Department for Transport

Connected and Autonomous Plant

Market Analysis

on behalf of **Department for Transport**

August 2024

COSTAIN

Costain has produced this report in collaboration with the International Transport Experts Network (ITEN) and Cambridge Econometrics, on behalf of the Department for Transport's Transport Research and Innovation Board (TRIB).

Costain led a specialist team to conduct the market analysis of Connected and Autonomous Plant (CAP). Costain is an active participant in the Infrastructure Industry Innovation Partnership (i3P), Plant and Earthworks Community (PEC) and CAP communities along with the Supply Chain Sustainability School plant group and has extensive experience of the National Highways CAP programme having been involved since its conception and undertaken the lead role on phases two and three.

ITEN is an association of SMEs and independent experts in transport, providing scientific and technical expertise, consultancy and strategic advice. Maple Consulting and independent expert researcher, Vijay Ramdas led the research for ITEN.

Cambridge Econometrics conducted the benefit quantification analysis of CAP, led by Lee Robinson, and developed a multi-tech, multi-period input-output model to estimate the expected economic benefits.

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Foreword

Infrastructure supports growth, improves lives and protects the planet. The Second National Infrastructure Assessment, from the National Infrastructure Commission, makes clear that a reliable, low carbon infrastructure system is critical to addressing some of the UK's biggest challenges including growing the economy and achieving net zero by 2050.

Delivering such an infrastructure system requires a significant increase in overall investment and, crucially, a step change in productivity from conception to completion. Government and industry have a number of levers at their disposal, and we need to work together to achieve this.

Historically, productivity growth within the UK construction industry has been low compared with the wider economy. Government has identified the use of technology and modern methods of construction as strategic priorities for increasing productivity and delivering time and cost savings[i].

Consistency and continuity is key to delivering our Nation's Infrastructure predictably and productively. A long-term plan for infrastructure, planning system reform and a portfolio approach that matches capacity with demand would give business and investors confidence in how the UK delivers critical infrastructure. With such a significant task on our hands, we also need to be realistic. Setting clear objectives to ensure infrastructure delivers on focused, critical and specific requirements, which target a minimum viable project, would be a big step in the right direction. That should be accompanied by suitable risk management which doesn't overpromise and is honest about where the risks sit.

Transforming productivity of construction activities is another important lever. This report focusses specifically on the role for Connected and Autonomous Plant (CAP): leading edge construction equipment that leverages interconnected technologies and autonomous functionalities to optimise processes.

CAP has the potential to enable a significantly more productive, greener, and safer way of working. This is already evidenced on projects across the country, but we need to enable a significant shift in the way we work. This report provides an analysis of the benefits of wider adoption of CAP and identifies the barriers and enablers as we consider its wholesale adoption.

I am delighted that Costain has been commissioned to produce this report by the Department for Transport's Transport Research and Innovation Board.

Alex Vaughan

Chief Executive Officer, Costain

Executive summary

The Government and industry are focussed on improving productivity across the economy to increase GDP, provide better value for money for public services to taxpayers and significantly strengthen the UK's position in global markets. The UK has the ambition of becoming a global powerhouse in technology and skills. Increasing the use of technology and collaboration in construction is already bringing benefits and will help further drive these targeted productivity improvements.

The construction sector in the UK currently lags significantly behind national productivity growth. However, this is a global trend, with UK construction mirroring global figures. A 2017 report by McKinsey identified a 1% per annum global construction labour productivity increase over the past two decades compared with 2.8% per annum for the total world economy and 3.6% per annum for global manufacturing.

"Connected and Autonomous Plant (CAP)" is a collective term for leading edge construction equipment that leverages interconnected digital technologies and autonomous functionalities to optimise construction processes.

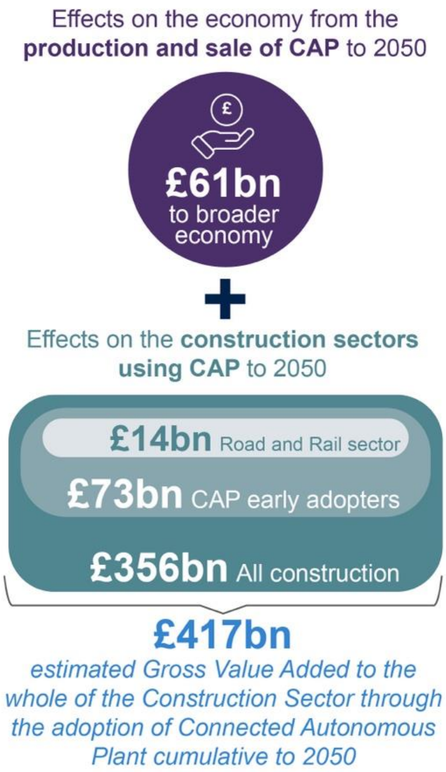
At present, there is not an overseeing authority that has established a definitive definition of CAP in the industry. In this report we have used the term to mean:

"Construction plant that is both connected and autonomous:

- **connected** to its environment through sensors or wireless transfer of data, and
- **autonomous** by undertaking part or all of its activity without human interaction."

Benefits

Industry's widespread adoption of CAP supports many of the productivity levers available to Government. CAP benefits deliver value in performance, safety, environmental and financial terms. They are achieved as a result of features including:



- Telematics and automation delivering energy savings and improved productivity
- Improved safety features preventing accidents and deaths
- Reduced carbon emissions

Barriers

This report identifies the barriers and enablers for the wider uptake of CAP in the construction industry, to provide Government with insight on CAP's potential, and in turn to accelerate its uptake and to improve how infrastructure is constructed and maintained.

To accelerate the uptake of CAP, industry will require upskilling and incentivising. Market barriers will need to be overcome, through further regulation, awareness and standardisation at all levels of the construction industry, the alignment of procurement practices, and the need for investment.

Report approach

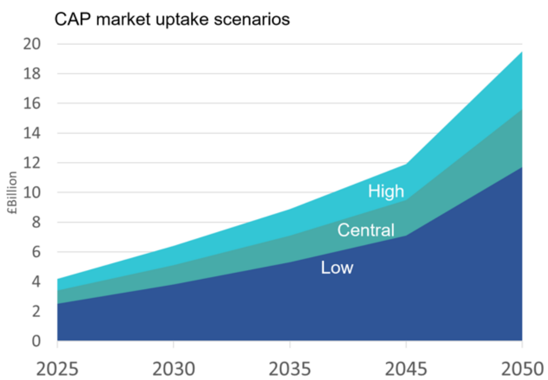
To research and produce this report, a diverse group of stakeholders was engaged, including plant equipment

manufacturers, technology manufacturers, technology installers, plant lease hire companies, contractors, representatives from industry media, plant distribution professionals, earthworks specialists, industry organisations, governmental bodies, and sustainability advocates. Through understanding stakeholder experiences and applications of CAP within the construction industry, the research was able to assess the CAP market size and quantify associated benefits, by applying the findings to develop an economic model.

Findings

The UK construction equipment sector is worth £15bn annually, with an estimated 20% of construction plant currently in use qualifying as having some degree of connectivity and autonomy. However, this is concentrated mainly in single application machines such as bulldozers and compactors with limited use in excavation plant (which typically has functions that support multiple interchangeable construction applications).

In the UK plant market in general, for smaller construction equipment there are factories that cater for the local market and export. For large plant, of high value but with lower volume of sales, manufacture is undertaken in a few dedicated factories, providing greater export opportunities. The UK market is a net exporter of some equipment types and a net importer of others. However, the UK is a net exporter of plant overall.



With all types of CAP considered, and a range applied to account for uncertainty levels in forecasting future sector behaviour, the graph (left) summarises the potential growth in the CAP market, with the central scenario current market size of **£3.4bn growing to £15.6bn in 2050**.

Analysis results

The benefits of this level of uptake would be significant, for the construction industry and the wider economy. The research estimates that by 2050 a central uptake scenario for CAP could result in the following economic benefits (as GVA, Gross Value Added).

The increases to GVA come from two main sources: the **production and sale of CAP** equipment, and the **increased output of the construction sector**.

The production and sale of CAP equipment to meet the construction sector's demand has a knock-on effect as equipment makers order more parts and services from their own suppliers, and they from theirs, and so on. Not only are all of these firms along the supply chain seeing increased revenues as a consequence, but more money is also paid to workers in these sectors, as they increase production. These worker incomes are spent in the economy, generating demand, which in turn generates production increases and knock-on effects in turn. The sum of all of these effects across the forecast period is worth around **£61bn**.

The benefits to the sector that the adoption of CAP equipment generates include higher productivity, savings on energy/fuel and safety improvements. Some of these benefits are distributed to shareholders as profits, some to paying off the loans used to buy the CAP equipment, and some to giving clients (or client, the UK Government) more for their money: producing more output for the same price.

This results in increased output from the road and rail sector worth £33bn over the forecast period, which translates into additional GVA of **£14bn**.

When scaled across the construction sectors most likely to adopt CAP, albeit with

increasing degrees of uncertainty as a result, this is estimated to be **£73bn**, and when scaled across the entire construction industry, this is estimated to be worth around **£356bn** in additional GVA, cumulative to 2050.

In addition to the financial benefits, CAP has the potential to achieve other value. For the road and rail sector alone, the **significant benefits** realised cumulatively to 2050 include:

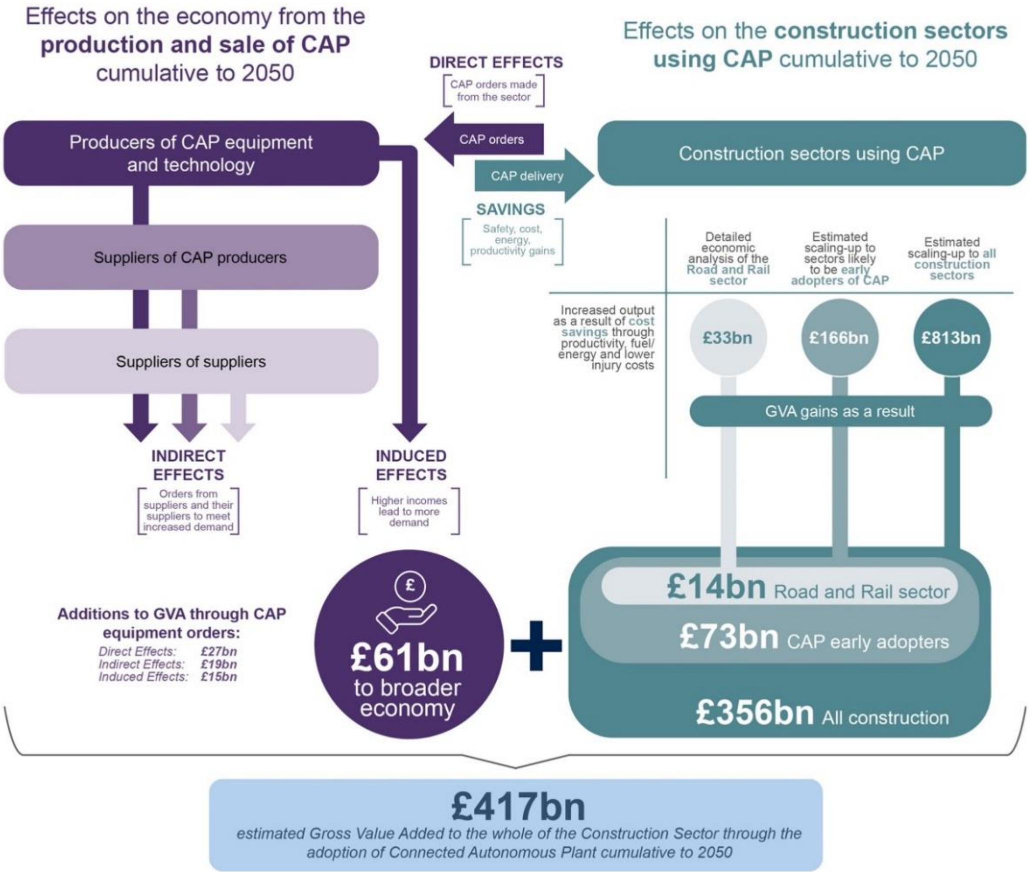
Safety	~**28,000** non-fatal incidents resulting in injury avoided ~**31** fewer deaths resulting from incidents
Environment	Reduced carbon emissions of ~**19,300kt** of CO_2e *equivalent to: the annual CO_2e absorbed by an area of forest the size of Wales* Fuel energy cost savings of **£10bn**
Employment	Net workforce growth of **29,000** Average wages increase by **12%**

The below graphic outlines how the effects on the economy from the **production and sale of CAP** and the widespread adoption and subsequent **increased output of the construction sectors using it** will lead to additional GVA of **£417bn** cumulative to 2050.

Future vision

An ambitious vision for major Government infrastructure projects in 2050 where CAP is fully adopted, sees most tasks on site being undertaken autonomously with fully integrated AI controlling machinery. There will be a higher skilled human presence on construction sites and any manual operation of machines would be rare. Human roles in the construction of the future will be in design and supervision, working in tandem with AI to deliver the greatest value.

CAP can propel the UK construction industry into a safer and greener era of greater efficiency and higher productivity. Enabling the adoption of CAP will unleash the construction industry's potential and support the UK economy in its ambition to become a global technology and skills leader.



1. Purpose of the report

Historically successive governments have seen infrastructure investment as a pathway to growth, and that is expected to continue. However, there are always many competing pressures on public spending, and for infrastructure investment to continue to be attractive, it needs to demonstrate increasing value for money.

The construction sector has a substantial stake in the UK's economy, representing 6% of GDP and 7% of the UK's total workforce[ii]. In terms of the value of new construction work and the number of employees in the sector, it is a growing industry with opportunities for further growth in the coming decade.

This growth is in part due to the very substantial Government investment in public infrastructure. In February 2024, HM Treasury and the Infrastructure and Projects Authority (IPA) published the latest National Infrastructure and Construction Pipeline. With 660 projects and programmes currently forecast to total up to £775bn, 30% of the investment is expected to be spent on transport infrastructure over the next 10 years.

This level of investment represents an opportunity to invest in delivering infrastructure using methods which are greener, more efficient, and safer. While these are positive aims in themselves, new methods are also required to tackle the construction sector's productivity challenge, a key theme of both the Cabinet Office's Construction Playbook and the IPA's Transforming Infrastructure Performance (TIP) Roadmap to 2030[iii]. This will involve a combination of improving uptake of existing technologies or construction practices and making use of the Government's targeted investment of 2.4% of GDP in Research and Development[iv].

However, there are practical, strategic, socio-technical, legal and financial barriers to the construction industry's adoption of CAP as the norm. Businesses across the supply chain are carrying investment risk from uncertainty in the long-term infrastructure strategy for CAP, resulting in low or slow uptake. The scale of the market is not well understood which inhibits a holistic investment approach to stimulate and accelerate adoption. This report considers the barriers which would need to be overcome, the enablers which could increase uptake, and the market opportunities which could result from high, central and low scenarios of CAP uptake in the construction sector.

Construction's productivity challenge

Both globally and nationally, construction productivity is a challenge for economies. The Office of National Statistics' 2021 report on productivity in the UK construction industry found that it had lagged behind the wider UK economy in growth[v] (Figure 1).

This follows a global trend; a 2017 report by McKinsey identified a 1% per annum global construction labour productivity increase over the past two decades compared with 2.8% for the total world economy and 3.6% for manufacturing. The report further found that:

> *"Examples of innovative firms and regions suggest that acting in seven areas simultaneously could boost productivity by 50 to 60 percent. They are: reshape regulation; rewire the contractual framework to reshape industry dynamics; rethink design and engineering processes; improve procurement and supply-chain management; improve on-site execution; infuse digital technology, new materials, and advanced automation; and reskill the workforce[vi]".*

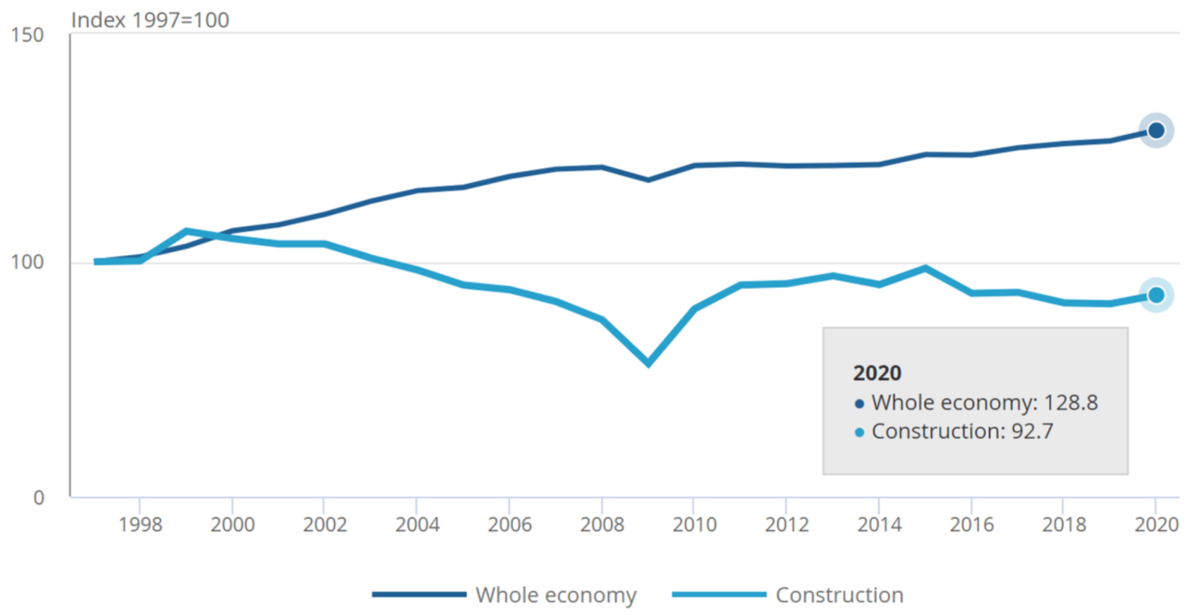


Figure 1 – Construction productivity in the UK has been slow compared with the whole economy (output per hour worked, UK construction industry and whole UK economy)[vii]

Investment in digital technologies for construction

Recent technological and digital advances provide opportunities to address this productivity challenge. It is widely accepted that by deploying digital techniques throughout the design delivers better solutions with more certainly during construction and operation. The Cabinet Office's Construction Playbook[viii] mandates contracting authorities to harmonise and digitise project delivery, calling for *"contracting authorities [to] incentivise the development of digital capabilities throughout the supply chain and other client organisations. This is not simply about contracting for specific capabilities but rather promoting integration and interoperability throughout the sector."*

Successful investment in digital technology for construction can be seen in the uptake of Building Information Modelling (BIM) over the last decade, triggered by a government initiative and subsequent industry mandate.

