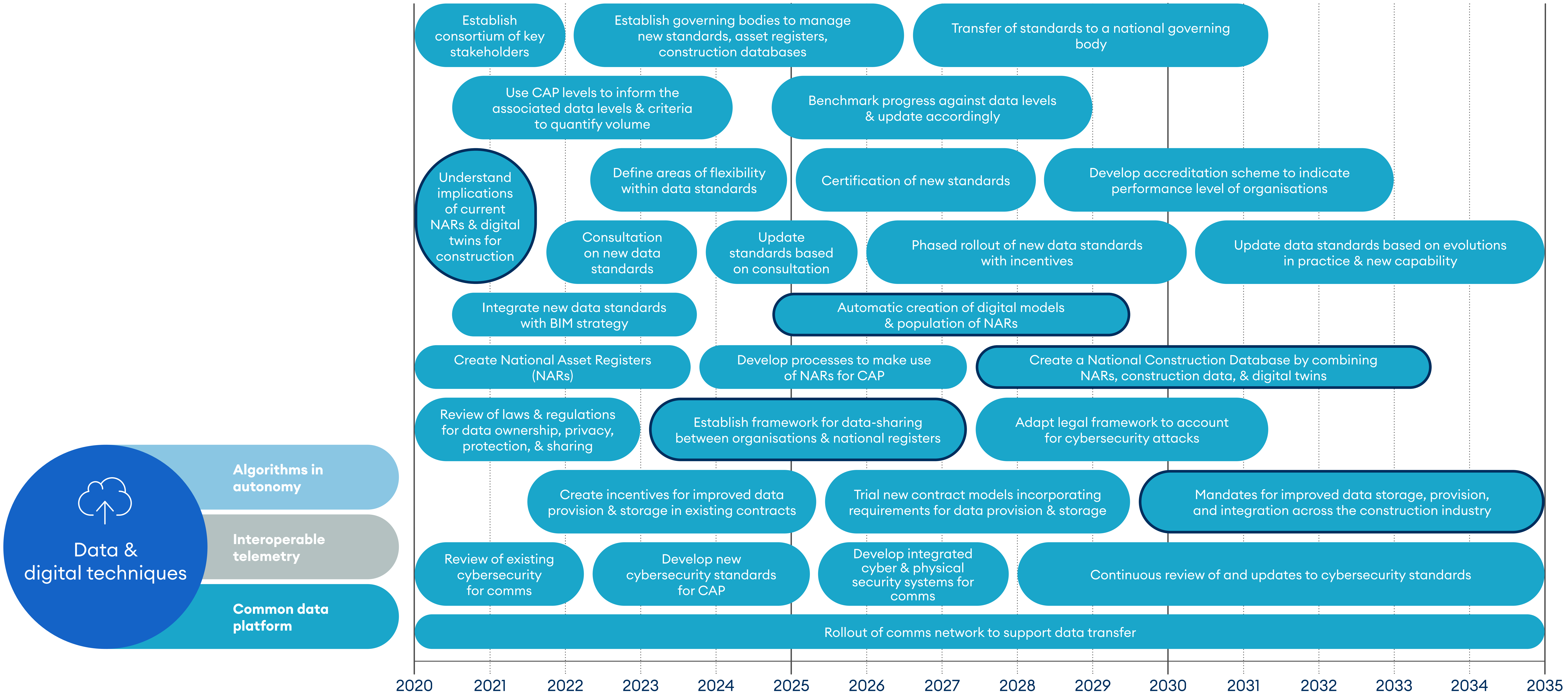

Data & digital techniques: Common data platform

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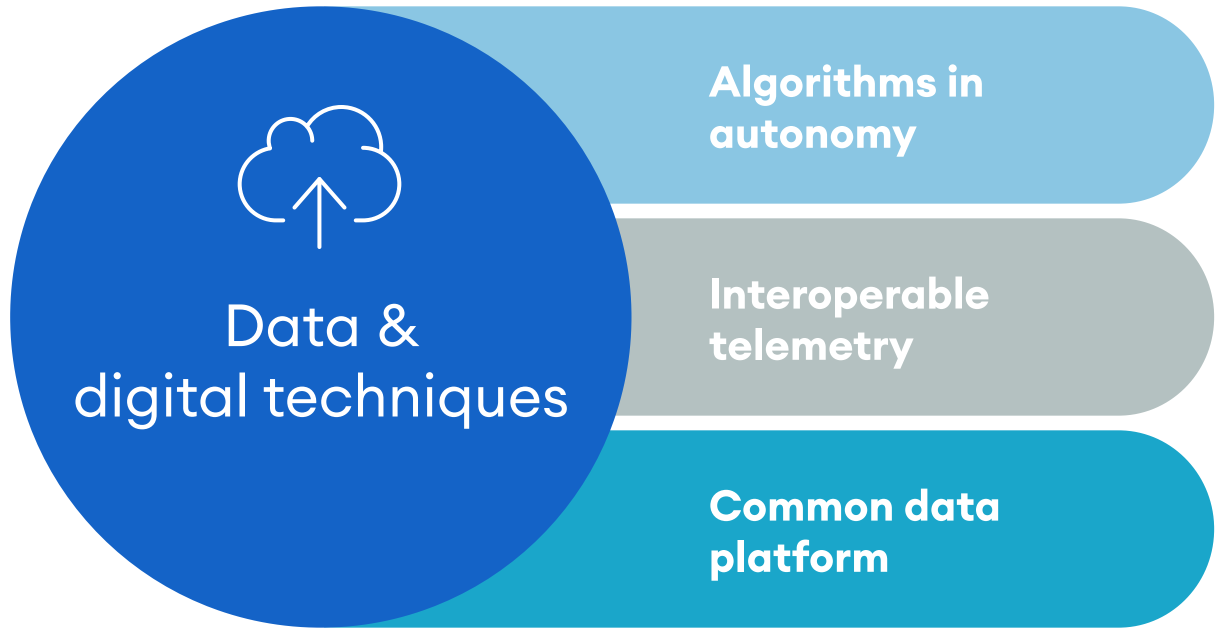