ISO 19650 - *Managing information with Building Information Modelling (BIM),* defines BIM as *"the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions"*. The Infrastructure and Projects Authority [ix](IPA) describes BIM as a *"combination of process, standards and technology through which it is possible to generate, visualise, exchange, assure and subsequently use and re-use information, including data, to form a trustworthy foundation for decision-making to the benefit of all those involved in any part of an asset's lifecycle. This includes inception, capital phase procurement and delivery, asset and facility management, maintenance, refurbishment, and ultimately an asset's disposal or re-use."*

In 2008, BIM was identified as having the potential to enable £2bn annual savings to UK construction and therefore was a significant tool for Government to reach the then target of 15-20% savings on the costs of capital projects by 2015.

The 2011 Government Construction Strategy introduced the requirement for fully collaborative BIM as a minimum by 2016, now referred to as the Information Management Mandate. BIM has since become established in the construction sector, with its collaboration, quality and

efficiency benefits becoming clear and technology advancing to include 5D BIM. 5D BIM incorporates schedule, costed components and materials into the information model which, when deployed through the lifecycle stages, can optimise resources and increase productivity achieved by automation processes.

BIM has been standardised through the UK BIM Framework and ISO 19650. Work has been undertaken by the BIM Interoperability Expert Group (BIEG) to build its success and it is a key part of the Transforming Infrastructure Performance: Roadmap to 2030, published in 2021[x].

However, digital modelling of design is just one part of making construction more efficient. Another major element is the use of plant and machinery on site, whether this is heavy plant like compactors and excavators, or newer and smaller technologies such as drones.

The use of plant is a major source of construction emissions. It has been estimated[xi] that emissions from construction plant can represent 5% of a road construction project (with 75% material production and 20% transport), with mid-range fuel use of 19 litres per hour for bulldozers, 45 litres per hour for large excavators, whilst even smaller excavating plant (such as a backhoe excavator) uses 7.5 litres per hour. Whilst decarbonisation targets will inevitably move fuel use towards electricity and potentially hydrogen, increasing efficiency will reduce energy use, no matter what the fuel. This will have positive impacts not only on the construction sector, but the wider economy and environment.

The CAP opportunity

National Highways define CAP as, *"construction plant that is connected to its environment through sensors or wireless transfer of data between a remote operator while the autonomy element refers to aspects of the vehicle's operation and also movement around a site[xii]"*. CAP provides the opportunity for the construction sector to rethink design and delivery, access new and more effective materials practices through automation, and provide new skills into the market. In turn, this would make the delivery of infrastructure more efficient, enabling investment in more of the UK's construction pipeline and growing the sector.

CAP represents a potential step forward in decarbonising infrastructure delivery. Carbon emissions through construction would be reduced by improvements in efficiency and reduction in human error, for example, rework or over-digging on site.

CAP adoption would also lead to improving safety, health and wellbeing in the industry. CAP has the potential to reduce fatalities on site by removing operators from high-risk environments, in addition to a reduction in stress and workplace injuries[xiii].

Analysis approach

In the delivery of major infrastructure, some of the key types of technology or machinery used are bulldozing, compaction, excavating, loading, geofencing and telematics. Within these, there are variable levels of maturity and usage, which influence their current and potential future impact. Currently bulldozing and compaction have the highest levels of CAP adoption and the most impact. Future widespread deployment to excavation and loading would have a significant impact due to the higher numbers of machines involved.

To understand the market CAP opportunity, its application within bulldozing, compaction, excavating and loading activities (representing around 80% of UK plant production), were modelled as these represent a large proportion of construction activities and have the best available data on levels and uptake of automation. Geofencing and telematics are supporting technologies which have the potential to enable many different forms of construction activity and were, therefore, considered in their own right.

For these four types of CAP, high, central and low uptake scenarios were modelled, considering economic benefits which will accrue to makers and users of this equipment between 2023 and 2050, as well as wider benefits such as reduced carbon emissions from plant and increased export of construction machinery.

The research also engaged sector stakeholders to identify and test the enablers and barriers to growth in the use of CAP to provide a clear summary of how these three scenarios could be reached.

Data and assumptions have been compiled based on national and industry data, and interviews with a wide cross-section of CAP and construction industry stakeholders. Details of the methodology for this market analysis can be found in Annexes E and F.

2. Work done to date on the uptake of Connected and Autonomous Plant

Defining CAP

National Highways has been an industry leader in the study and uptake of Connected and Autonomous Plant. In 2020, National Highways' Safety and Engineering Standards (SES) led Phase One of their CAP project, which involved collaborating with over 100 organisations and the Infrastructure Industry Innovation Partnership (i3P), in order to develop a Connected and Autonomous Plant Roadmap to 2035[xiv].

When defining CAP, it is important to consider the terms connected and autonomous separately to fully appreciate their significance.

Connected references the plant's ability to communicate outside of its own internal systems enabling the bi-directional flow of data between itself and other plant, or wider to approved networks and systems via encrypted communication links such as 5G.

Regarding the term **autonomous**, a recent CITC Global conference paper titled 'The Future of Automated Plant in Construction', made an important distinction in the use of the term. The paper highlights that automation refers to the conversion of a well-defined task which would usually be conducted by a human to one undertaken by a machine or computer. Autonomy is the ability of a system to operate independently in conducting tasks, without control or intervention by humans or other systems. Despite making this distinction, the term autonomous if often used to cover both aspects[xv].

For many of the construction tasks performed in present-day construction site environments, the CAP ambition is to be able to create an automated process and system where the tasks are completed safely within proven operational constraints and legislation.

It is important to note that while they may overlap, the term 'Plant' is not the same as 'Non-Road Mobile Machinery' (NRMM). Separate work is being undertaken, including by the DfT, on how NRMM could be used effectively to decarbonise and improve efficiency in the construction sector.

National Highways CAP Roadmap

Launched in 2020, the National Highways CAP Roadmap sets out the requirements for significant uptake of CAP across National Highways and other infrastructure client and delivery organisations, and crucially outlines a path to achieving these requirements.

Following extensive stakeholder engagement across the construction and infrastructure industries, a set of nine overlapping workstreams were identified, with workstream progress required to meet the Roadmap's aims (Figure 2). These aims can be summarised as developing the required standards, legislation and user

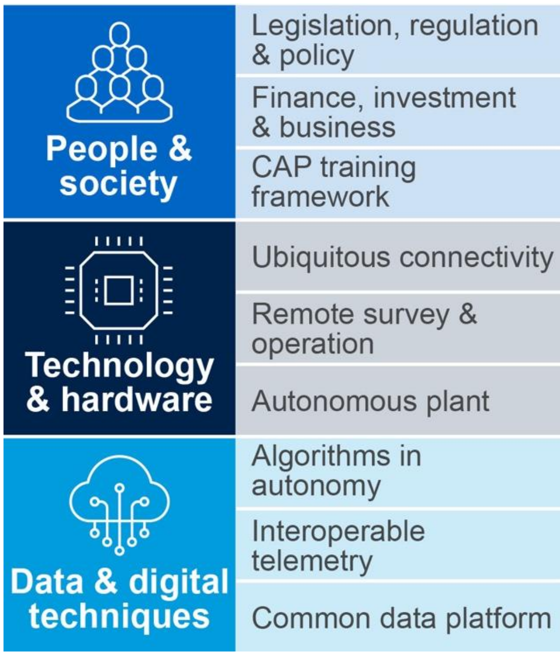


Figure 2 – CAP Roadmap identified nine overlapping workstreams

understanding to allow the wide scale uptake of CAP in the construction industry.

CAP maturity levels

In 2021 and 2022 National Highways' CAP project continued with phase two, with the objective of developing a matrix of maturity 'levels' for CAP to act as a standardised measure across clients, sites, users and original equipment manufacturers (OEMs). Involving over 250 leading industry experts, it was an industry-wide collaboration of supply chain contractors, National Highways, academia and i3P.

The CAP Levels are a means by which to rate plant based on five core capabilities, giving the industry a standardised set of measures to express CAP capability for different plant types and uses.

These five OUDAR capabilities, Figure 3, are:

Observe: How automated a system is at acquiring data from its environment

Understand: How automated a system is at processing data to determine its environment based on observations

Decide: How automated a system is at deciding what action to take based on its understood environment

Act: How automated a system is at carrying out an action based on a decision

Responsibility: Who or what is ultimately responsible for the continued safe operation of the machine

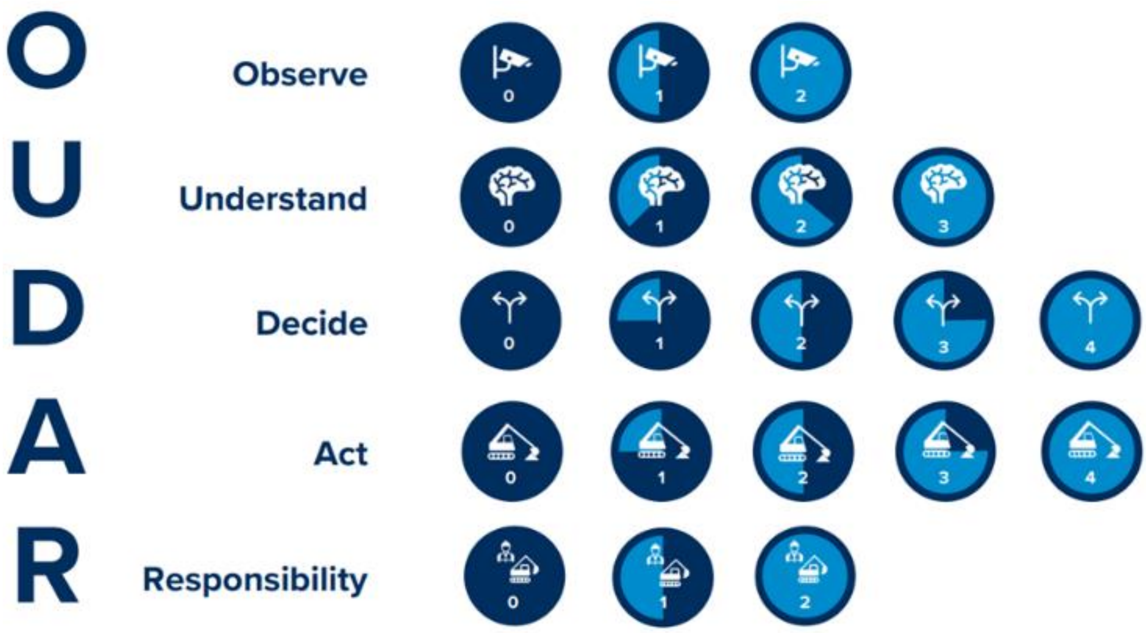


Figure 3 - Shows CAP maturity levels as developed in CAP phase 2

Example 1 of CAP Maturity levels (OUDAR Levels) as applied to existing plant: Robomag[xvi].

Figure 4 - BOMAG Robomag Autonomous Roller

OUDAR	Level	Description
Observe	**2**	Robomag is equipped with GNSS, LIDAR and stereo cameras to allow it to observe its environment in high-fidelity automatically. It also has drum sensors and other proximity sensors for collision avoidance.
Understand	**2**	Robomag uses observed parameters to understand its environment automatically. The GNSS receiver, for example, allows the machine to understand its position within a geofenced site area. The drum sensors, for example, enable automated understanding of stiffness.
Decide	**3**	The machine calculates the most efficient way of completing pre-set tasks within the geofence and begins operating; a manual route override is available prior to tasks beginning.
Act	**4**	The machine implements the predefined compaction task, without the ability to override these operational inputs. Utilising interpreted data from drum sensors, Robomag automatically adjusts compaction force for consistent stiffness, increasing for soft spots and decreasing for hard spots.
Responsibility	**2**	The machine is responsible and capable of maintaining its safety without intervention from a human.

Table 1 - Classifying the Automated Capability of Robomag Autonomous Roller

Example 2 of CAP Maturity levels (OUDAR Levels) as applied to existing plant: CAT Command for Compaction[xvii].

Figure 5 - CAT CS56B Compacter

OUDAR	Level	Description
Observe	**1**	CAT Command for compaction, for example a CAT CS56B contains all required sensors including dual RTK positioning and radar object detection that allow the vehicle to run in AUTO mode.
Understand	**2**	The system uses observed parameters to understand all environmental parameters required to complete the compaction task.
Decide	**2**	The operator inputs a task and the system asses if it is able to run in AUTO mode. If the systems are operating as normal, the machine will carry out its task until completion.
Act	**3**	The machine implements the input compaction task. The difference to Robomag is that the machine is being more closely supervised. The operator must react to system messages to continue in AUTO mode.
Responsibility	**2**	The system is responsible of maintaining the safety of the machine in AUTO mode; however, it will ask for human intervention where required.

Table 2 - Classifying the Automated Capability of a CAT CS56B Compactor

Overview of most recent CAP project and initiatives

The National Highways CAP project is now in phase three, with three distinct but interrelated tasks:

Legislation and Ethics/ Commercial and Standards review: which identifies and outlines standards and commercial barriers to CAP adoption.

Design for Machines: which develops guidelines to maximise adoption of 3D machine control, removing barriers to getting compatible designs into machines.

Virtual Testbed: which develops the architecture for a dashboard which gives a view of the maturity of CAP operating on a given site.

This report sits separately to National Highways' Roadmap but is complementary to the commercial review of barriers to adoption.

In developing and defining CAP, the need for an industry standard became clear and has now been developed. 'PAS 1892:2023 Connected and Automated Plant' defines and specifies the use of CAP in construction and maintenance works for the purposes of procurements and deployment.

There are also several regulations and standards that are not directly related to CAP, but to which CAP technologies would have to comply with or consider, such as the Automated and Electric Vehicles Act 2021, Cybersecurity regulations, the Data Protection Act, and regulations associated with Cooperative, Connected and Automated Mobility.

3. Current state of the Connected and Autonomous Plant market

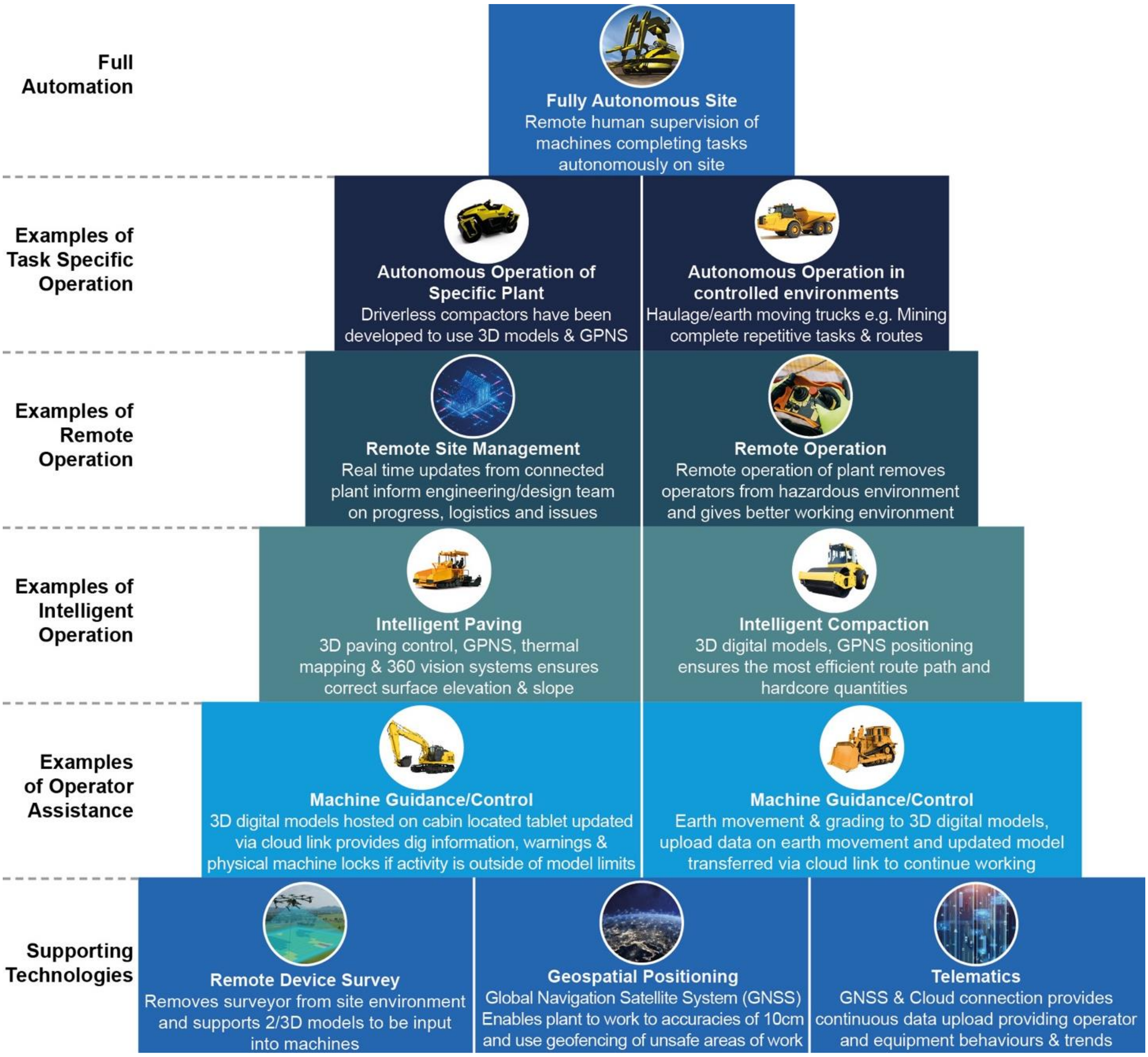


Figure 6 - CAP applications and their increasing levels of maturity

Elements that enable CAP (e.g. machine assist, semi-autonomous operations, connectivity) are currently being adopted gradually across the construction sector. They can achieve functions, such as real-time data transfer, remote operation, distance control between vehicles, and geofencing of plant within specified location parameters, that can improve the efficiency and effectiveness of construction activities. Examples include the use of GPS and data transfer to ensure correct and even levels of compaction, or machine operator assist to prevent over-digging during excavation and more efficient grading based on pre-set parameters. In these cases, the operation is still undertaken by a human, but the connectivity aids performance.