Outcomes

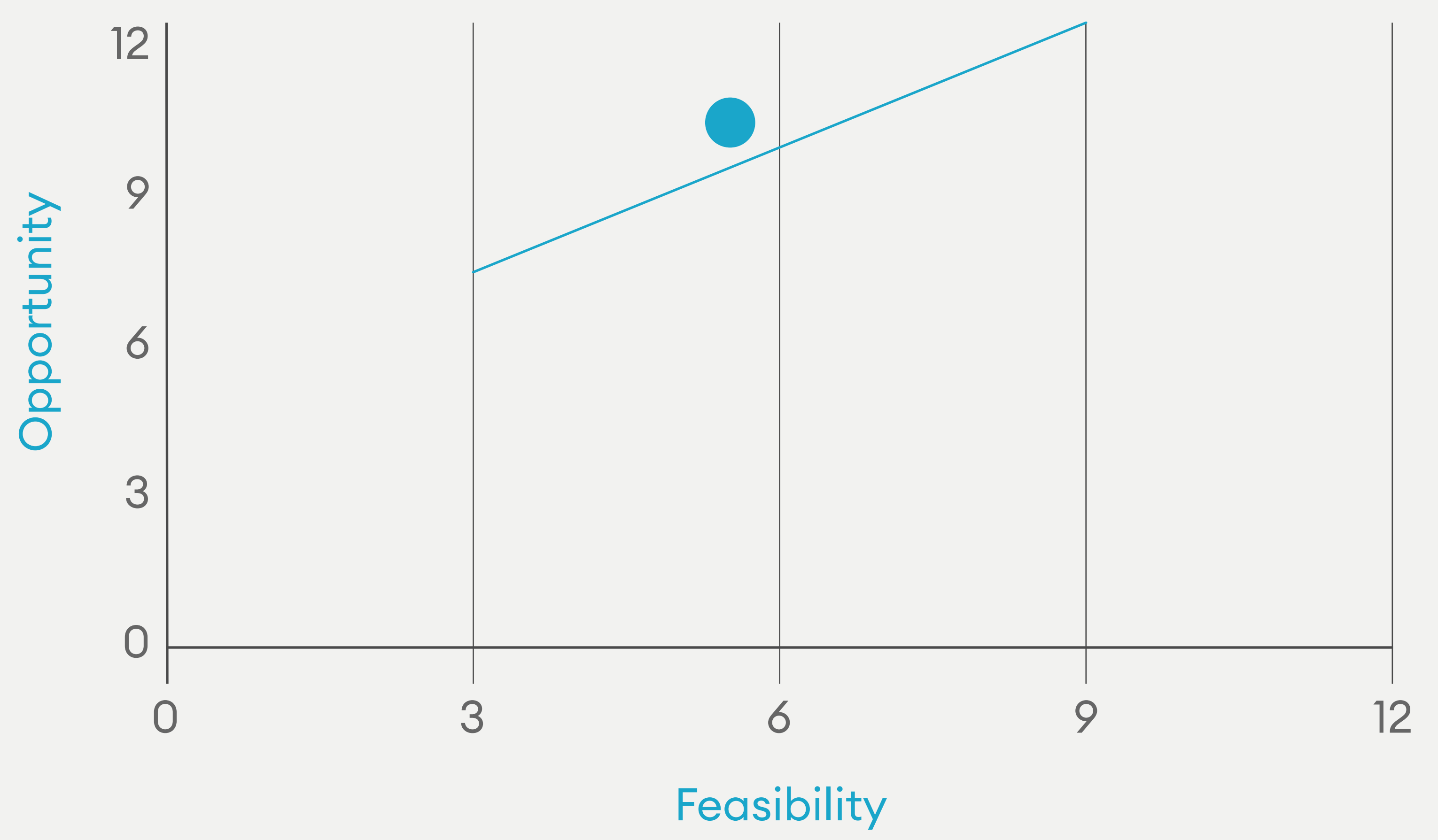
The common data platform is a pillar that supports the feasibility of CAP. Common standards for data will facilitate efficient collection and exchange of the information required to achieve automation. The initial challenge will be to understand the array of standards that both influence and will be influenced by CAP. As for other components of the Roadmap, collaborative partnerships will be required between industry, government, standards providers and sector bodies to understand the ecosystem, identify good practice and define the areas in which standards adoption or development is required.

Governance bodies will be established to manage the framework for the sharing of data and the development of standards. This will facilitate the availability of digital models and asset registers to support digital design and remote/autonomous operation. This will lead to a requirement to supply digital data to/from stakeholders within contracts. Real-time delivery of this information will be enabled by the communications technology delivered in other workstreams.

As collection, processing and delivery of data to support CAP becomes routine, it will be possible to mandate this within contracts, supporting real time creation of digital twins for in- and as-built models, and populating a national construction database.

The National Underground Asset Register should deliver **£1.2Bn** of benefits.

Opportunity & feasibility



The development of a common environment to share data is an important opportunity, necessary to achieve the full benefits of CAP. A common data environment should include all aspects of construction. Analysis of the data will facilitate the development of new strategies and techniques to bring about an improvement in safety. The data itself represents an additional value source that can be used to deliver reductions in whole-life costs through the optimisation of construction and maintenance.

However, there is uncertainty over the feasibility of this stream. The technology is expected to be available in the medium term, but may require a large amount of retraining and retrofitting to achieve broad use. Furthermore, it is unclear how the development and implementation of common data environments fits within current legislation, due to the mixing of public and private information.

Despite this, current government policy is for the creation of a number of different data environments, including the National Underground Asset Register.