Automated plant integrates some aspects of autonomous operation either within certain areas or for certain functions, with or without an operator present in the cab. This technology is already in use in the mining sector (refer to Section 3 Mining subsection). Such activities could include

hauling materials on a preset GPS path, excavation within defined parameters or construction activities such as 3D printing. Whilst connected plant does not imply that automated activities are undertaken, automated plant must have connectivity.

When considering CAP, it is pertinent to note that this can include technology fitted to a machine by the manufacturer during construction, or 'aftermarket' technology retrofitted to a machine. The latter could be undertaken by an owner-operator contractor or plant hire company to a new machine or a machine already in use before being sent to a site.

Whether factory-fitted, or fitted as an aftermarket technology, CAP technology has two main components: the hardware and software. Depending on the level of automation, the hardware could comprise sensors, GPS location, cameras and lidar to map the position of the plant on the site.

Whilst some machinery manufacturers have commercial arrangements with technology providers, in general, any machine can be fitted with hardware from the main manufacturers. The hardware tends to be a one-time capital cost.

The software provides the platform for users to update site drawings with design and levels, as well as far wider applications in enabling connectivity, automation, data gathering and analysis. Where this is used currently, this would assist the operator in undertaking the work, for example, by preventing over-digging and fine control. In a fully autonomous future scenario, the software will be used to program the machines to undertake the task with no operator.

The software, which can be 2D or 3D depending on the application, is generally purchased on a subscription basis. There are potentially some interoperability issues regarding the software developed by the different sensor companies, but this relates to specific functionalities rather than a complete lack of compatibility. There is also an ISO standard in development which is likely to aid this. This is particularly relevant for the UK market, with the large rental fleet, where there could be multiple combinations of plant and technology hired for a construction project.

In most cases, the CAP currently in use is carrying out simpler and mainly repetitive tasks (such as bulldozing and compaction), in which efficiency improvements can, however, lead to significant value gains. The improvement in efficiency is not limited to the completion of simple tasks, but also in freeing up skilled operators to focus on the more complex tasks where human interaction is required.

The use of CAP can also deliver carbon reductions by operating more efficiently than manual operations through the prevention of over-digging or through consistent compaction and optimising job site efficiency. For example, bucket loading accounts for 40% of fuel consumption, prevention of over-digging offers significant carbon saving potential, whilst correct compaction can significantly improve expected road life.

However, current use of CAP is limited mainly by the existing structure and culture within the construction industry such that productivity is not explicitly incentivised and there is no evidence of commitment from across public and private sector procurers and suppliers. Slow adoption is influenced by aspects such as the absence of defined long-term strategy and targets that will motivate the transformation from traditional

Trimble Inc. reports, that there are over 100,000 earth-moving (dozer) vehicles fitted with machine control worldwide. In one study a side-by-side comparison of standard machines and ones with machine control technology was undertaken for shaping a side slope in a new road construction project with an experienced operator and a beginner. With machine control, the experienced operator completed the same task 41% faster with a 75% increase in accuracy, whilst the less experienced operator worked 28% faster with a 100% improvement in accuracy.

working practices, business models in use (e.g. leasing of construction equipment), lack of a resilient pipeline of future works, perceived risks of data gathering and sharing as Standards are yet to be defined.

Increasingly, incentives resulting from market dynamics are being put in place and these include importance being given to improving health and safety in work sites by reducing human intervention, mandating the use of aspects of CAP such as machine assist, decarbonisation targets, rapidly evolving digitalisation, changing demographics resulting in difficulty in resourcing on-site workers.

The CAP market in the UK

According to the Construction Equipment Association's 2023 Report, the construction equipment sector (made up of Original Equipment Manufacturers (OEMs) with UK production facilities and overseas OEMs with UK offices, accessory suppliers, trade publishers, service providers and equipment distributors) has had significant growth since 2018.

The Report states that *"the sector has seen substantial growth in its total revenue, which has increased to over £15 billion in 2021/22, from £13 billion in 2018. […] Employment in the sector rose 10% from 40,000 to over 44,000 in the same period*[xviii]". Original Equipment Manufacturers (OEMs) account for about 48% of revenue within the construction equipment sector distributors 21%, component suppliers 20% and other services & suppliers accounting for the remaining 11%.

This growth has been accompanied by "significant annual investment in Research and Development (R&D), amounting to £250 million[xix]". Decarbonisation stimulus has enabled R&D investment by the OEMs with ~3% growth between 2014 and 2022, despite the difficult economic circumstances.

Approximately 20% of equipment currently in use fits under the CAP umbrella, through use of semi- or full-automation or elements of connectivity[xx]. This however is not uniform with higher percentages in single application machines and a lower uptake in excavators.

Company	Equipment
BG Pavers	Asphalt Finishers
Caterpillar	Articulated Dump Trucks, Backhoe Loaders, Engines, Compact Wheel Loaders
Hewitt Robins	Crushers, Screens
JCB Cheadle	Articulated Dump Trucks, Backhoe Loaders, Crawler Excavators, Engines, Mini Excavators, Telehandlers, Wheeled Excavators, Wheeled Loaders
Komatsu	Crawler Excavators, Wheeled Excavators
McCloskey	Crushers, Screens
Mecalac	Compaction Equipment, Site Dumpers
NC Engineering	Site Dumpers, Telehandlers
Phoenix Engineering	Asphalt Finishers, Spreaders
Red Rhino Crushers	Mini Crushers, Screens
Sandvik	Crushers, Screens
Telestack	Screens, Feeders and Conveyors
Terex	Omagh Crushers, Screens
Thwaites	Site Dumpers
Volvo	Articulated Dump Trucks, Rigid Dump Truck

Table 3 - Key OEMs and the equipment they manufacture in the UK

OEMs sell equipment directly to the market or through dedicated suppliers. Given the large proportion of hire plant in the UK, a large number of machines will be purchased by large plant hire companies. Around 30% of the market is occupied by companies that own their plant and top-up additional requirements with hired machines. Discussions with plant hire companies reveal that they will supply CAP technology if the client requests it, but they do not routinely fit the technology. Their telemetry has shown that where they have fitted CAP technology, only a small percentage of the users take advantage of the features available. Discussions with OEMs suggest that the main purchasers of CAP are either smaller contractors who see the value in technology, or where it is mandated by clients procuring large schemes.

The UK has a significantly larger hire fleet than European comparators, with 65-70% of all machines being leased rather than bought. Where hire firms have added CAP technology to machines, they have found that most customers are unwilling to pay the additional hourly hire rate. Hire companies also have a business model based on being able to provide machines with more or less immediate turnaround and resale of the equipment after four to five years. Fitting or removing CAP equipment is an additional cost to them which delays the hire or sale in a highly competitive market.

Use of CAP in the UK construction sector

Currently, CAP technology is used in some areas in the UK construction sector including dozing, grading, compaction and excavation, but the distribution of each is not uniform across construction projects.

Dozers and graders

Machines such as bulldozers and graders have relatively high rates of adoption of machine control. Equipment manufacturers contacted as part of this report's research are of the view that around 40 - 70% of the units in use are fitted with machine control in the factory, with some additional (but unknown numbers) units retrofitted with aftermarket technology.

Compactors

Compactors are increasingly being fitted with technology, as intelligent compaction offers significant benefits in terms of road

HS2 undertook a series of trials of semi-autonomous compaction operations during Phase 1 construction from London to Birmingham. The use of intelligent compaction reduced the number of passes required from a guideline of 7 to 3 based on actual ground measurements. This resulted in a series of benefits, namely, improved quality based on the assurance of passes completed to the compaction required, a significant increase in productivity and fuel savings of 30%.

One of the key aims of the trials was to derisk the technology for deployment on the now cancelled, Phase 2. This was in part to demonstrate overall cost savings and to overcome the cost pressure, where the cheapest machine was purchased or rented by contractors. Based on the savings achieved, there is confidence that the contractors would have invested in intelligent compaction for Phase 2. Whilst there will be future large infrastructure schemes where CAP can be used, many of the Phase 2 replacement schemes do not have the same risk profile, so adoption is likely to be lower.

Other outcomes of interest, which augur well for future growth in CAP adoption, include:

- Willingness from the contracting community to participate in trials
- The ease and speed with which participating operators were able to become proficient in the handling of the systems
- The confidence of the participating operators and the site teams regarding the safe and predictable nature of the operations.

construction quality, by either ensuring that the specified number of passes have been completed or that the stiffness resulting from compaction is in accordance with design. A large plant hire firm reported that 100% of their compactors are fitted with CAP. One manufacturer noted that the levels of compaction achieved by non-CAP machines currently in use exceed figures specified in the standards, risking either over-compaction and/or wasted effort and thereby driving up costs.

With intelligent compaction, it would be possible to reduce the number of passes, achieving corresponding time, labour and fuel savings. Intelligent compaction is one of National Highways' key priorities for the next road period. In addition to improved construction, it offers fuel savings from not overworking, and a safety improvement through the avoidance of reworking. Reworking carries higher risk to safety as it is unplanned.

Excavators

Excavators are reported to have around 10% of units fitted with intelligent machine control in the factory, plus some (unknown numbers) retrofitted with aftermarket technology. Here too, the distribution is not uniform, and through our engagement with several manufacturers and the Construction Equipment Association, it is understood that excavators in the 13 to 20 tonne range are most suitable for 2D or 3D technology adoption; above this size is largely haulage, whilst below the size are utility works.

Fitting of machine control to smaller machines such as mini-diggers or backhoe excavators is unlikely to be achievable in the short to medium term, partly because the cost of fitting the technology could be as much or more than the cost of the machine, and because the sheer range of tasks these machines undertake would make fitting suitable technology difficult. A JCB 3CX (standard backhoe excavator) on any given day could be breaking out concrete or tarmac, trench digging, undertaking earthworks or hauling materials, making it difficult to choose appropriate technology and to justify the cost.

Telematics

A particular growth area for CAP in the UK is telematics which is useful across fleets. This is used by both hire companies and owner-operators and gives a view of the performance of the fleet in terms of utilisation, idling time and performance. This can be useful in several areas. Traditionally, maintenance of construction plant is based on a schedule of hours worked, however, understanding how the machines are performing enables predictive and preventative maintenance, thereby improving performance and saving fuel. Another key area is having the visibility of machine use and being able to put procedures in place and change operator behaviour, such as excessive engine idling. In an American study[xxi], it was estimated that 10 – 30% of fuel use on construction sites is from nonproductive idling, which can be reduced by 10 – 15% using telematics. This backs up anecdotal information from an OEM who stated that one of their clients reported significant fuel savings from a live telematics system.

Geotagging and geofencing

In a wider definition of CAP, geotagging and geofencing are increasingly used to derive safety benefits by keeping people and plant separate from one another and avoiding hazardous areas. Beyond that, there are potential efficiencies to be gained through real-time asset tracking of equipment, vehicles and materials for resource allocation and live route planning and fuel savings. For example, one study reported that companies using geolocation technology saw a 30% decrease in fuel costs and a 15% improvement in overall fleet productivity[xxii].

Global uses of CAP across different sectors

CAP and similar technologies are in use in several sectors at varying levels of adoption. This is advantageous for stimulating growth in uptake, as whilst the applications might be different, technologies that are inherently sub-sets of CAP, such as sensing, geo-positioning, connectivity and remote operations, are transferable to the construction sector. This will also help to lower costs, as the market is larger, which drives R&D and competition, and builds confidence in the systems.

Rail and Light Rail

Discussions with Network Rail reveal that currently progress in the adoption of CAP is not explicitly included in the long-term strategy, due to the higher age profile and lower utilisation of equipment. However, aspects of technology that will result in an organic progression towards CAP, are increasingly being adopted to improve efficiency of infrastructure management and the safety of track workers. This includes examples of automation of certain tasks, such as ballast tamping, removal and replacement of sleepers and automated inspection (e.g. using robots such as FELIX to replace manual inspection of switches and crossings etc, drones, remote sensing tools).

More generally, as there is relative control over vehicles using the track infrastructure and the associated operational systems such as signalling, delivering automation for rail is more straightforward compared to the road sector. This is particularly the case for light rail operations such as metro services which have smaller networks and often a single operator controlling the infrastructure and vehicles. Examples include the Docklands Light Railway and various metros including Paris, Tokyo, Copenhagen, Barcelona, Nuremberg, Budapest and Dubai[xxiii,xxiv] that have either some lines or the entire network operating autonomously.

There are also examples of heavy rail operation including fully automated freight trains in north-western Australia operated from a control centre in Perth, 1,500 km away[xxv]. The relevance to CAP is the increased use of, and confidence in, remote operation of machinery or remote supervision of autonomous machines.

Figure 7 - Network Rail's ballast cleaner system (BCS) in operation, which limits worker exposure to hazards[xxvi]

Mining

Mining is an ideal use case for autonomous operations with repetitive routes travelled by the vehicles. A 2020 article states that around 500 autonomous trucks were working in surface mines in the world, of which 80% were in Australia, which was a 32% increase from 2019, with numbers predicted to triple by 2023[xxvii]. Komatsu and Caterpillar collectively accounted for 93% of the vehicles being operated at that time. The improved efficiency from introduction of autonomous trucks at Newmont's Boddington gold mine in Western Australia in 2021 is expected to deliver benefits including extension of the mine's life and an IRI (Internal Rate of Return) of over 35%[xxviii]. There are parallels to the construction sector in terms of the remote use of machines, potentially in a challenging environment. Moreover, the market leaders are also major manufacturers of plant and CAP technology.

Ports

Various aspects of port operations can be automated including ship-to-shore movement, crane operation, yard movement and container stacking. A report on automated ports[xxix] predicts a potential decrease in operating costs of 20-25% and an increase in operating efficiency of 30-35% compared to conventional port operations. Much of the automation goes beyond the general vehicles and into the digitisation of port operations, including the use of digital twins, artificial intelligence in port operations and the use of drones for inspection and visibility of operations[xxx]. Job site optimisation and monitoring by drones are both areas where significant productivity gains can be made in the construction sector.

Military

Drones and unmanned aerial vehicles have been used for surveillance and in active battle situations for many years. The British Army is conducting trials to determine options for delivering last-mile supplies of items such as fuel, ammunition and food in battlefield situations, which are typically hostile environments[xxxi]. Recognising the potential of autonomous vehicles and robotics, the British Army opened the Expeditionary Robotics Centre of Expertise in 2021[xxxii]. Given the typically rough terrain and requirement for accurate positioning, there are some aspects that are transferable to construction.

Agriculture

McKinsey and company report[xxxiii] that agriculture faces significant pressures around the availability and cost of labour, e.g. fertiliser costs have increased by 15% per year, spiking after 2021. Automation is being introduced to reduce costs and address consumer preference around organic and sustainable farming, in areas[xxxiv] such as harvest automation, autonomous tractors, seeding and weeding, drone monitoring and delivery of fertiliser and weedkiller. The report shows savings of between US$200 and US$800 per acre in vineyards from automated pruning, spraying, weeding and harvesting. The use of geo-positioning could be transferable to construction, whilst the general advancement in robotics could potentially be transferred to applications in the construction sector.

Aviation

The construction of airports lends itself readily to the use of machine control with the movement and grading of vast amounts of earth to construct the terminal building and the larger areas of supporting taxiways and runways. It is critical to ensure the required base layer thickness and compaction conforms to the design specification along with the correct elevation and level. An example where this technology was adopted was the Western Sydney Airport, Australia.

Runway and taxiway maintenance activities are also taking advantage of 3D machine control technology where the reprofiling (resurfacing) of worn surfaces is required to be undertaken outside of airport operating hours resulting in an extremely tight overnight working window. This was the case for the reprofiling of the Luxembourg Airport[xxxv] in 2021 and 2022 with the work described as a high-precision, highly complex mission with no room for delays and made possible by 3D machine guidance being implemented by a skilled team.

4. Current and future size of the Connected and Autonomous Plant market

The construction equipment sector was worth £15bn in 2022[xxxvi], of which £6bn is sold domestically and £9bn is exported.

The production and sale of CAP equipment leads to economic benefits as the OEMs producing the CAP equipment add value to the economy with this increased demand.

Interviews have been conducted with plant equipment manufacturers, technology manufacturers, technology installers, plant lease hire companies, contractors, representatives from industry media, plant distribution professionals, earthworks specialists, industry organisations, UK and international governmental bodies, and sustainability advocates. More details are provided in Annexes E and H to understand their broad perspective of CAP. In addition, past data from within the CAP and construction industries has been reviewed. This combined bank of information has been used to produce and inform an economic model which calculates the current and future potential market for CAP. Findings are detailed below and in Annex F.

The analysis addresses four key equipment architypes – bulldozing and grading, compaction, excavating and loading, which make up a significant proportion of that market, and are expected to continue to do so, as shown in table 4 below.

	£m				
	2025	2030	2035	2040	2050
Total	13,206	14,592	16,110	17,787	21,682
Bulldozing	990	1,094	1,208	1,334	1,626
Compaction	330	365	403	445	542
Excavating	9,244	10,214	11,277	12,451	15,178
Loading	2,641	2,918	3,222	3,557	4,336

Table 4 - Plant market size projections (all equipment)

Approximately 20% of equipment currently in use fits under the CAP umbrella, through use of semi- or full-automation or elements of connectivity[xxxvii]. Based on broad stakeholder engagement and interviews, it is estimated that the share of equipment that is connected and/or autonomous will be as follows across the equipment types:

Bulldozing and grading, **compaction**, and **loading** is expected to be 100% CAP by 2050, reflecting existing high uptake and singular highly repeatable applications.

The adoption of CAP technology in **excavation plant** is expected to reach 60% by 2050. With the cost of CAP technology expected to reduce, a business case can likely be made for use on smaller machines (e.g. 5 to 7 tonne). It is unlikely that there will ever be 100% adoption of CAP on excavators, particularly the very small (1 to 2 tonne) machines that are typically used for small projects such as landscaping, small excavations and general use on farms, where the benefits that can be gained with larger machines would not be realised. At the other end of the scale, machines above around 50 tonnes are typically used for loading in mines, quarries and other such applications. In the short term, some of the benefits of machine assistance may not be realised here because they undertake fewer precision tasks which currently gain most from CAP. In the longer term, these could be good candidates for remote operation or full autonomy.

The below table 5 summarises the potential growth in the CAP market, with the central scenario current market size of £3.4bn growing to £15.6bn in 2050.

	£m				
	2025	2030	2035	2040	2050
Total	3,377	5,086	7,112	9,503	15,611
Bulldozing	283	469	690	953	1,626
Compaction	94	156	230	318	542
Excavating	2,245	3,210	4,350	5,692	9,107
Loading	755	1,251	1,841	2,541	4,336

Table 5 - Plant market size projections (CAP only, central scenario)

In addition, significant growth is expected in the market for geofencing technology. The geofencing market growth will likely accelerate in coming few years before levelling off around 2030, with market size in 2035 potentially 10 times what it is currently.

With all types of CAP taken into consideration, and a range applied to account for uncertainty levels in forecasting future sector behaviour, table 6 summarises the potential growth in the CAP market to 2050.

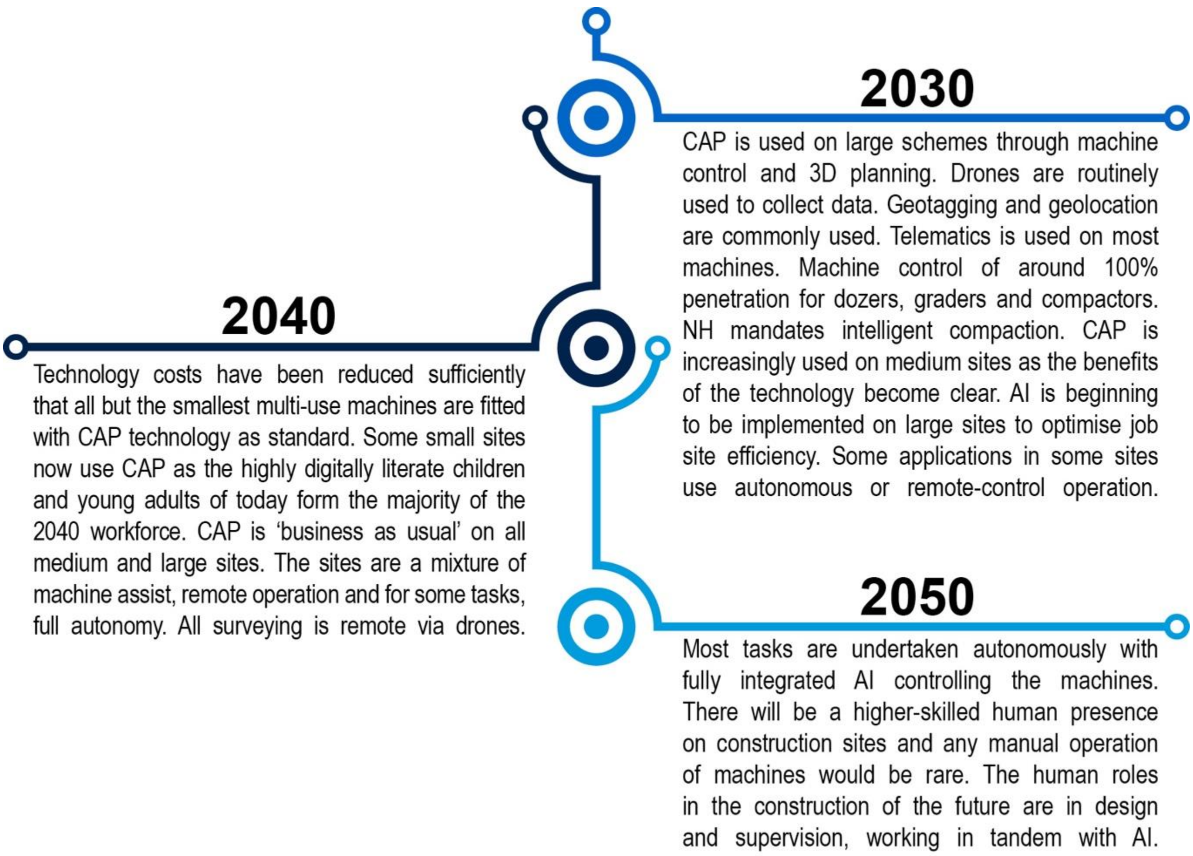
	£m				
	2025	2030	2035	2040	2050
High	4,221	6,358	8,889	11,879	19,514
Central	3,377	5,086	7,112	9,503	15,611
Low	2,533	3,815	5,334	7,128	11,708

Table 6 - Forecast growth in CAP market

The CAP market size is then impacted as when orders for CAP equipment are made, the CAP equipment producing sectors increase production to meet these orders, resulting in increased Gross Value Added (GVA).

Future vision for construction

An ambitious future vision for major Government infrastructure projects is outlined below, presenting scenarios where CAP is fully adopted and utilised by the construction sector. This is not intended as a prediction, but rather a vision of the degree of change that might be expected through the years 2030, 2040 and 2050.



5. Market Opportunities for the Connected and Autonomous Plant market

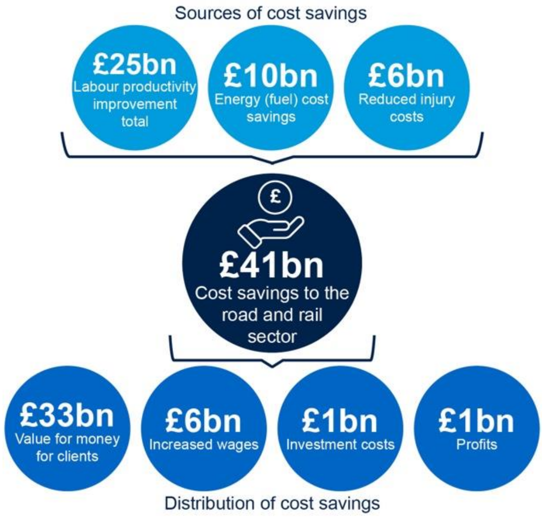
The market opportunities relating to CAP would not be limited to only those delivering major infrastructure but be felt across the construction sector and in the wider economy. The below opportunities are modelled on a central CAP uptake scenario for the road and rail sector, but while this is the sector examined in detail, rough estimates for the transportation and overall construction sector more broadly are made by scaling these benefits up to from the relative size of this sub-sector to the full size of the parent construction sector.

There are three scenarios that have been modelled: high uptake and high impacts; central scenario; and low uptake, low impacts. The purpose is to span a wide range of potential impacts of CAP. Many of the assumptions have built in ranges of estimates for high, central, and low, as outlined in the modelling methodology in Annex F.

Cost savings as a result of CAP

The cost savings to the road and rail sector total **£41bn** cumulatively to 2050 and derive from three sources:

- **Worker productivity: £25bn** improved productivity of workers with access to equipment with CAP. Benefits to labour productivity from the uptake of CAP include: more accurate task completion, reducing overwork and human error, gathering of data allowing for more efficient design and construction programme planning, and more efficient use of time on site.
- **Fuel savings: £10bn** energy (fuel) savings by machines that idle less and are used more efficiently.
- **Lower injury costs: £6bn** in reduced injury costs as CAP improves safety standards and makes operations more ergonomic.



From the detailed analysis conducted for the road and rail sector, the results have been scaled up to consider:

- Construction sectors likely to easily adopt CAP, or **early adopter** sectors, including wider civil engineering applications, utilities and specialised construction activities involved with demolition and site preparation.
- **All construction sectors** in the economy, including residential and commercial developments and all other construction sector activity.

For the **early adopter** sectors comprised of disciplines most likely to easily adopt CAP in practice, by scaling up the road and rail sector analysis, the total cost savings produced by CAP cumulatively to 2050 are estimated to be around **£207bn**.

When considering the whole construction industry, including **all construction sectors**, by scaling up the road and rail sector analysis, the total cost savings produced by CAP cumulatively to 2050 are estimated to be around **£1,012bn**.

The cost savings that CAP allows will be distributed to paying off the loans to buy the CAP, profits for shareholders, increasing value for money for customers (more output for same cost), and paying higher wages to workers.

A further benefit of CAP is that clients of the road and rail sector enjoy more infrastructure development for the same investment, in that the sector can deliver more for the same costs. Some of the additional value that the sector produces, discussed above, is distributed to capital costs of investing in CAP and some to profits, but a large portion of it, **80% (£33bn),** goes into improved delivery, which increases value for money for the Government as a major purchaser of road and rail infrastructure.

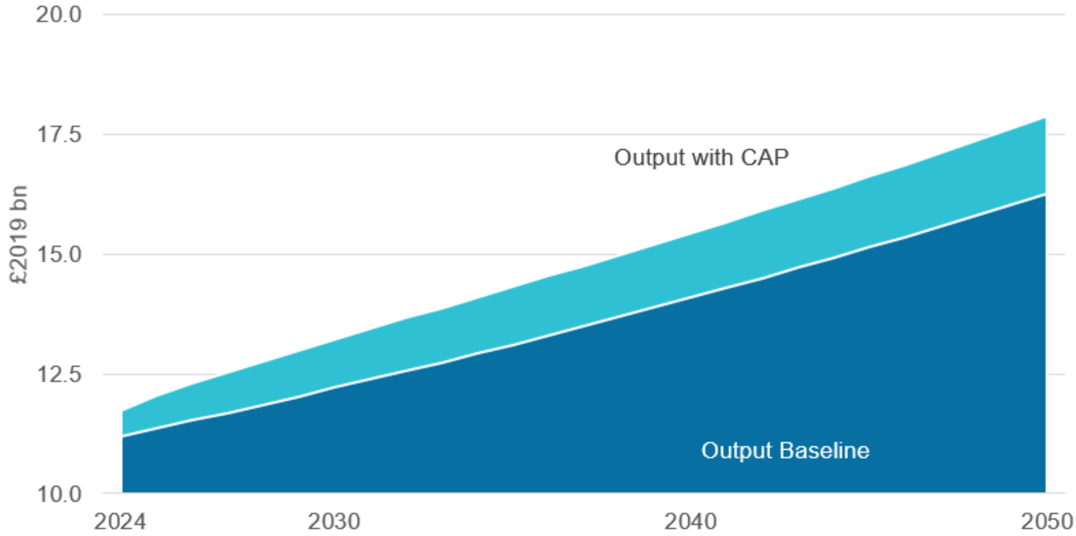


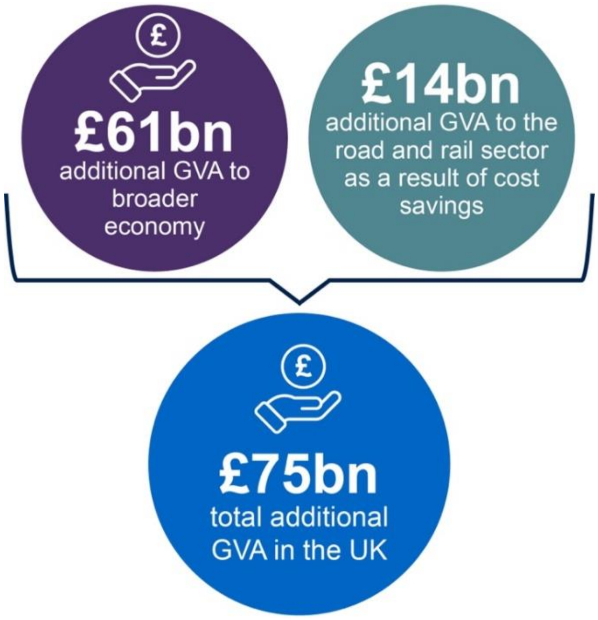
Figure 8 - Value for money gains for Government clients in the road and rail sector (central scenario) – lighter shade representing a total of £33bn gains up to 2050[xxxviii]

Figure 8 shows the output produced by the road and rail sector with and without CAP. The difference between the 'Output with CAP' and 'Output Baseline' areas represents additional output delivered to customers of the road and rail sector for which they pay the same price. Based on the assumption that UK Government clients are effectively the only customers of the road and rail sector, this additional output delivered for the same cost represents a value for money gain for Government.

Additional GVA in UK

Gross Value Added (GVA) is revenues minus the costs of goods and service inputs into production. The sources of value added include labour and capital, and public services, and GVA is mostly distributed to workers, shareholders, and taxes. The more efficient an operation is at converting its inputs into a product or service, the higher the GVA to revenue ratio will be. Also, sectors with low material inputs and high inputs of worker skill, such as consultancy or programming, will have a high GVA to revenue ratio.

The additional GVA calculated for this market analysis is the total additional value being produced by the UK economy cumulatively to 2050 due to the productivity improvements resulting from CAP in the road and rail sector and the effects on the supply chain of producing that CAP equipment.



Total Additional GVA: **£75bn**

Of this Total Additional GVA, the additional GVA to the road and rail sector itself is **£14bn**.

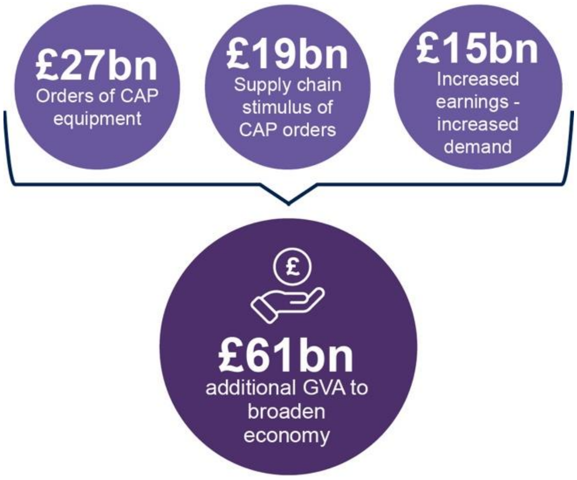
The additional GVA to the broader economy up to 2050 is **£61bn**.

When orders for CAP equipment are made, the CAP equipment producing sectors increase production to meet these orders, and this results in increased GVA (termed 'direct effects' by economists).

These firms in turn increase their orders from their suppliers, and they from theirs, and so on. This supply chain response leads to increased demand, increased production, and therefore adds GVA in the various sectors of the economy which are responding to increased orders from their customers (indirect effects).

Finally, all of this increased output by the CAP producing firms, their suppliers and their suppliers' suppliers leads to more demand for labour, which increases peoples' incomes, which they then spend in the economy, creating demand for goods and services, which then further increases GVA (induced effects).

- **£27bn** direct effects
- **£19bn** indirect effects
- **£15bn** induced effects.



When considering the whole construction industry, including all sectors, by scaling up the road and rail sector analysis and incorporating the benefit to the broader economy (£61bn), the total additional GVA produced by CAP cumulatively to 2050 can be estimated as **£417bn**. This is while noting that by scaling up the detailed analysis, there are increasing levels of uncertainty in the findings.

The following graphic summarises how the effects on the economy from the **production and sale of CAP** and the widespread adoption and subsequent **increased output of the construction sectors using it** lead to additional GVA of **£417bn** cumulative to 2050 for the construction sector as a whole:

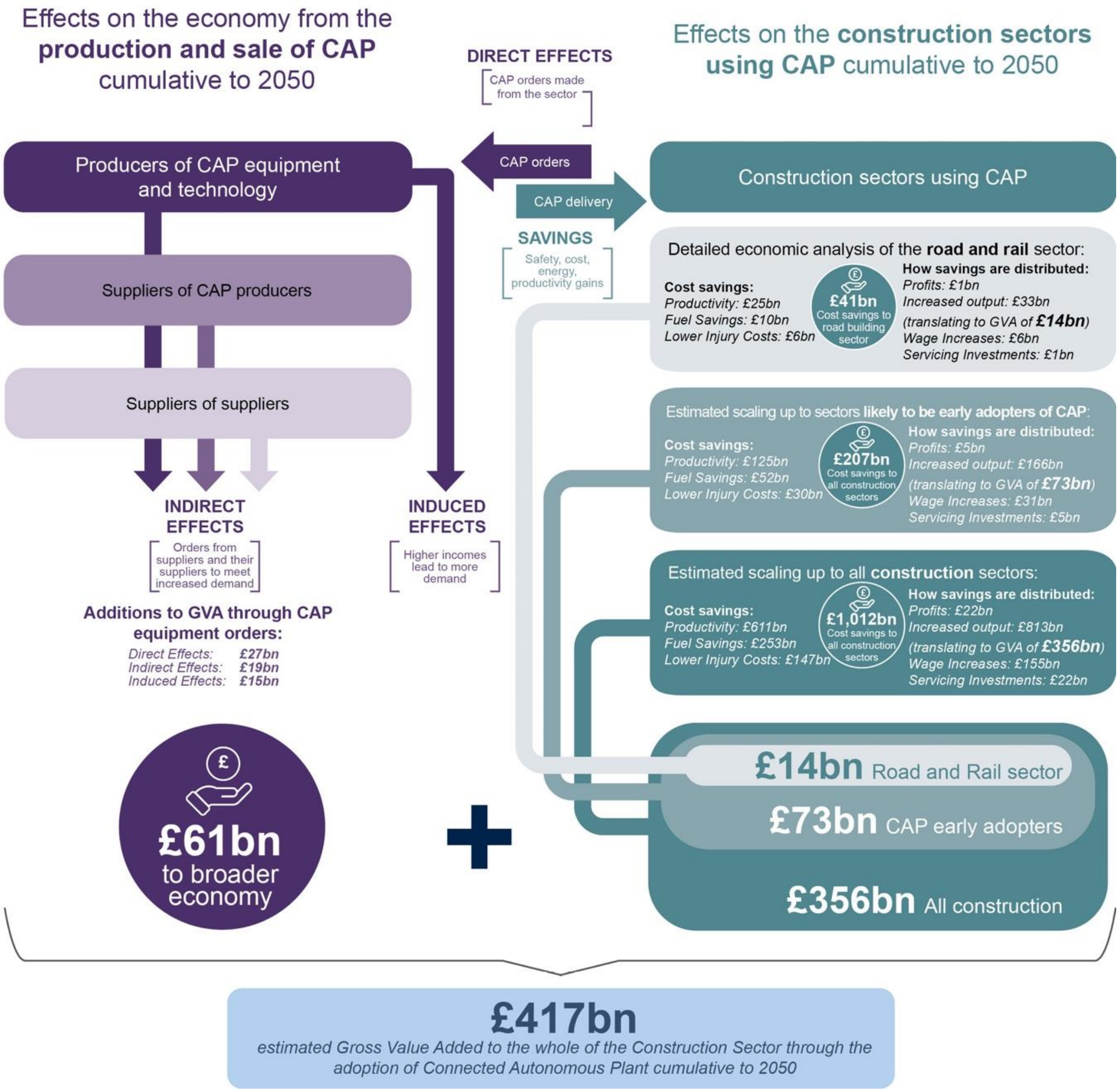


Figure 9 - Overview of the sources of the economic benefits of CAP and how they are distributed leading to additional GVA cumulative to 2050

Employment and wellbeing changes

The introduction of CAP inevitably has effects on the demand for labour in the construction sectors using CAP. Improved productivity of workers means fewer people are needed to get the same work done. Alternatively, the same number are needed to do more work, and the balance of additional output and productivity reducing labour demand is determined in the benefit quantification model's assumptions.