The Appendices

Appendix A: Example CAP technologies

Telemetry

Many kinds of telemetry have been employed in the construction industry for some time. The majority of the captured information relates to machine data – for example, the utilisation and efficiency of machine use, the location of the machine on the job site, and status reports on fuel usage, the condition of consumable components, and general machine health. (The Construction Index, 2012)

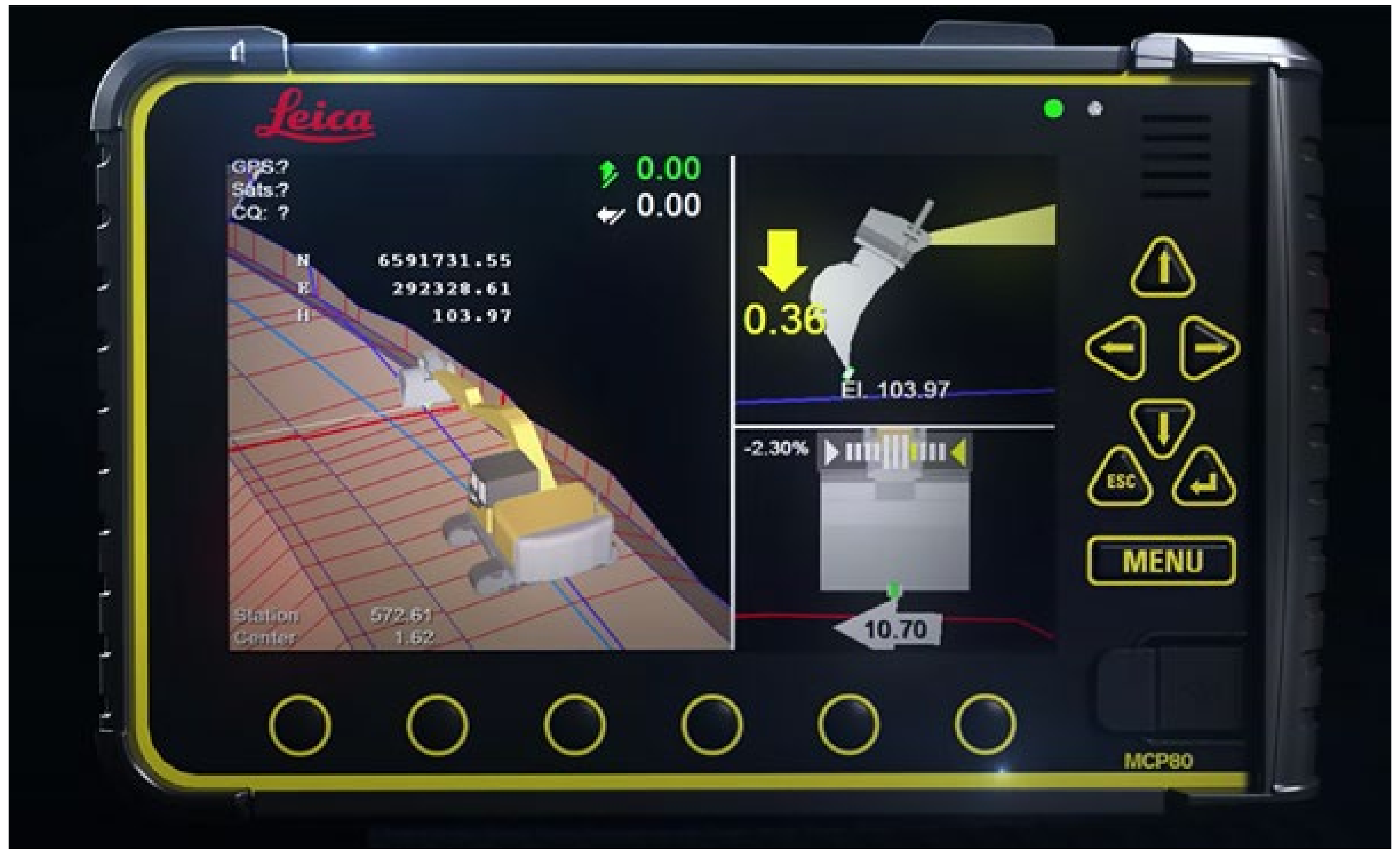
However, a growing proportion of telemetric data relates to measurements capturing the performance of the machine itself, and delivering as-built information to operators and designers. This can be delivered to a control centre to help fleet managers and site co-ordinators understand the status of each site.

Telemetric solutions can be provided as an integrated part of plant (from OEMs), or via a range of retrofitting solutions that can be applied to upgrade existing equipment. As most fleets make use of a mixed collection of plant from different manufacturers, the Association of Equipment Manufacturers and the Association of Equipment Management Professionals have collaborated to create an industry-wide standard for data sharing (Association of Equipment Management Professionals, 2019).

Geofencing & 3D Machine Control

By including a positioning system (global or local) on plant, and appropriate sensing equipment to track the configuration of all actuating components, it is possible to set spatial limits on the range of motion for any particular item of plant. No-go areas can be defined, to avoid collisions with surrounding objects or to prevent plant from departing from defined areas. These limits can be static (programmed into the on-board computer) or they can be dynamically monitored (using sensors to analyse the surrounding environment.) 3D machine control can be considered as an extension to this principle. (Topcon, 2019) (Leica Geosystems, 2019) (Trimble, 2019)

An example: by combining accurate locational information with digital terrain models, it is possible for plant to (semi-)autonomously cut to grade. This can also be used in reverse, uploading the exact position of the cutting edge to the digital models to provide as-built models of earthworks.