The uptake of CAP and associated changes in skills requirements would lead to the following changes to employment.

Relative to a baseline of no CAP equipment being rolled out, the road and rail construction sector workforce would **reduce by 25,400** by 2050 due to increased productivity.

However, across the broader economy **around 54,800 additional workers** would be required by 2050 due to economic activity stimulated by CAP (arising from the same effects discussed in 'Additional GVA in the UK'), figure 10. It is expected that these jobs would be higher paid and higher skilled in comparison the no-CAP baseline, figures 11 and 12.

The current average sector wage of around **£43,100** would rise to around **£49,000** in 2050 in real terms in the no-CAP baseline but would reach **£54,900** if CAP was adopted. Average wages in the road and rail sector therefore **increase by 12%** as a result of CAP by 2050.

These changes to the distribution of jobs may address current challenges faced within the sector, such as an ageing workforce, and may also increase diversity by making work more accessible, and by increasing the safety and wellbeing of employees.

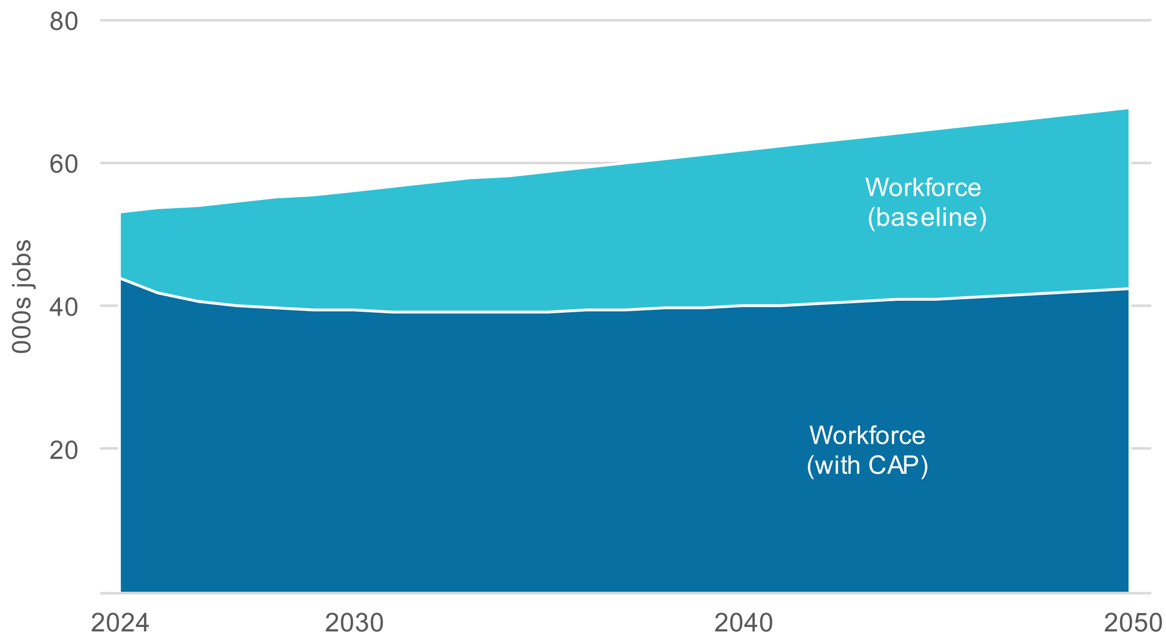


Figure 10 - Road and rail sector workforce change in labour demand (central scenario)

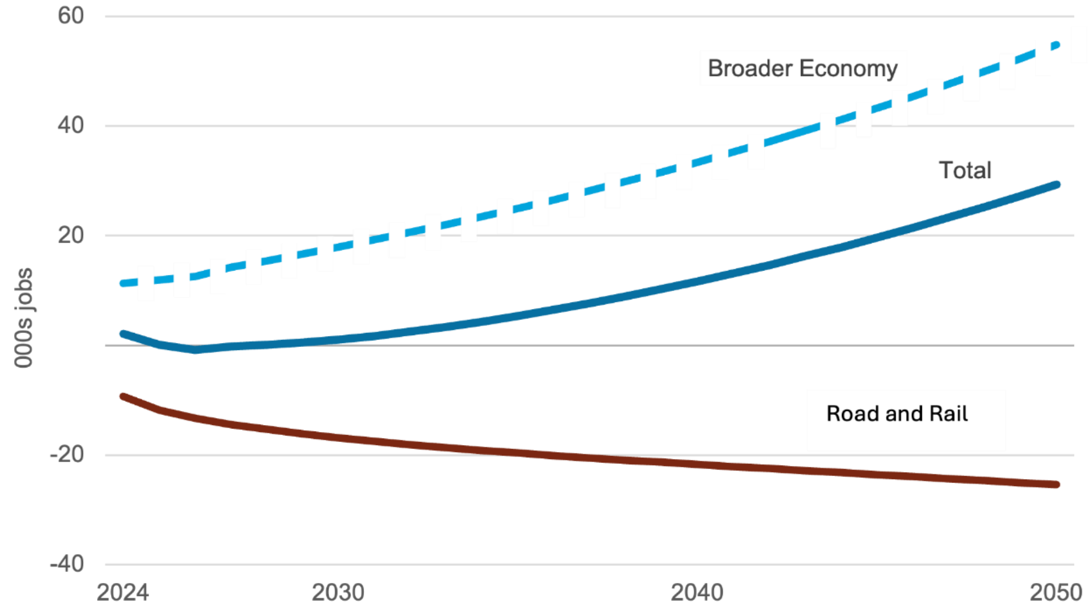


Figure 12 - Total labour demand changes in the road and rail sector and to the broader economy due to CAP sales (central scenario)

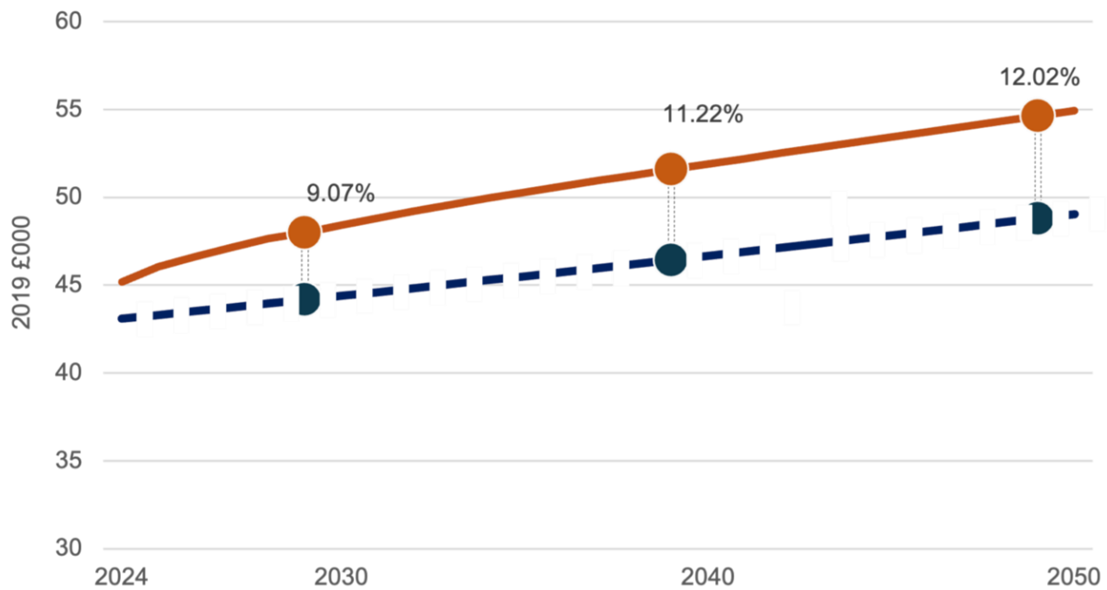


Figure 11 - Average wage increases due to CAP in the road and rail sector compared to baseline (central scenario)

Safety benefits

The safety benefits associated with the uptake of CAP in the road and rail sector have been modelled up to 2050.

- Around **28,000 injuries** resulting in injury avoided
- **31 fewer deaths** resulting from workplace incidents
- Costs as a result of injury **reduced by £6bn**

It would also be expected to see wellbeing improvements in the construction sector linked to safety improvements.

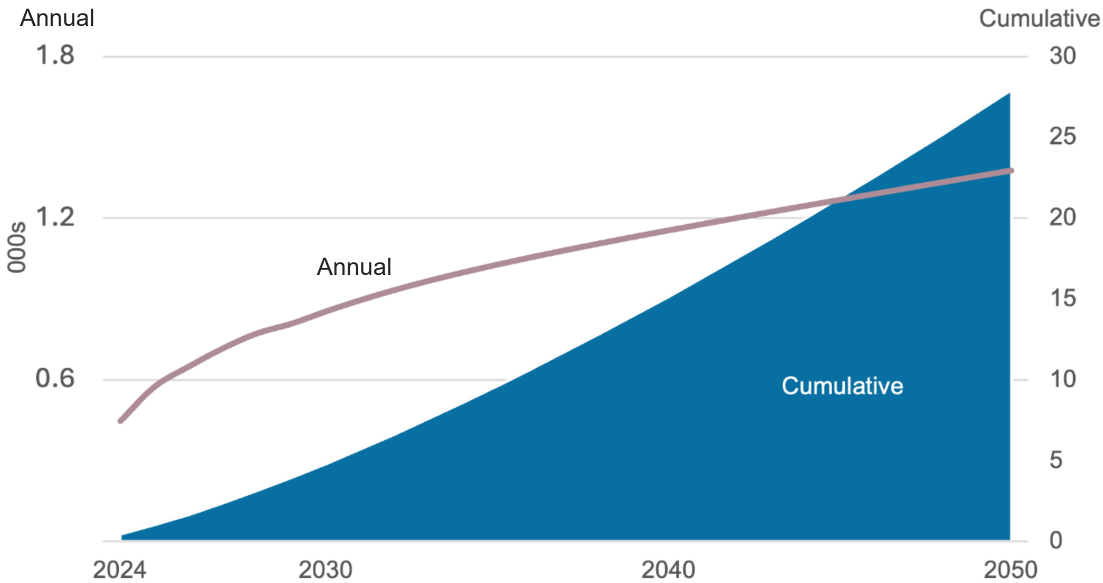


Figure 13 - Number of workplace injuries prevented through CAP uptake in the road and rail sector (central scenario)

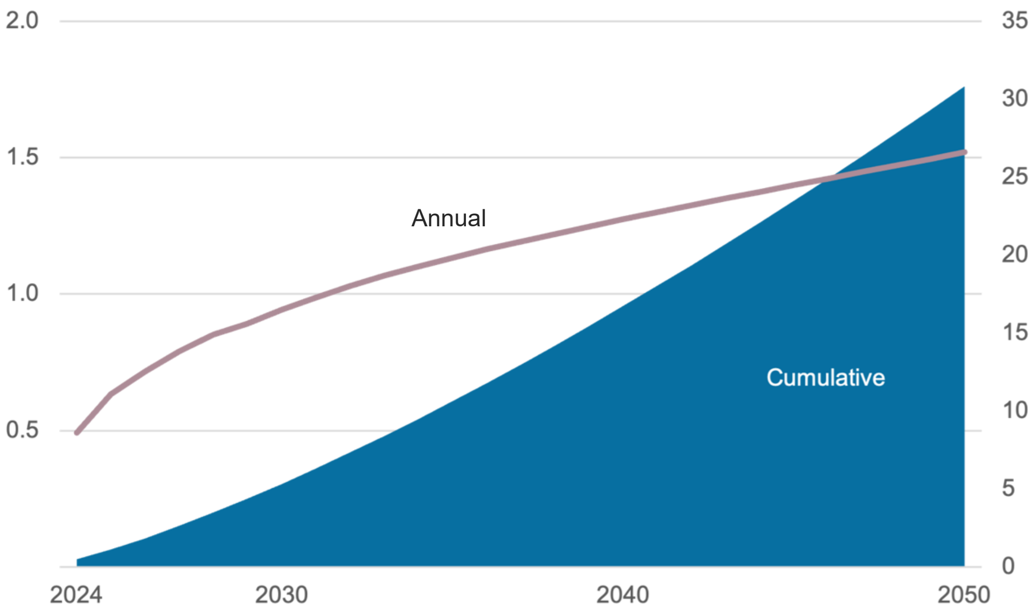


Figure 13 - Number of workplace deaths prevented through CAP uptake in the road and rail sector (central scenario)

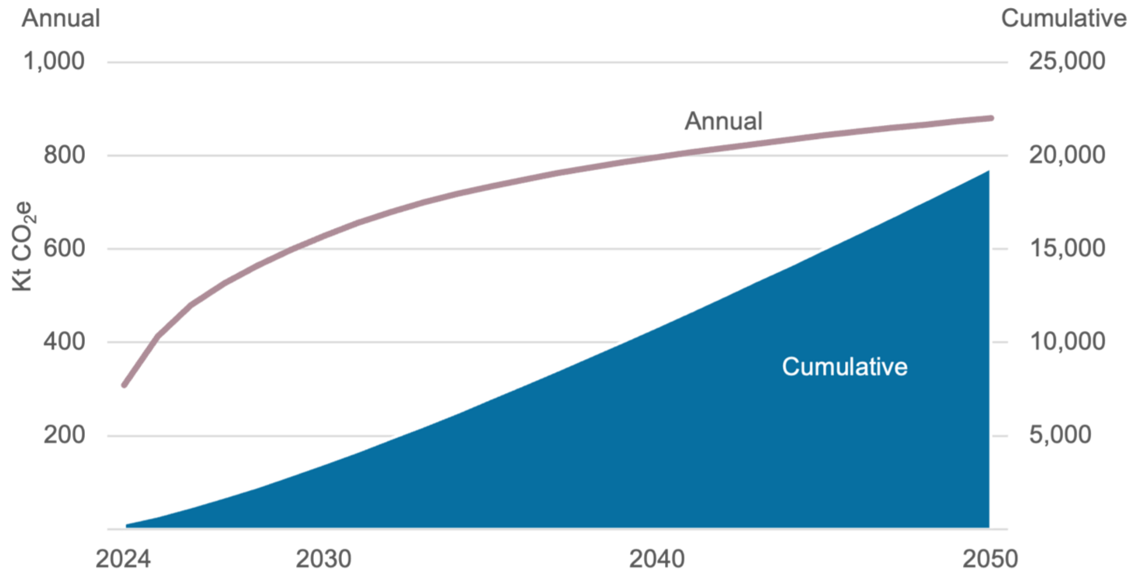


Figure 15 - Reduced carbon emissions through CAP uptake in the road and rail sector

Environmental benefits

Environmental benefits based on more efficient work on site and reduced emissions from use of plant are estimated as follows for the road and rail sector:

Environment	Reduced carbon emissions of **~19,300kt** of CO_2e *equivalent to: the annual CO_2e absorbed by an area of forest the size of Wales* Fuel energy cost savings of **£10bn**

6. Barriers to growth in Connected and Autonomous Plant usage

As part of this market analysis's research phase, interviews with stakeholders identified several areas which pose barriers to the wider adoption of CAP, and these include:

- **Lack of government support**, advice and commitment around new technologies being developed and adopted.
- There is a **lack of regulation** and mandate for the adoption of CAP which breeds a hesitancy to invest.
- **Lack of awareness** from senior decision makers within industry, either from client, contracting or production stakeholders, as the added value from CAP is not well understood, and aversion to investment risk is the baseline safe approach.
- The uncertainty associated with the time and resources required for **training and development** of the workforce, and the standard or level of competence required.
- **Variance in level of maturity** for different types of technologies and plant and lack of awareness of what is available on the market. *Through their CAP programme, National Highways developed a standardised measure to describe a machine's CAP capability (Section 2, OUDAR). At present, the application of the levels is purely voluntary and there is an ongoing requirement to establish their application, including a certification scheme.*
- Concerns over investing in equipment that is **incompatible with existing technology** already deployed.
- There is a **lack of digital maturity** in the construction process, and lack of understanding as to how data can be harnessed to increase productivity. If data is not required by customers (through lack of digital maturity and understanding), then there is less incentive for suppliers to provide it. Similarly, when manufacturers provide CAP plant features, projects often do not use the data or the functionality it provides to its full potential.
- Projects are not specifying or mandating the use of CAP during **tender**. *Procurement structures disincentivise innovation – there are no requirements for CAP and clients are known to question why the investment should be made.*
- The general aversion and **fear of new technology** from the workforce and customers due to the perceived impacts it would have on working practices and employment prospects.
- The need for increased **capital investment** in purchasing the technology and any associated cash constraints. *CAP is currently more expensive than standard plant so financial benefits need to be demonstrated. The cost of a fully machine control enabled piece of plant is £60k – 80k more expensive that the equivalent standard plant.*
- Additional **research and development costs** to current levels of investment. There remains risk due to the uncertainty on industry's direction and the potential cost of failure inhibits investment.
- The **legal implications** or exposure to new or perceived risks posed by CAP not being defined or known by stakeholders, e.g. lack of accredited training for operators and concerns about risk ownership, e.g. the legal risk associated with any on-site injuries.

- **Insurance liability** and uncertainty over liability and insurability of CAP-delivered operations.
- **Skills scarcity** and labour shortage – there will be an increasing demand for highly skilled trained CAP operators.
- **Safety unknowns**, with new technology changing the hazard profile could inhibit adoption, especially when moving quickly to full autonomy of some operations.
- **Connectivity limitations** of site and their variety e.g. 5G network coverage.
- **Data management** and security complexities in the processing, storage and protection of data.
- Areas of constrained growth as **external stimulus** is needed from other technology development sectors, e.g. battery technology.

The following table summarises these key barriers and highlights their applicability and impact to key stakeholder groups.

Barriers

Key stakeholder group	Gov. Depts.	Gov ALBs (clients)	OEMs	Contractors	Owners/ hirers	Operators
Lack of government support	■	■	■	■	■	■
Lack of regulation	■	■	■	■	■	■
Lack of awareness from decision makers	■	■	■	■	■	
Training and development investment			■	■	■	■
Variance in CAP level of maturity			■	■	■	■
Incompatibility with existing technology			■	■	■	■
Lack of digital maturity in construction processes	■	■	■	■	■	■
Procurement requirements at tender	■	■	■	■		
Fear of new technology	■			■	■	■
Capital investment to buy CAP or retrofit				■	■	
R&D cost	■	■	■	■		
Legal implications	■	■	■	■	■	■
Insurance liability			■	■	■	■
Skills scarcity				■		
Safety unknowns				■	■	■
Connectivity limitations				■		■
Data management and security		■	■	■	■	
External stimulus from other technology	■	■	■			

Table 7 - Key barriers to CAP adoption and their applicability to stakeholder group

7. Enablers of market growth

Enablers for the uptake of new or existing technology can be understood either as policies, legislation, procurement or practices which make uptake easier and more accessible, or as incentives to uptake. This section of the report covers both aspects as concluding recommendations.

With regards to the **use of CAP**, learning should be taken from methods used to incentivise uptake of comparable technology. Two such examples where incentives facilitated behavioural change and adopting new ways of working include the growth of Building Information Modelling (BIM) usage in the construction industry and decarbonisation to meet net zero targets.

The following example is part of HS2's learning legacy[xxxix] to reduce emissions requirements:

HS2 – reducing emissions in construction NRMM retrofit

In a bid to reduce emissions linked to construction activities and improve local air quality, a retrofit solution was developed as part of High Speed Two's (HS2) innovation programme. It became the first certified solution to address the significant air pollution generated by Non-Road Mobile Machinery (NRMM).

Exhaust technology is added to the existing combustion engine system to upgrade machinery to meet the required engine emissions class. The solution was initially fitted and trialled on piling plant to quantify the emission saving potential, which led to the results being validated and certified to make the solution available industry-wide.

HS2 estimate that direct capital savings of £300m were made in avoiding plant scrappage and the need to purchase high volumes of large specialist plant.

With reference to **BIM**, key incentives have included shared risk and reward, early contractor involvement and multi-party agreements. Mandating the use of the technology as the price for doing business in the public sector was implemented in April 2016 and the UK technology's market value is predicted to increase from US$2.6billion in 2020 to US$4.7billion in 2026[xl]. Monetary rewards linked to key performance metrics (appropriately weighted) have proved to be a strong motivating tool for the supply chain. On HS2, for example, proposals to link milestone payments to contractors with delivery of BIM data have helped to upskill personnel through the implementation of tools, guidance, educational opportunities.

With regards to **decarbonisation**, various incentives and penalty schemes have been adopted to encourage modal shift in support of achieving net-zero.

Incentives for non-motorised transport infrastructure in Germany included an initial investment of €1.5bn by the Government as well as incentives to encourage users to transfer from cars to bikes.

Many governments have introduced financial models and tax incentives to increase the pace of change and switch to alternative fuels for vehicles / infrastructure. National Road Authorities incentivised shift towards low carbon construction fleets through contract conditions, carbon targets and incentives, e.g. grants/support to invest in new machinery to meet targets around carbon reduction.

Reduced public transport cost, reimbursements, tax deductions and subsidies have been introduced to increase public transport use while parking fees, congestion taxes and high fuel cost are seen as means to discourage private vehicle use in urban areas.

The global challenges of decarbonisation, the need to minimise material consumption, increasing costs as well as recruitment challenges in the construction sector have increased pressure on governments and the supply chain to adopt technologies such as

CAP to improve efficiency, reduce human intervention, reduce emissions and better maintain the value of existing assets.

Based on a review of relevant literature and discussion with industry stakeholders, the research has identified the following as key enablers to the increased uptake of CAP.

Taxonomy

Construction sites vary in size and layout, and are constantly changing environments in terms of activities, machines and people on the site. This provides unique challenges in terms of automation as well as connectivity.

A primary enabler would be a taxonomy and vocabulary tailored to the needs of the construction sector. National Highways' Connected Autonomous Plant (CAP) Levels has set off the process in the UK and is expected to provide clarity to guide the industry towards transformative change. It provides a first of its kind industry-wide scoring system, establishing a common language and providing a standardised measure for scoring plant and machinery according to its level of automation.

Procurement practices

The benefit of setting out the technology requirements at the tender stage has been demonstrated by the Government backed major construction project in Japan; the bid documents set out the technology the contractors had to use so that the focus was on delivering the project as soon as possible.

Other Governments have gone further, which may show further benefits. Scandinavia, particularly Norway, is the leader in the use of machine control in Europe (Annex A). A key driver of this success is that it is mandated for construction projects. Norway currently has 8000 digitally trained operators and has achieved paperless offices in this sector.

Some major UK delivery bodies such as National Highways (NH) and HS2 Ltd have set the ball rolling in the UK by mandating the use of intelligent machine control on some of their projects. The mandate has spurred some of the equipment owners to retrofit their machines with the appropriate technologies.

It should be noted that in Costain's view, mandates would not work in isolation, and it is important to demonstrate the benefits to suppliers and clients. Changing mindsets within construction organisations is a complex process and the industry needs to be helped to recognise specific benefits that technology can bring to their projects.

In the UK, the market is dominated by rental companies that hold ~68% share of the equipment supply chain (unlike Europe where there are more owner-operators of equipment). Legislative and regulatory incentives are needed to incentivise rental companies to adopt embedded systems against the risk of a large proportion of the UK market being locked out of technology adoption.

Investment and Research and Development

There is large investment from construction companies and equipment manufacturers as they seek to gain competitive advantage or remain competitive – approximately £250 million according to CEA. There is existing R&D tax relief from government supporting companies that work on innovative projects in science and technology to offset some of the associated costs, and this is likely to continue as companies seek to remain competitive.

There have been pathfinder projects carried out by NH, such as the A14 Improvement Scheme, which benefitted from innovation funding. There has been significant funding into CAVs from Innovate UK and other sources.

There has been research funding to investigate CAP technology and deployment as per National Highways' three phases of CAP projects. National Highways

also provided research funding to help the development of the automated cone laying equipment to develop a solution to a specific challenge (Annex D).

Whilst private R&D investment will continue, much of the technology has been developed that can offer significant safety, labour, fuel and efficiency savings through semi-autonomous operation. What is needed now is deployment, which requires funding for the training of engineers and operators.

Strategic and holistic approach to CAP uptake across industry

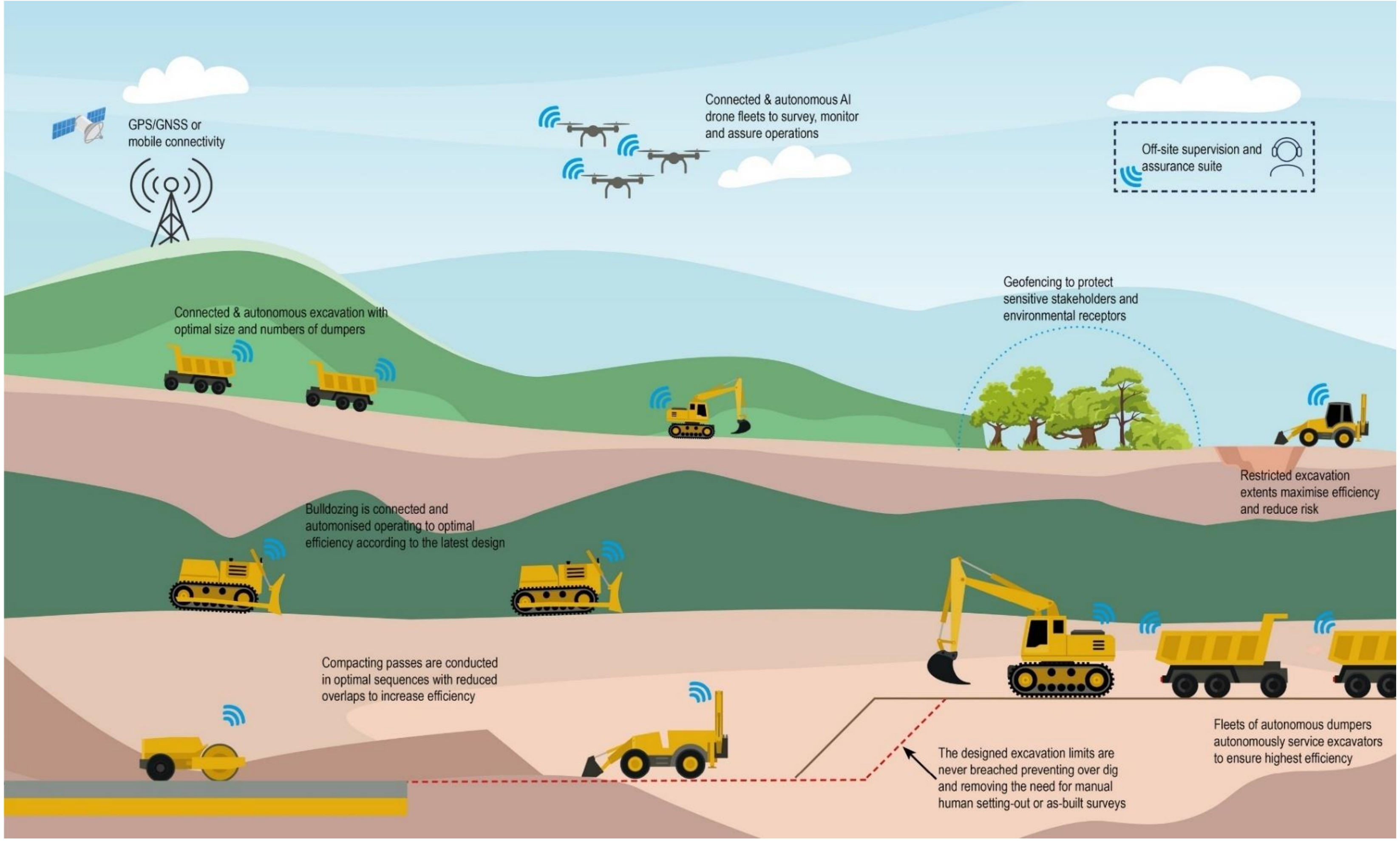
CAP is in Network Rail's long-term thinking but not included as a specific issue in their long-term planning, i.e. it features as a general point in strategy. Unlike National Highways with its CAP Roadmap, growth in Network Rail is expected to be organic rather than strategic.

It is also important to note that security in the pipeline of major infrastructure in the UK is central to helping organisations plan their procurements and strategies in a way that enables investment in new technology.

8. Future impact of Connected & Autonomous Plant

A diagram of a fully CAP-enabled site of the future.

Figure 16 - CAP-enabled site of the future



Annex A: Case Study – Norwegian Public Roads Administration

Overview

Over the last decade, the Norwegian Public Roads Administration, the Government department responsible for national road infrastructure in Norway has embraced the use of technology solutions to increase productivity and build better infrastructure. Specifically, improving the interface between designers and contractors, where collaboration has typically been poor.

Their approach was founded on establishing 'model-based' project requirements, where models take contractual precedence over drawings in all instances. This has led to efficiencies across the industry, accelerating digitisation and optimising the delivery and maintenance of national infrastructure.

To fully comply with the requirements, the construction industry has proactively adopted the use of Connected and Autonomous Plant (CAP) Machine Control as the norm on construction sites in Norway.

2012: Models take precedence over drawings contractually

In 2012 the Public Roads Administration specified the use of 3D-models and mandated that the models take contractual precedence over issued construction drawings. This initiative changed the way the industry operated, as it required all disciplines to be 3D-modelled without exception. This significantly increased the quality of site data and standardisation of data formats.

The construction industry's compliance with the requirement led to:

- Multidisciplinary collaboration models as standard, which include construction methodology to optimise process and identify any clashes between disciplines early
- Setting-out information derived directly from the model rather than drawings, with the model acting as the single source of truth and digital data more easily extracted by engineers and technicians on site
- The model being adjusted in real-time with the 'as-built' information for assurance and future maintenance throughout the asset's life

Government procurement documentation stipulated that for any disputes or discrepancies, the relevant disciplinary model (e.g. drainage, structures, electrical) takes contractual precedence over the interdisciplinary-model (combining all disciplines), the visualisation-model (viewed in context with the existing setting) and the design drawings.

Figure 17 - Example project existing aerial view[xli]

Figure 18 - Example project visualisation model view[xlii]

With contractor and designer working in collaboration, this requirement needed designers to share information and updates regularly (many times a week) to ensure configuration was maintained and the single integrated model was always accurate. Once the common data environment was established to accommodate the data volumes and programming interfaces, the process became fast and efficient throughout the duration of the project.

Following the 3D-model mandate, the Administration analysed sample projects over a 5-year period between 2009 and 2014 to assess the impact. The study compared projects with 2D-drawings and separate 3D-disciplinary models to those with compliant collaborative multidisciplinary models. It was found that contractual change as a percentage of contract value reduced from 19% to 7.5%.

It is understood that customers were getting better value from their investment, with more reliable schedule, cost and quality expectations from their supply chain.

2016: Nye Veier, an ambitious client for new roads

With digital collaborative construction demonstrating savings, in 2016 the Norwegian Government launched ‘Nye Veier’, a state limited company dedicated to the construction of new roads. Nye Veier had a renewed mandate with the core objective to build more road infrastructure with the same level of investment, ambitiously targeting 33% lower costs and 50% faster delivery.

Nye Veier consulted with their supply chain on how to build more roads for less money, and it was agreed that a high degree of digitisation of all processes would be required. A mandate followed which contractually required a single online model to be used for all projects, which is comparable to what was Building Information Modelling (BIM) Level 3 in the UK.

BIM Level 3 was defined as the use of a single online project model with construction methodology and sequencing, cost and lifecycle management information – enabling all disciplines to work simultaneously on the same common data environment which eliminates design conflicts. BIM levels in the UK have now been replaced by the UK BIM Framework (which meets the ISO 19650 standard).

Contracts were procured on a best-value basis, and bonuses for innovation and improvements were introduced.

Every disciplinary and interdisciplinary model is updated in real time as the design develops, and crucially the client has access to all data in real time.

Key enabling factors

Through multidisciplinary collaboration, the use of parametric design and a single model, contractors are better **incentivised to innovate** as design changes are faster to implement technically, to configure and to assure. This agile approach enables simple technical queries as well as complex design changes to be resolved far quicker than traditional methods.

There has been a considerable **investment in training** across the industry – in collaboration with key academic and private partners, the sector has to date invested in the specialist training of over 1,000 engineers and addressed the cultural barriers to enable the nation-wide adoption of Virtual Design in Construction (VDC)

All **setting out and surveying is derived from the 3D-model**, rather than design drawings, and any updates are made live so that the latest design is always reflected in the 3D-model, leading to plant operators always having the correct construction information.

Rather than designing assets and then building, construction in Norway is being **designed and built in parallel**, which

allows for the optimisation of the design throughout the project.

Having every discipline working from a single 3D-model necessitates a **culture of complete collaboration and unity**, with contracts that reward innovation and efficiency. The use of machine-controlled CAP has been a necessary outcome through compliance with the model-based design requirement. For public road schemes, contractors are generally responsible for all design and are contracted early in the lifecycle to develop an optimal solution, and typically under an operation and maintenance agreement following completion.

Outcomes of increasing CAP adoption

This industry step-change incentivised and encouraged the use of Machine Control, as it was far more efficient and accurate to have plant working from live models uploaded automatically to the plant fleet's onboard computers, than wait for the production and manual setting-out of the design by others from drawings.

All parties involved in construction use the single issued-for-construction (IFC) model, including work supervisors, plant operators, engineers, designers, client representatives and even key stakeholders such as planning authorities.

Presently, all plant delivering infrastructure projects in Norway is connected and uses Machine Control, with the few exceptions including mini-excavators or specialist large machines. In other construction disciplines, model-based delivery has been the norm for the last five years, which has also led to the vast majority of plant in the rest of Norway's construction sector being classed as CAP. Subcontractor owner-operator and hire-fleet machines alike use the common data environment platform and are managed together as a fleet by the lead contractor.

In 2022, Nye Veier reported that having built 121km of new roads since launching and with a further 83km under construction, it has achieved a cost saving of 18%, with considerable socio-economic value added through the building of better infrastructure. This is attributed to multidisciplinary collaboration and the efficiencies gained from the government-led initiative to accelerate digitisation and optimise the delivery of national infrastructure.

Gap analysis: Key differences in approaches in the UK and Norway

It is important to note that both the UK and Norway share the common ambition to increase the productivity of infrastructure construction and deliver better value assets in both their delivery, operation and maintenance. Successive governments in both countries regard infrastructure investment as an enabler for economic growth and in supporting social and environmental sustainability goals – both recognising that the digitisation of industry is vital to helping achieve this.

The UK and Norway, while geographically close neighbours, have many differences in the factors that influence how infrastructure is delivered. These range from topographical, geological and climate factors, to population density and movements, to financing and asset owner and operator arrangements.

These factors make direct comparisons between approaches to infrastructure delivery more nuanced. This case study focuses on a high-level technical view, and further investigation would deepen the understanding of the differences between the UK and Norway, especially in terms of legal, contractual and procurement approaches.

However, the gap analysis (Table 1) highlights some key differences between the approaches to construction in the UK and Norway in relation to their adoption of CAP and digital construction more widely.