Leica Geosystems 3D Machine Control solution

Compaction

Intelligent and remotely controlled compaction systems are a well-developed example of the potential of CAP. On-board sensing capability provides information on the temperature of the mat and a measure of how compacted the layer is. On-board location systems allow a heat map of number of passes or the measured compaction to be generated. This information can be used to control the operation of the plant, reducing the amplitude of compaction to achieve a target stiffness and providing feedback to operators to enable a consistent degree of compaction across the surface. Smaller compaction systems have been converted to remote operation, removing the need for a human operator to push or ride the instrument, thus avoiding the health risk associated with exposure to the vibrations from compaction. (BOMAG, 2019) (Hamm, 2019) (Intelligent Construction, 2019)

BOMAG Robomag Autonomous Compactor

Driving & Logistics

The use of (semi-)autonomous driving has been trialled for use in moving earthworks on construction sites. This technology is being extensively used in both the mining industry and in a number of ports around the world. Improving autonomy in driving is a key enabler for automating a variety of construction tasks, as it controls the basic principle of moving plant around on site. Currently, a range of applications are being developed, including driver assist functions which prevent collisions, automate positioning relative to other machines, and carry out position-specific tasks.

Most semi-autonomous systems follow pre-determined routes with little capacity for deviation. Typically, a human operator is involved, who must resolve any problems

Colas Autonomous Impact Protection Vehicle (Colas, 2017)


WG Line Marking Robot (Tiny Mobile Robots, 2019)

encountered. The 'slaving' of machines to mimic the route of a master vehicle has stimulated a key step forward in autonomous driving. This allows the equipment to follow the master, as shown by the autonomous impact protection vehicle in the illustration above. (Colas, 2017)

Drones & Robots

Small robots and drones have been employed in a variety of applications. Drones are primarily used for surveying, providing topographical information to populate design models along with periodic as-built information from recording the evolution of a construction site. This information can be used to monitor progress, to identify bottlenecks, and to support asset management at the completion of construction.

Further applications include the use of devices for autonomous staking or laying out, where a site map with appropriate stake points is provided to the drone and it autonomously lays out the site. Small robots are applied for pre-marking the required location of line markings. (Tiny Mobile Robots, 2019) These applications of drones and robots offer significant time savings and improved safety when compared to conventional techniques. They can exist as broadly standalone implementations of CAP.

Augmented Reality

A number of platforms have been developed to integrate digital design and on-site activity through Augmented Reality (AR). These systems display a 3D model of the proposed design, overlaid on the physical reality, so that designers and operators can understand how a design works in its exact context. It can be used to walk clients through prospective constructions, improve understanding amongst operators for planned activities, and identify potential complications in the design before construction has begun.

By integrating AR systems with existing documentation, it is possible to “see” objects which are normally obscured, such as pipework and cabling, and accommodate them into designs and planned work schedules. This can avoid costly damage to existing infrastructure and eliminate hazards from dangerous asset strikes. Trials have been performed where each aspect of a build is RFID tagged with the relevant BIM information so that the AR system displays the appropriate data as you view the object (Hyeon-seung Kim, 2013). Other trials have made use of the digital information to create twins which can be explored through AR systems, drawing the information directly from the databases according to the user’s location and orientation.

Modular Construction

The use of connected and autonomous technologies within the construction industry does not need to be restricted to on-site operations. Significant advances have been made in the use of off-site, modular construction techniques to move construction from a more traditional operational model to a modern process. Modular construction takes many forms, but it uses a common principle of manufacturing repeated modules or sections of a building off-site in a factory environment, which are then transported to the construction site and assembled.

This can range from prefabrication of different components, such as walls or floors, to complete the construction of internally finished units, in volumetric construction.

Modular construction can be considered an inherently digital approach: the design documents are produced digitally so that repeated cells can be identified and specified. The off-site construction factories can be modelled on manufacturing production lines, making use of robots to consistently and accurately perform repetitive tasks. As modules are completed, they are transported to the construction site, so they arrive when they are needed as a just-in-time delivery. This avoids materials having to be stored on site for significant amounts of time (McKinsey and Company, 2019).

Modular Emergency Refuge Area

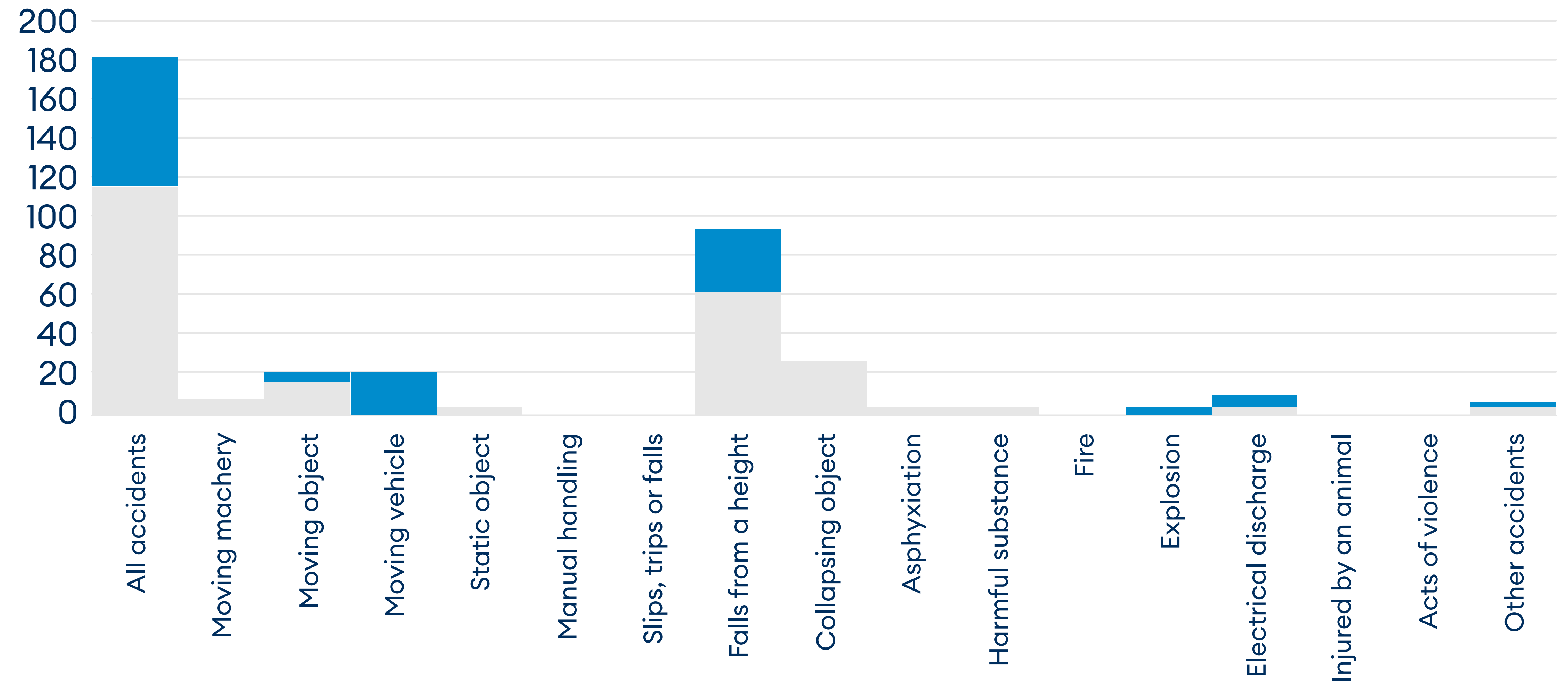
Appendix B: Benefits case studies

Automation will affect all parts of the construction process, and its potential benefits will evolve along with the technology. However, even at this early stage in its evolution, there are clear examples of the value the new technologies will deliver.

Safety of the workforce

Significant effort has been made to optimise the health, safety and wellbeing of construction workers over the past 30 years. However, the reduction in the rate of injuries has flattened since 2010. Construction site accidents are commonly associated with the interface between people and plant, or they result from exposure to harmful environments – this accounts for ~20% of incidents (Health and Safety Executive, 2019). It is estimated that CAP could have reduced the number of incidents that occurred in the last five years by over 30%, or 7,500 incidents. This would have brought a reduction of £180M in accident related costs. (Health and Safety Executive, 2019)

CAP preventable accidents 2014-2019



CAP will also deliver improvements to the working environment. It is estimated that over £1.2Bn of costs arose as a result of worker illnesses in the sector in 2018, a significant proportion of which were associated with musculoskeletal disorders. CAP will reduce exposure of workers to the demanding activities that contribute to such disorders. Furthermore, absences and reduced performance associated with workplace stress affect over 15,000 workers a year. By minimising high pressure, noisy and stressful environments, CAP could deliver annual benefits of up to £250M.

The awareness, control and advanced decision making of CAP-enabled devices will deliver benefits through specific applications of the technology. For example, striking underground assets during excavation exposes workers to hazards, damages plant, and disrupts construction. Automated excavation will reduce this risk, drawing on underground mapping, sensing systems and intelligent algorithms to geofence sensitive or hazardous assets. Whilst direct costs to the value of several thousand pounds can be associated with every strike, this increases more than thirty-fold when indirect costs are included (Transport Systems Catapult, 2017). There are potential annual cost benefits of ~£25M.

Komatsu Excavator using 3D Machine Control

Efficiency

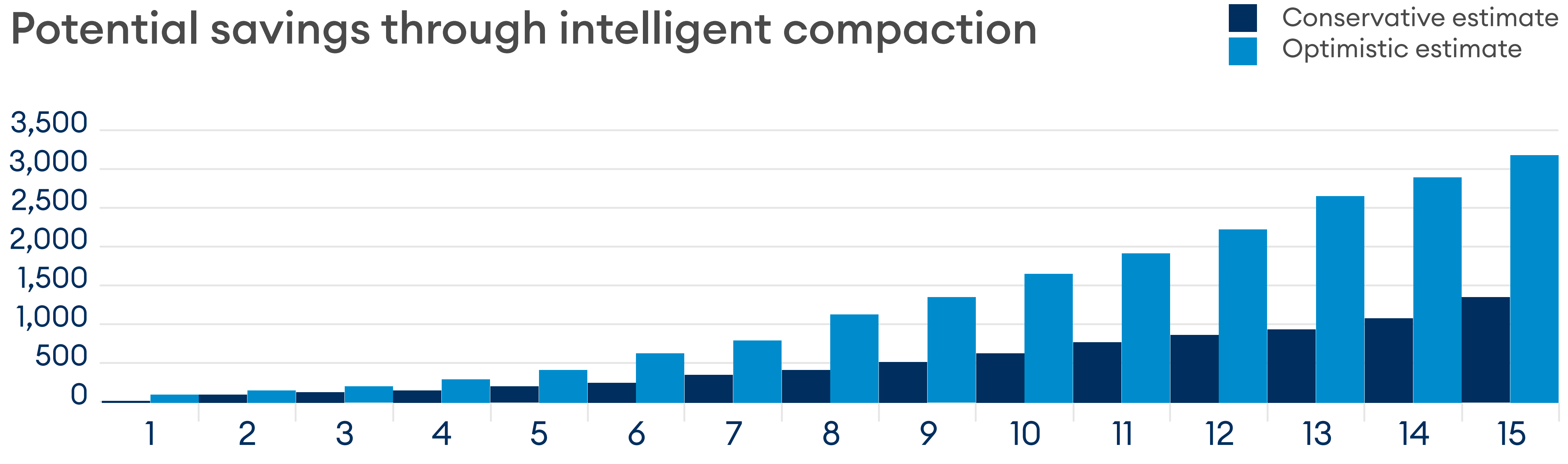
Automated control will deliver direct benefits to the efficiency of site construction. Direct comparisons between traditional methods of excavation, grading or laying, and machine-assisted methods of activity have identified cost reductions of up to 80% in areas such as load movements. In addition to savings related to time and equipment, fuel savings of up to 50% can be achieved. The potential cost savings achieved through the application of CAP on a 50km dual carriageway road construction scheme could amount to over £125M (based on the breakdown of work structure and associated costs per lane km of road construction reported by EC Harris and TRL, 2009).