Area	UK approach	Norway approach
Adoption of Building Information Modelling (BIM)	In 2016 BIM Level 2 was set as a minimum requirement on public sector projects, requiring a fully collaborative 3D model to be produced. In 2019, BIM levels were replaced by the UK BIM Framework which set out the UK's approach to adopting BIM and the requirement for meeting the Information Management Mandate, based on the ISO 19650 standard.	In 2012, the Norwegian Public Roads Administration mandated that 3D-models were to take contractual precedence over 2D-drawings in all instances. In 2016, Norway's new roads client contractually mandated the requirement for contractors and designers to work from a single collaborative 3D-model simultaneously on the same common data environment, which optimised the solution and eliminated conflict.
The use of Machine Control	In 2019, National Highways introduced guidance as part of the 'raising the bar' health and safety initiative which specified that all its sites must use 3D machine control for all earthworks operations, unless a specific business case is provided.	All construction design is done using a single IFC model, so there is no alternative other than to construct from the 3D-model. There are no setting-out drawings or 2D-plans made available. Using CAP with Machine Control is a truly viable option, hence the near 100% uptake across the industry.
Availability of CAP capability	All major construction plant manufacturers offer CAP capabilities, but they are often under-utilised. For example, a UK plant distributer engaged as part of this market analysis has been providing a grade-assist function on all its plant as standard since 2017, however from its telematic data, knows that only 20% of machines use this functionality in practice.	It is now very rare in Norway for construction plant not to be using Machine Control. Subcontractor owner-operator and hire fleets comply with using the digital model, as there is no alternative way to deliver their tasks on site.
Incentivisation of innovations and efficiencies	Specific incentivisation is addressed on a case-by-case basis depending on the client organisation delivering the works. Any potential benefits of an identified innovation or efficiency may be outweighed by the cost and time needed to change the design without the use of a single multidisciplinary model, meaning any benefit may be lost.	Innovations and improvements to design and construction are contractually incentivised with payments to contractors. Design changes can be identified and implemented quickly through parametric design, collaboration and constant model iteration, so delay impacts can be significantly reduced. This incentivises the decision to adopt innovation and efficiencies

		as cost, quality, safety and environmental benefits can be realised with minimal impact to the schedule.
Stakeholder interfaces	While it is common-place for UK projects to work from integrated 3D-models, client and third-party stakeholder assurance and acceptance of designs and as-built records require 2D-drawings and construction documentation to comply with their requirements. This requires additional process and subsequently can add time and cost inefficiencies to projects, while also adding exposure to the risk of conflicting information and configuration discrepancies.	All stakeholders accept and work from the single IFC 3D-model. This includes delivery authorities, planning authorities and consent granting bodies, as well as lower tier suppliers, such as rebar fabricators, who can access the latest model, fabricate and deliver the materials to the correct site locations just-in-time for installation.

Table 8 - Comparison of the approaches influencing the uptake of CAP in the UK and Norway

Annex B: Case Study – Construction application

Semi-Autonomous & Intelligent Compaction – Finning Caterpillar, EKFB joint venture on behalf of HS2 Ltd.

The new High Speed Two (HS2) railway comprises of 140 miles of track, four new stations, two depots, 32 miles of tunnels and 130 bridges. This requires a vast amount of earthworks, estimated to be 53 million cubic meters on the 50-mile section through Buckinghamshire, Oxfordshire, West Northants and South Warwickshire[xliii]. These works present a huge opportunity to trial and realise the efficiencies to be gained from adopting Machine Control technology in the industry.

The innovation team at HS2 requested Finning and Caterpillar to facilitate trials of innovation technologies for their main works contracts. Main works contractor for this section Eiffage, Kier, Ferrovial Construction and BAM (EKFB) joint venture enabled the testing of a semi-autonomous and intelligent soil compactor Cat® CS76B equipped with Command for Compaction along with Machine Drive Power (MDP) and mapping technologies at an HS2 site in Newton Purcell[xliv]. Both of these measuring technologies from Caterpillar require calibration on the material and jobsite, removing manual assumptions made on attributes such as material type and moisture content, and therefore making the readings more accurate and relevant to the specific site. The trial was held in a flat test area on a clay sub-base.

Task context

Historically operators would manually operate plant to complete grading and compaction. The traditional technology would use an accelerometer-based system that would measure ground vibration energy. The operator would complete the suggested number of passes to try and achieve compaction. This could result in gaps in coverage and inconsistent compaction. Such errors could require

Figure 19 - Example of compactor trial site

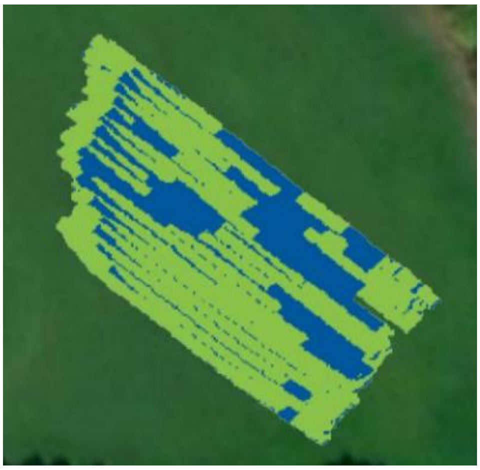


Figure 20 - Map readings showing blue areas of below density compaction with a high number due to poor overlap

rework or further compaction after testing is completed.

Demonstrating the benefits

In order to demonstrate the benefits of Caterpillar's Semi-Autonomous and Intelligent Compaction systems to the HS2 and EKFB's Innovation & Engineering teams, Finning devised a three-step plan:

1. Conduct the operation normally, with pass-count mapping enabled on the Trimble-powered system.

2. Install the measuring technologies, Machine Drive Power (MDP) sensor and Compaction Meter Value (CMV) with the

Figure 21 - Manual compaction showing misalignment of passes and overlaps.

operator, setting compaction targets and comparing the pass-count with the actual work achieved. Defects and anomalies are monitored within the work area, establishing possible savings in time, energy and required re-work.

3. Install Command for Compaction to enhance the operation of the machine to remove missed areas, over-worked areas and improve quality, especially on overlaps.

The system takes control of steering, speed, direction and vibration, enabling the operator to concentrate on safety and the mapping system so that anomalies can be reported as they present on the map.

Lane management is automated, and issues of uneven or missed overlap are eliminated, meaning that only actual anomalies were identified on the compaction map, which would need to be investigated prior to more material being applied for the next material layer.

Outcomes

An operator with two years' experience in compaction was allowed to test the system with around 30 minutes of tuition. They were quick to learn and fed back that the technology was easy to use, intuitive and that they were comfortable to release the driving control to the machine.

The trial of this CAP-enabled compactor required only two passes of the machine instead of the normal six, meaning a reduction in work done and time taken by two thirds.

Figure 22 - Semi-Autonomous Compaction showing aligned passes with

Annex C: Case Study – Technology retrofit

Machine control CAP retrofit – Flannery Plant Hire and Leica[xlv]

Figure 23 – CAP retrofitted enabled plant in operation

Overview of technology

Technology system ConX from Leica allows bulldozers and excavators to be part of a plant network where data can be shared, and messages sent and received. In the past when an engineer's drawing is updated, they would have to inform the site and work would stop until information is issued.

With ConX, the engineer can update the drawings remotely. Design drawings are uploaded onto computers and transferred onto various machines while Leica 3D positioning instrumentation continuously tracks the actual position of the blade or bucket and compares this to the design data in the drawing.

Any discrepancies are automatically corrected via the machines' hydraulics to ensure the machine is working accurately and efficiently. The site team are always aware of either formation levels or finished levels, which helps relay progress back to the client accurately.

An example application is across multiple earthworks sites, where progress and quality needs to be monitored, but the engineering and surveying resources are spread across the programme and are not on site all of the time. By retrofitting connected technology to the plant, Leica's ConX site management system enabled this monitoring and measurement of progress to be conducted remotely.

ConX is used on the project to relay excavation progress, including details of design depths achieved to allow the projects to be planned more efficiently. Leica's 3D GPS instrumentation on the machines measure the line and level of the excavation while a Leica base station on site ensures GPS readings are accurate to approx. 20mm.

Outcomes

The main advantage of using the equipment is that a single engineer/surveyor can check the accuracy of earthworks and excavate the ground without constantly returning to site to check progress against drawings. This reduces costly mistakes (such as over-digging) and limits potential rework and process.

Any problems on site can be surveyed and instantly escalated to decision makers to quickly act, while being armed with the exact coordinates of its location.

Having the actual data relayed in front of you also gives the site team the knowledge from which to make decisions and can improve the accuracy of excavations by ensuring there is no over- or under digging.

Ultimately, this has a positive effect on project cost and efficiency. Machine records provide quality assurance of the work carried out and ensure a smoother handover at the end of an operation.

Benefits summary

- Tasks more likely to be completed right-first-time
- Increased predictability and ability to control costs
- Less wear and tear on machines and reduced down time and maintenance cost
- Increased plant utilisation and flexibility
- Increased productivity
- Lower operating costs
- Improved operator performance and a shorter training period
- There is no need to manually survey and repeatedly set-out markings on site
- There is greater data integration between machines and operatives, increasing efficiency

"…Working remotely means that I can control a number of jobs and respond to all their needs much more efficiently than if I had to get into a car and drive to each site. Machine control is a must, [and] this has helped us work more efficiently. We are pleased with the performance of [Leica 3D GPS retrofitted instrumentation] and the tangible financial benefits that it brings - it has also improved the quality and accuracy of our final product which we have been able to demonstrate to our clients in the field."

(Quotation from the Works Manager from the example project)

Annex D: Case Study – Operations & Maintenance application of CAP

Automated cone laying vehicles – National Highways[xlvi,xlvii]

Marker cones are needed to protect road users and road workers while essential work is carried out on roads. Deploying cones is still typically a manual task, involving two people on the rear of a vehicle working in tandem. Most of this work is at night, in any weather. Workers can together lift up to 10 tonnes of equipment per shift, adjacent to high-speed motorway traffic, it can be a hazardous and frightening task.

Solution overview

Working with a group of industry experts, National Highways have developed two automated cone-laying vehicles which will take the human element out of cone laying.

The aim is for both vehicles to be the routine go-to options for cone laying on the network. This will eliminate one of the biggest risks facing roadworkers.

The first vehicle, developed by Highway Care, has completed its on-road trials and is now in the marketplace for use by maintenance contractors working on England's strategic road network – motorways and major A-class trunk highways.

The second vehicle, developed by King, differs from the Highway Care project in that it relies on a revolver-style design, meaning a huge rotating drum that deploys and collects the cones in a continuous cycle.

Figure 24 – National Highways' second automated cone-laying vehicle[xlviii]

Benefits

The manual method for deploying cones currently features two people on the rear of a vehicle working in tandem. Usually working at night and in all weathers, the workers each lift up to six tonnes in cones alone per shift. The automated vehicles will improve safety and free up two workers for other tasks.

An average 1m-high cone weighs around 10kg. A typical 4km closure involves putting down – and later removing – between 260-300 cones, meaning that two workers will both handle between 5-6 tonnes of cones per shift. When additional equipment such as frames, signs, lamps and sandbags are factored in, it is not unreasonable for them to lift between 8 and 10 tonnes per shift. A single kilometre of coning can take 15 minutes to install and remove, resulting in an exposure time to live traffic of around two hours per shift.

Outcome

By deploying and adopting this technology, the exposure of workers to the risk of falls, collisions with passing vehicles/debris are reduced, and the risk of muscular-skeletal injury eliminated by removing the manual operation of laying and lifting multiple tonnes of marker cones in all weathers.

Annex E: Engagement methodology

Stakeholder engagement methodology

A Communications and Stakeholder Engagement strategy was drafted and issued to plan the engagement process. The strategy followed the OASIS planning structure, outlining objectives, audiences, strategy, implementation and scoring/ evaluation. The project team reviewed the plan to guarantee the best quality and ensure clarity over the process.

Following the strategy, the team then conducted a thorough stakeholder mapping exercise. Initially, creating a broad list of all stakeholders, using team members' knowledge, desktop research and resources from previous CAP projects.

Once a comprehensive list was established, the team mapped stakeholders onto the stakeholder map (example in figure 25) which determined each stakeholder's position of influence and levels of interest in CAP, as well as their sentiment. They also grouped stakeholders into ten larger stakeholder groups including central government bodies, OEMs and plant owner/hire companies. This helped target the engagement.

With stakeholders mapped and grouped, the team began outreach. An engagement timetable was developed and based on the mapping exercise, highlighted the highest-priority stakeholders for which engagement was crucial. These stakeholders were known to be influential in CAP, and to have varying degrees of sentiment to CAP to ensure a diversity of opinions was heard from.

A one-to-one interview approach was the most appropriate approach to engaging with the multiple and varied parties. A semi-structured interview format was selected. The majority of meetings were recorded, and a note was taken to support the report writing process. The interviewers asked all stakeholders for extra data and evidence where possible, and for details of any additional stakeholders the team should be talking to throughout the engagement process.

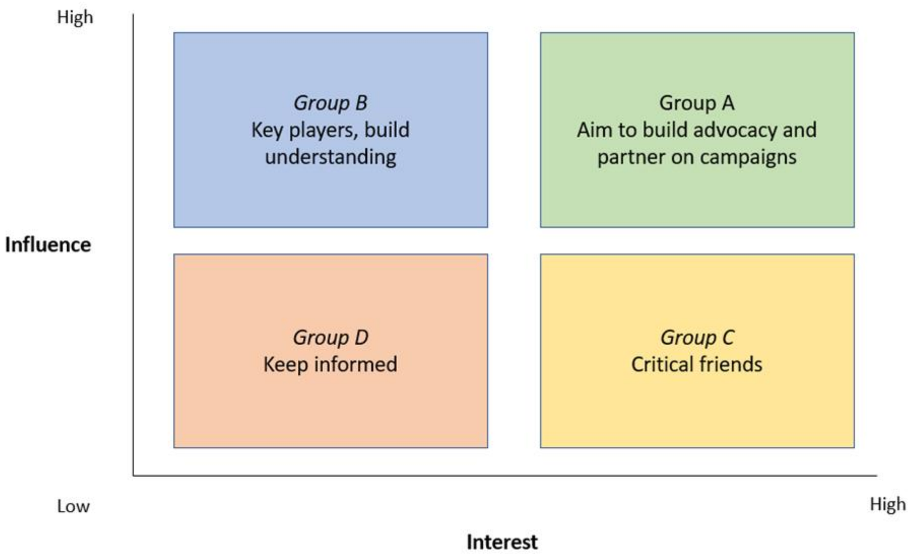


Figure 25 - Stakeholder map structure

Annex F: Benefit quantification methodology

Methodology and Assumptions

Scenarios

There are three scenarios:

- HIGH: high uptake and high impacts
- CENTRAL: central scenario, and
- LOW: low uptake, low impacts.

The intention is to span a wide range of potential impacts of CAP. Many of the assumptions have built in ranges of estimates for high, central, and low, as discussed below.

Types of Impacts

There are two aspects of capturing the economic impacts of CAP:

1. **CAP Sales**: The production and sale of CAP equipment
2. **CAP benefits**: The benefits from using CAP equipment

The team forecast these relative to a baseline scenario of no further CAP roll-out, so that the effects of CAP are isolated and quantified.

CAP Sales

The benefits to the UK economy of CAP equipment are calculated using an input-output (IO) model. At its most basic, an IO model forecasts the impacts on the entire economy of a given change in demand for a single sector's output. Suppose it is a demand increase. The sector (call it sector A) responds to an increase in orders by increasing orders from its own suppliers, who then do the same. Their suppliers are likely to be in different sectors than the sector A's, and in this way, the cascading of demand increases throughout the economy reaches a broad range of sectors. All of the businesses experiencing higher demand will increase demand for labour, which in turn increases spending power in the economy, further increasing demand. In this way, the original demand stimulus multiplies.

The IO methodology allows projections of employment and Gross Value Added (GVA) that a given demand increase generates. But it requires knowing which sectors see increases in demand and the size of those demand stimuli to model with any precision. This approach is used on a year-by-year basis in response to the increases in demand that sales of CAP equipment imply.

The objective is to forecast the benefits that will arise from CAP. That is, the benefits which will not otherwise materialise if CAP is not rolled out. So for each type of equipment, the economic impacts are modelled as being only for the CAP component of the equipment, as it is assumed that the non-CAP component would have been sold anyway.

For example, for a sale of a bulldozer fitted with the equipment that lets it operate as connected autonomous plant, the CAP equipment fitted to the bulldozer (such as computer sensors and electronics) is put through the IO model, but not the actual bulldozer itself, since the bulldozer would have been sold anyway if there were no CAP rollout, it just would have been sold as a conventional, no-CAP bulldozer.

Given the data needs of the IO model and the objectives, there are a few sets of assumptions that needed to be made:

1. What pieces of construction equipment will be modelled?
2. What are the projected market demands for these pieces of construction equipment?
3. What proportion of them will be CAP enabled?
4. What share of the total sale price of them will reflect the cost of the CAP components?
5. What sectors produce these CAP components?

Types of Cap equipment

Six architypes of CAP equipment have been modelled:

- Bulldozers
- Compactors
- Excavators
- Loaders / Handlers
- Telematics
- Geofencing

Telematics and geofencing will be discussed at the end of this section. Discussion of the other four types, the automated equipment, follows.

Market Demand for CAP equipment

The four types are assumed to cover all of the construction equipment market, since the evidence suggests that the umbrella they cast over sub-types makes this a plausible assumption. They have the following shares of total sales:

Bulldozers	7.5%
Compactors	2.5%
Excavators	70.0%
Loaders / Handlers	20.0%

Total UK construction equipment sales in 2022 were £15bn, of which £9bn were exports and £6bn domestic sales. Domestic market growth is assumed to be:

2022-29	2029-50
4.29%	1.45%

Export market growth is assumed as follows:

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
-8.3%	-2.0%	-2.0%	-2.0%	6.2%*	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%

2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%

**This is based on information from the 2023 CEA report projecting a decline before a return to 1.1m units in 2027.*

The market sizes are scaled in each scenario as a proportion of the central estimates:

High	1.25
Central	1.00
Low	0.75

Proportion that will be CAP enabled

The share of each piece of CAP equipment that will be fitted with CAP is modelled as increasing linearly over time, with the following proportions for 2024 and 2050:

	2024	2050
Bulldozers	20%	100%
Compactors	20%	100%
Excavators	20%	60%
Loaders / Handlers	20%	100%

Share of sale price and sectors producing the Cap equipment

The following table shows which sectors produce all parts of a piece of CAP enabled equipment, with the shaded cells being the CAP only component of that equipment, which is the share of the total sale price that is occupied by CAP:

	Bulldozers	Compactors	Excavators	Loaders / Handlers
Other transport equipment	80%	70%	70%	70%
Computer, electronic and optical products	20%	30%	30%	30%
Electrical equipment	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**

Telematics and Geofencing

Telematics was considered too small in sales to either obtain evidence for or put through the IO model.