Quality

The lifetime of road pavements is influenced strongly by the quality of the construction. Accelerated deterioration occurs when traffic loads a poorly constructed surface. Furthermore, as the road surface profile achieved using automated machine control is significantly smoother than conventional approaches, fuel consumption improvements are delivered alongside longer pavement lifetimes (Hu, 2018).

It has been estimated that the introduction of machine control across all road surface replacement schemes could deliver increasing year on year benefits totalling over £3Bn by 2035. Surface profile improvements that give fuel consumption reductions of up to 2% could reduce annual fuel consumption costs for road users by a further £300M.

Potential savings through intelligent compaction



Speed of Construction

Modular construction has the potential to offer significant benefits in reducing the time required to complete a construction project and for the return on investment to be realised. This benefit arises throughout the construction process: as modular construction makes use of repeated modules, design can be reused across multiple projects, with reduced updating for each situation. Alongside this, modular construction allows for parallelisation of construction activities, most notably between the site preparation phase and the construction phase. This is further supported by the ability to make use of just-in-time logistics to further reduce wasted time. Finally, off-site manufacturing improves right-first-time product delivery, which reduces the risk of overrunning project schedules.

These factors combine to give a 20-50% reduction in the time required to successfully complete a build, depending on the size of the project and the degree of parallel activity possible (McKinsey and Company, 2019). While converting this reduction in build time to a financial benefit depends on the construction being built, the National Audit Office estimated that volumetric construction would result in £90/m^2 in benefit for the construction of affordable housing for the rental sector (National Audit Office, 2005).

Appendix C: Development of the Roadmap

The University of Cambridge Institute for Manufacturing's road-mapping process was applied in the development of the Roadmap (Institute for Manufacturing Education and Consultancy Services, 2019). A business ecosystem mapping workshop established the sectors that influence or are influenced by CAP, and the relative weighting of these sectors. The sector-level ecosystem is shown opposite. The size of the circle indicates the relative importance and influence attributed to each sector by the ecosystem mapping. The thickness of the connecting lines indicates the relative importance of the links between sectors.

As the model shows, CAP will be driven by a combination of government and other policy setting agencies, along with principal contractors within the construction industry. Government will determine policy, support the funding and investment, and control the legislation and regulation to enable CAP. The adoption of CAP by industry organisations and their strategies for implementation will play a significant role in the direction CAP takes, determining the areas considered for key focus.

Research and academia will feed into development of CAP through calls delivered by the research councils and private industry to address specific needs. This proceeds in parallel to R&D undertaken by technology companies such as OEMs, plant and telecommunications companies. All of these parties will feed into the creation of new standards and regulation to support the changes to the construction sector and the wider environment.

The development of CAP in the UK construction sector will draw on the experience of automation in parallel industries (such as manufacturing) and sectors (such as mobility) and other countries. It is crucial that both the public and the workforce are engaged, which will be influenced by media presentation and representative trade bodies.

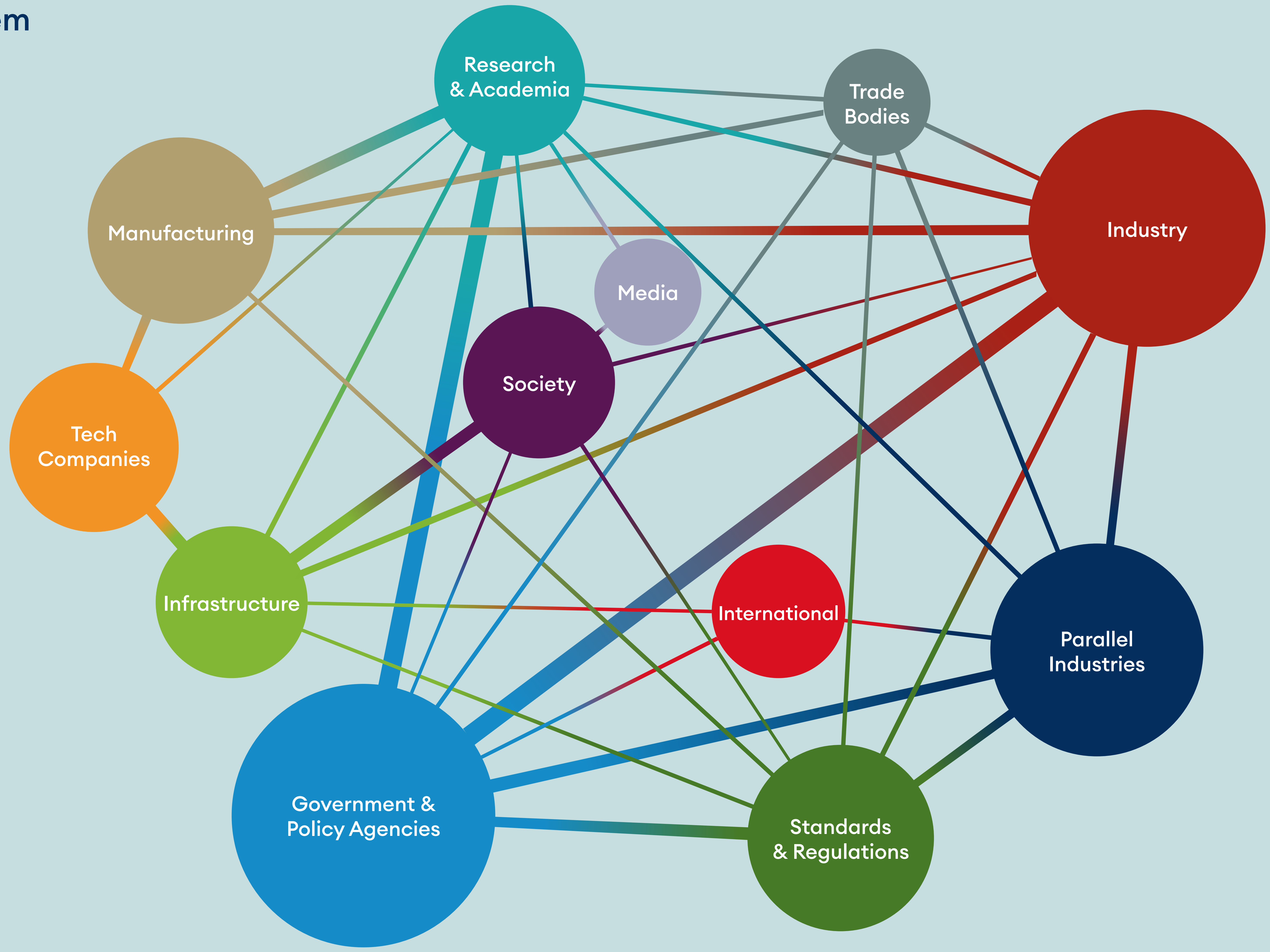
The weighting of each sector identified in the ecosystem mapping was used to guide the sectors invited to attend the road-mapping workshop. The aim was to the balance the attendees to match the balance of sectors from the ecosystem map.

Building on the stakeholder consultation, the road-mapping workshop examined the challenges and barriers to CAP adoption, and the routes to overcoming these. The first stage of the workshop identified and shortlisted the trends and drivers. This was followed by the identification and prioritisation of methods that would respond to these trends and drivers, including the identification of expected outcomes. The nine activity streams were developed and refined, and a set of summary business cases drafted for each, along with an assessment of the scale of the opportunity and its feasibility.

Following the workshop, the trends and drivers identified in the first stage were analysed to shortlist the current needs of the construction sector, and to clarify the vision that would be achieved as a result of the successful implementation of CAP. The individual Roadmaps developed in the workshop were reviewed, aligned and gaps addressed. Interdependencies and cross-linkages between the streams were examined to identify the milestones and their impact on timescales for each stream.

Further supporting activities, considered critical to achieving each stream, were identified and incorporated into the Roadmap for each stream. Finally, the streams were combined to generate a strategic Roadmap outlining the overall direction of CAP adoption.

CAP business ecosystem



Appendix D: Opportunity & feasibility assessment

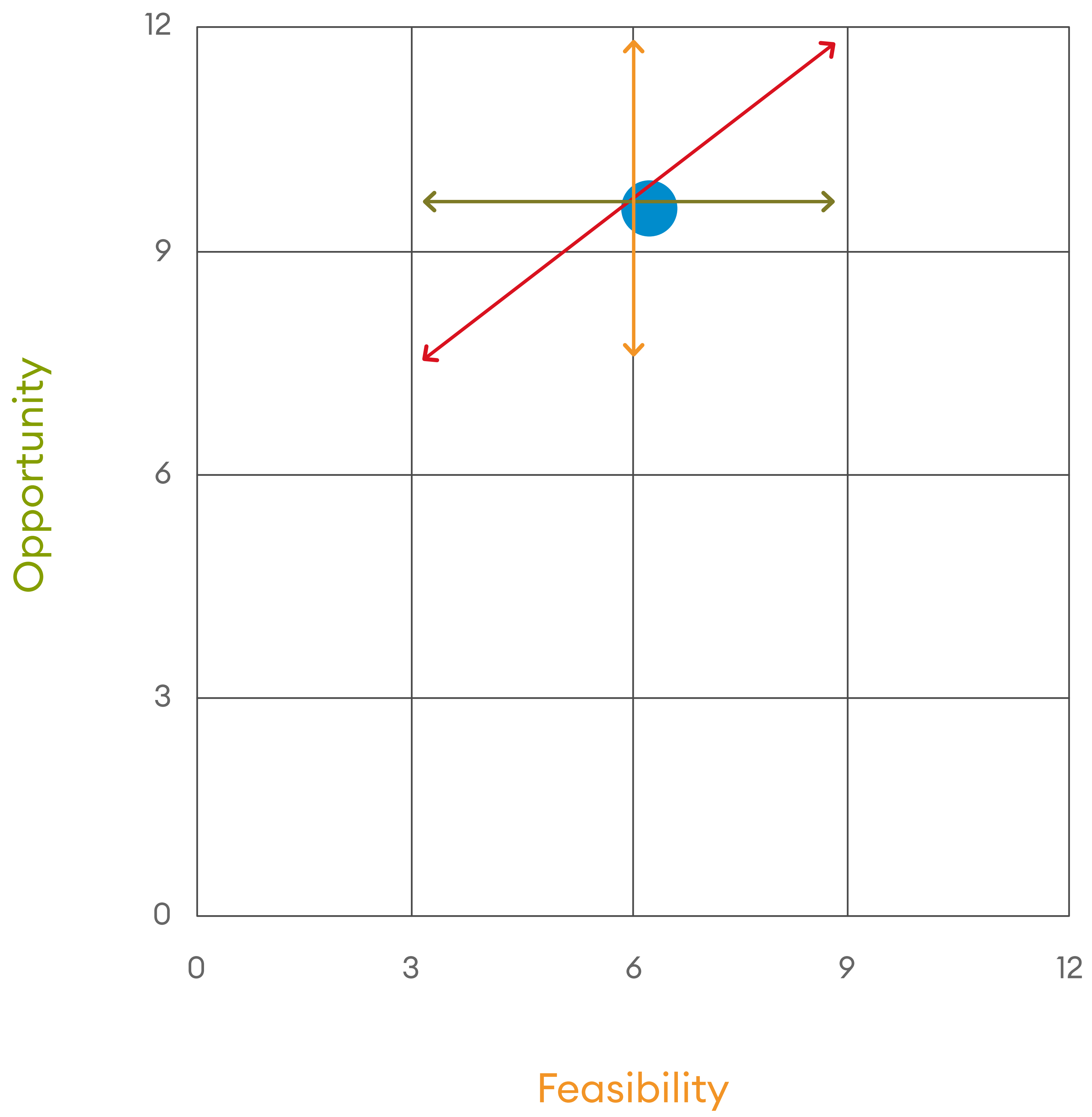
The opportunity and feasibility assessment quantifies the size of the business opportunity presented by the Roadmap stream, and the feasibility of delivering it. It aims to provide information to help leaders when developing programmes.

Whist creating the business cases upon which each of the nine Roadmap streams were based, workshop delegates were asked to estimate the opportunity size and its feasibility. All delegates voted on each business case, using a set of four scaling statements.

- **Opportunity** was classified according to the safety and economic benefits, the capacity to change and digitise construction activities, and the potential to create new methods of construction.
- **Feasibility** was assessed according to technology availability, the complexity of implementation in existing systems, how it aligned with existing legislation, regulation, and government strategy.

The scaling statements used in the workshop are shown in the next two pages. Delegate votes were aggregated to produce mean opportunity and feasibility scores – an example is shown by the blue dot on the graph. The range of scores expressed across all delegates for opportunity (green arrow) and feasibility (orange arrow) defines the worst-case to best-case line of opportunity and feasibility for each stream. The size of this line is a good indicator of the first step to take when delivering each stream. For example, if there is much uncertainty regarding the opportunity and feasibility, then it would be appropriate to carry out an investigation to provide a better understanding of the requirements and the associated potential.

An opportunity-feasibility graph is presented for each activity stream within the Roadmap.



Scaling statements for Opportunity

Factor	Description	0	3	6	9	12
Potential to transform construction activities	Changes to construction methods, techniques, tools, strategies	No change to current activities	Small scale changes to individual activities	Small changes to multiple activities or large changes to individual activities	Large changes to multiple activities	Widespread revolution across multiple aspects of construction
Safety	Change in the number of casualties associated with construction activities	Significant increase	Minor increase	No change	Minor decrease	Significant decrease
Economic efficiency	Change in the whole life cost of construction activities	Significant increase	Minor increase	No change	Minor decrease	Significant decrease
Range of potential applications	Can be adapted to ~X% of construction activities	0%	25%	50%	75%	100%

Scaling statements for Feasibility

Factor	Description	0	3	6	9	12
Technological achievability	When the technology required to deliver will be available	Not during the timeframe of the Roadmap	In the long term of the road map	In the medium term of the road map	In the short term of the road map	Currently available
Implementation	Complexity in converting technology or users	Requires complete replacement or complex reskilling	Requires a mix of replacement and retrofitting or reskilling	Requires major retrofitting or reskilling	Requires some retrofitting or reskilling	Requires little or no retrofitting or reskilling
Legislation & standards	Compatibility with current standards or legislation	Requires large transformation of standards or high legal risk	Requires some change to standards or low legal risk	Fits with current legislation and standards	Meets or surpasses current standards and somewhat reduces legal exposure	Meets or surpasses current standards and greatly reduces legal exposure
Governmental strategy	Alignment with government strategy on related areas (e.g. safety, environment, etc.)	No or contra-alignment with current strategy	Partial alignment with current strategy	Aligns with current strategy	Will influence future strategy and policy	Will shape future strategy and policy

Appendix E: Contributors

This Roadmap has been created using the expertise and knowledge of the following organisations.

A-One+
A Plant
Amey
Atkins
Bachy Soletanche
Balfour Beatty
BAM Nuttall
Bentley
BOMAG
Bosch CVO
Buckingham Plant Hire
CA Blackwell
Cambridge Centre for Smart Infrastructure & Construction
Caterpillar
CITB
Cohda Wireless
Connected Places Catapult
Costain
CSJV
DB Schenker
Department for Transport
EDF Energy
Environment Agency
Epitomical
Finning
Flannery Plant Hire
GAP Group
Heathrow Airport
Highways England
HS2
i3P
Institute for Manufacturing
Jacobs
James Fisher and Sons
JCB
JF Prolec
Kier
Kozut
KTN UK
Lecia Geosystems
Masternaut
Marubeni-Komatsu
Morgan Sindall
Murphy
MTC
Network Rail
Nokia UK
Northumbrian Water
Norwegian Public Roads Administration
Onwave
Ordnance Survey
SAP
Satellite Applications Catapult
Sitech UK and Ireland
Skanska
SMT GB
Speedy Services
Tarmac
Tekla
Tideway East
Topcon Positioning GB
Trimble
TRL
UKAEA
University College London
University of Birmingham
University of Cambridge
University of Edinburgh
University of Southampton
University of Surrey
Vodafone Limited
Volvo
Wacker Neuson
Walters Group
Willow Hire
Wireless Infrastructure
Zenzic

Appendix F: Disclaimer

The content of the Connected Autonomous Plant Roadmap (“Roadmap”) is provided for general information only. It is not intended to amount to advice on which you should rely. You must obtain professional or specialist advice before taking, or refraining from, any action on the basis of the content set out in this Roadmap. We make no representations, warranties or guarantees, whether express or implied, that the content or information set out in the Roadmap is accurate, complete or up to date. In particular, you should be aware that the information contained in the Roadmap may be subject to change or affected by economic, market and political changes.

You acknowledge and agree that neither Highways England nor any of the authors or contributors of any content in this Roadmap shall be liable for your reliance on any of the information set out in this Roadmap.

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