Geofencing is assumed to have a current UK market size of £160m, of which 80% is serviced by UK firms. UK firms also capture around £70m worth of the export market. This leads to the following current market values:

UK Producer Revenues	£195m
Domestic Market size	£160m

The market is projected to grow at the following rates. After 2035, it grows at 1% in perpetuity.

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Annual growth rate	80%	30%	30%	30%	20%	20%	10%	5%	1%	1%	1%	1%

Geofencing is assumed to be entirely CAP, so that the whole sale price is put through the IO model. The producing sectors are:

Computer, electronic and optical products	50%
Electrical equipment	50%

UK road and rail spending on CAP

The amount that the UK road and rail sector spends on CAP is not the entire market value, which includes exports and sales to other sectors. For some calculations around stock of CAP and investment costs, the share of total sales which was purchased by the UK's road and rail sector was isolated.

Firstly, the analysis isolates which of total sales go to UK construction sector (40% for all except geofencing, which has its own assumptions around domestic and foreign markets). The road and rail sector share of the UK construction sector is calculated (around 4%), and this is the proportion of UK sales of the CAP components of construction equipment that is used to calculate investment costs to the road and rail sector, and the total accumulated stock of CAP equipment.

CAP benefits

The analysis forecasts the benefits of CAP for a single sector, UK road and rail. CAP is in Network Rail's long-term thinking but not included as a specific issue in their long-term planning, more a general feature point in strategy. Unlike National Highways with its CAP Roadmap, growth in Network Rail is expected to be organic rather than strategic. Other construction sectors may use CAP, but the evidence able to be discussed and obtained, and which are of interest to DfT, relate to the road and rail sector.

In alignment with the Office of National Statistics (ONS) standard industry classification categories for construction, the detailed economic analysis was conducted on the **construction of roads and railways**, which includes:

- Construction of roads and motorways
- Construction of railways and underground railways
- Construction of bridges and tunnels

From this detailed analysis conducted for the road and rail sector, the results have been scaled up to consider construction sectors likely to easily adopt CAP, or **early adopter** sectors, including:

- **Construction of roads and railways** (above)
- Construction of utilities projects
- Construction of other civil engineering projects
- Some specialised construction activities, including site investigation, preparation, and demolition.

Additionally, from the detailed analysis conducted for the road and rail sector, the results have been scaled up to consider **all construction sectors** in the economy, which includes residential and commercial developments and all other construction sector activity, as well as all the above.

The forecasting of the benefits of CAP is done differently. Quantified benefits do not go through an IO model like the sales of CAP equipment do, since they are not creating demand stimuli that trigger a supply chain response, but rather manifest in benefits in productivity, safety, and value for money in the single sector of focus, road and rail.

There are a few types of benefits:

1. Fuel savings resulting from deploying telematics
2. Labour productivity resulting from the use of telematics and automated types of CAP
3. Reduced injury costs due to more ergonomic and safer operations
4. Workplace accidents prevented
5. Workplace deaths prevented
6. Reduced carbon emissions

The first three of these are quantified in monetary terms and translate into additional value retained within the sector, which is distributed between profits, better value for money for clients, and paying the investment costs of the CAP investments.

Accidents and deaths prevented by improved safety features of CAP sites, such as geofencing and machine safeguards, are not monetary measures, but numbers of incidents prevented.

Carbon emissions are expressed in kilotons of CO_2 and are linked to reduction in fuel use.

All of these benefits are defined in relation to some key metrics:

- GVA[xlix] and output of the sector

- Workforce of the sector

These are estimated using historical data with average historical growth rates applied to them. Some assumptions are necessary on the relation between the aggregate construction sector and the more granular road and rail sector to fill in gaps in places. This is done in the Data sheet of the model.

Scaling benefits to level of accumulated CAP

Many of the benefits are defined as achieving a certain percentage by 2050. For example, by 2050, fuel used in machine idling is reduced by 12.5%. In a given year, the actual benefit will not be the 2050 value, which is only achieved with full CAP roll-out, but some proportion of it, reflecting that less CAP is being used at that point. Therefore the proportion of 2050 CAP is used as a guide to how much of the final year benefits have materialised in any given year.

A couple of approaches are possible, but it was chosen to converge towards it logarithmically. The chart below shows how this compares to a (roughly) linear convergence. The assumption of a log approach is that the benefits of CAP are quite front loaded, with large benefits materialising with each piece of CAP added to the stock, and these benefits gradually diminishing with more CAP purchases as the stock of CAP grows. It aligns with the economic theory of diminishing returns. That is, the first piece of equipment boost production tremendously, and as more and more equipment is accumulated, the marginal benefit of each additional piece of equipment is lower than the last. It effectively increases the value of investing in equipment, since benefits that are front loaded decline less steeply when discounted; offset larger, less heavily discounted investment obligations earlier; and, in generating cumulative benefits, start accumulating earlier.

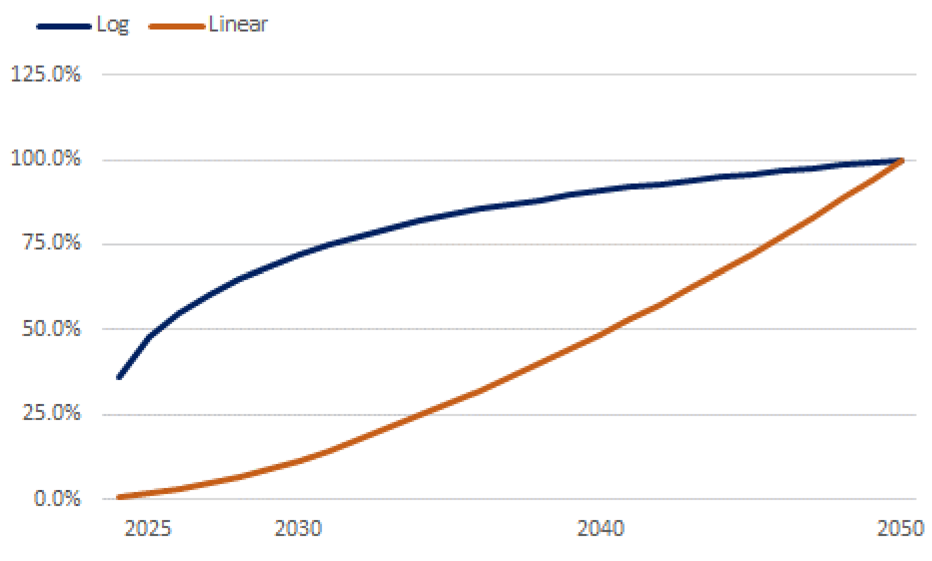


Figure 26 - Logarithmic vs linear convergence

Thus the natural log of CAP stock in a given year is taken, as the proportion of natural log of CAP stock in the final year as a guide to how much of the final year benefits have materialised in that year.

The proportions of benefits realised in a given year using this approach are:

2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
38.0%	49.3%	56.4%	61.5%	65.7%	69.4%	72.7%	75.6%	78.2%	80.4%	82.4%	84.1%	85.7%	87.2%

2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
88.5%	89.7%	90.9%	92.0%	93.1%	94.1%	95.0%	95.9%	96.8%	97.6%	98.4%	99.2%	100.0%

Fuel Savings

To estimate the value to the sector of saved fuel, three assumptions are needed:

1. The fuel currently used by the sector
2. The price of fuel
3. The expected reductions that CAP will afford

Current fuel use by the sector is assumed to be 1,450 million litres of diesel and fuel price is £1.40 per litre. The fuel price is assumed to stay constant throughout the period, since the model works on real values, and adding forecasts of varying fuel prices would, for the objective of isolating CAP impacts, be more noise than signal. It is also noted that diesel fuel use is likely to be reduced and replaced by other sources such as electricity or hydrogen. Whatever the fuel used, a reduction in consumption will result in cost savings, and for the purpose of the model fuel costs of whatever type are assumed to be the same cost as diesel.

There are two ways that fuel is saved:

- **Reduced idling**: machines do not run idle as connected control shuts down vehicles not in active operation
- **More efficient use**: through no wasting of movement, and more efficient movement, fuel is saved.

The annual fuel savings are assumed to increase linearly. Idling is assumed to comprise around 20% of current fuel use and savings from CAP can never exceed the fuel volumes that would have been used on idling in the absence of CAP (20% of baseline fuel use).

Efficiencies are also capped at 50% of baseline fuel use. But in practice, neither idling nor efficiencies savings approach these theoretical limits.

The savings are assumed to be the following for the three scenarios:

Idling Savings

	2050
High	19.0%
Central	15.0%
Low	11.0%

Efficiency Savings

	2050
High	25.0%
Central	20.0%
Low	15.0%

The actual benefits converge to that over time using the proportion of 2050 CAP accumulated in a given year to estimate that proportion, as discussed under ‘Scaling benefits

to level of accumulated CAP', above. The fuel savings when multiplied by the fuel price are the monetary value of the CAP effects.

Injury costs

The estimated costs of health conditions that CAP could prevent, like musculoskeletal conditions (collectively referred to here as injury costs), are £612m for the sector in 2022. When divided by the workforce, this translated to a cost per worker of £9,254. The baseline forecasts of workforce multiplied with this figure project estimates of injury costs.

The percent reduction in injury costs for the high, central, and low scenarios are assumed to be:

	2050
High	25%
Central	20%
Low	15%

As with other future benefits, the actual benefits converge to that over time using the proportion of 2050 CAP accumulated in a given year to estimate that proportion. When multiplied by the baseline injury costs, this results in the injuries cost savings due to CAP.

Increase of GVA to revenue ratio

Both fuel savings and injury cost savings increase the ratio of GVA to revenue. They do this by lowering the cost of goods (fuel) and services (health, insurance). This is used later for calculating workforce size.

Productivity

With CAP equipment, labourers can do more work in the same time, as a reduced need for re-working, more accuracy, and faster, more accurate equipment frees up time. The evidence suggests a central scenario could see 60% improvement in labour productivity by 2050. The high and low scenarios vary around that, so that the productivity gains and the years by which they are achieved are assumed to be:

	2050
High	75%
Central	60%
Low	45%

Actual benefits converge to these rates over time using accumulated CAP stock as a proportion of final year amounts, as discussed above. Worker productivity increases linearly from the first to the second figure. This is *extra* productivity – that is, in addition to the organically occurring labour productivity growth that would have occurred without CAP (which is actually quite low).

Distribution of additional value

Loans and Profits

The additional value retained in the sector by fuel savings, labour productivity, and lower injury costs are first used to pay off the loans used to buy the CAP, for which it is assumed a weighted average capital cost of 4.5%, and as profits for shareholders, and assumed a fixed profit rate of 4.5% for this. The portion of added value that are allocated to these demands are set such that the net present value of servicing both of them is zero, which means that all required dividends and loan repayments are met, taking into account the time value of money.

To calculate the costs to the road and rail sector of paying off loans used to purchase CAP, the entire sales of CAP equipment are not used, but those that were bought by the UK road and rail sector, discussed above under 'UK road and rail spending on CAP'

Value for money and wages

The remaining cost savings are shared between delivering additional value for clients and giving workers higher wages. This can be set in the assumptions sheet, but it was decided on an agnostic approach and to split these gains 50-50. This means that the percentage gain in wages should roughly equal the percentage additional value a client receives for the same cost.

Effect on workforce

Allocating cost savings to delivering additional output for clients means output is increased. This implies that, for a given level of productivity (which was defined previously, taking into account CAP benefits), more workers are needed to produce this output. After accounting for reduced inputs form injury and fuel costs, the workforce needed to produce the new level of GVA is calculated[i], and this is the new workforce size. Thus there are two mechanisms operating in workforce size:

- Higher productivity means fewer workers are needed for a given output level
- Cost savings funnelled into delivering more output for clients increases labour demands

In the central scenario, the net effect is negative, meaning the productivity effect predominates.

Workplace deaths prevented

The construction sector workplace death rate obtained from the analysis research was used (not for the road and rail sector alone, so must assume it is similar to this more aggregate sector), which is 2.91 per 100,000 workers, and multiply that by the workforce in each scenario (determined through the process discussed under to obtain expected deaths in each year). This is reduced by a percentage, which CAP equipment is expected to make possible to obtain the expected deaths if CAP is rolled out. These are:

	2050
High	87.5%
Central	70.0%
Low	52.5%

Actual benefits converge to these rates over time, as discussed previously.

Workplace accidents prevented

For accidents prevented by CAP, the same methodology as prevention of deaths is adopted, but using a different rate, which for the construction sector is 2,640 per 100,000 workers. The reductions in accidents through CAP by 2050 are:

	2050
High	87.5%
Central	70.0%
Low	52.5%

Benefits converge to this over time, using stock of CAP as a proxy.

Reduced carbon emissions

Carbon emissions are calculated directly from the reduced fuel usage discussed above under ‘Fuel Savings’. The kg of CO_2 emissions for a litre of diesel (2.64) is multiplied by the fuel savings in each scenario and converted into kilotons of carbon not emitted due to CAP. It is noted that in future, a greater proportion of construction plant will be powered by other, lower carbon fuels, so actual carbon emission reductions are uncertain.

Iterative approach

Cost savings are affected by injury costs. Cost savings in turn affect the value channelled back into increased output for clients, which in turn affects the required workforce, which (given that injuries are calculated as a rate of the workforce), affects injury costs. This circular logic is not possible to solve using Excel spreadsheet functions, so an iterative macro is used, which repeatedly solves the chain and takes the end values to the start until the differences in all results are tiny enough to be considered a converged solution.

The iterative solver also sets the share of cost savings allocated to investment costs and profits until these are covered and the share of the remainder going to clients and workers until the shares equal the values set in the assumptions sheet (e.g. if 50% of gains are to go to clients, then it will iterate until the percentage gains that clients receive roughly equal the percentage wage increase that workers receive).

Results

The results of the model, which can be accessed in the ‘Results’ sheet of the benefit quantification model file, are summarised table 8 at the end of this section and are discussed below.

Additional GVA

In the central scenario, relative to a baseline of no CAP equipment roll-out, the effects of introducing CAP equipment into road and rail leads to additional gross value added to the UK economy between 2024 and 2050 totals £75.8bn (£2.8bn per annum). This is the total additional value being produced by the UK economy due to the cost savings of CAP being channelled into higher output and the effects on the supply chain of the production and sales of CAP equipment.

Of this total GVA addition, £14.4bn is generated by the road and rail sector itself and £61.4bn is generated in the broader economy.

The £61.4bn added by the broader economy derives from the production of CAP equipment. When orders for this equipment are made, the CAP equipment producing sectors increase production to meet these orders, and this results in increased GVA (direct effects). But these firms in turn increase their orders form their suppliers, and they from theirs, and so on. This supply chain response adds GVA in various sectors of the economy (indirect effects). Finally, all of this increased output by the CAP producing firms, their suppliers and their suppliers' suppliers leads to more demand for labour, which increases peoples' incomes, which they then spend in the economy, creating demand which further increases GVA (induced effects).

The additional £14.4bn produced by the road and rail sectors derive from cost savings being channelled back into increasing output, and therefore delivering more benefits for clients (or client, the UK government). The cost savings arise from three sources: improved productivity of workers with access to equipment with CAP; fuel savings by machines that, largely due to telematics technologies, idle less and are used more efficiently; and reduced injury costs as CAP improves safety standards and makes operations more ergonomic.

Value for money

A further benefit of CAP is that clients of the road and rail sector enjoy more infrastructure for the same investment. Some of the additional value that the sector produces, discussed above, is distributed to capital costs of investing in CAP and some to profits, but of the remainder, some goes to increasing earnings for workers and some goes into improved delivery, which increases value for money for the government as the purchaser of road and rail infrastructure. The government receives an extra £33bn of value in this way over the 26 forecast years. By 2050, this is an extra £1.6bn per year, or 9.9% extra over what it would have gotten in the baseline.

Workforce and salary

The introduction of CAP inevitably has effects on the demand for labour in the construction sectors using CAP. Improved productivity of workers means fewer are needed to get the same work done. (Alternatively, the same number are needed to do more work, and the balance of additional output and productivity reducing labour demand is determined in the model’s assumptions).

Given the assumptions discussed above, in the road and rail sector, 25,400 fewer workers will be demanded in 2050 relative to what would have been needed in a no CAP baseline, which is a 37% reduction.

However, because of the additional GVA being generated in the broader economy, more workers are demanded across the supply chains responding to the demand for CAP equipment (see 'induced effects' above). 54,800 additional workers will be demanded because of this mechanism, meaning the net effect on the UK economy is 29,400 additional workers being demanded in 2050 than in a no CAP baseline. This reflects a nationwide outcome, and geographical distribution of employment impacts have not been analysed.

Though there are job losses in the industry (relative to a no CAP baseline), those that remain enjoy greater benefits. The improved productivity of CAP equipment means each worker is adding more value and this is reflected in their earnings. The average real sector salary of £54,937 per annum is around £5,900 higher than the £49,043 that would have occurred in the baseline. This is a 12% increase.

Improved Safety

The remaining workforce not only earns more, but it also enjoys improved working conditions. Mentioned above was the more ergonomic design of operations, which result in fewer instances of musculoskeletal damage. This is reflected in lower costs to employers of loss of workdays, compensation, and so on. This results in cost savings of £6.3bn to employers in the road and rail sector. But of course, this is also a quality-of-life gain for workers (which, being subjective and difficult to measure is not quantified here, but may be noted as a benefit and proxied by the injury costs reduction).

Aside from the slow attrition musculoskeletal conditions, what can be measured of is the specific incidences of workplace deaths and accidents that CAP can prevent. By improving safety, through geofencing giving stronger safeguards against entering dangerous areas or automated machinery having failsafe mechanisms to prevent dangers such as collisions, the rate of death and injury is reduced. Note that the rate is reduced, so that with a smaller workforce, there is less potential for incidents anyway, but that considered, in the central scenario, there are around 31 fewer deaths in the 26-year forecast period and around 28,000 fewer non-fatal accidents.

Climate Impacts

The reduction in fuel use discussed above results in lower emissions each year. The cumulative effect in the central scenario is around 19,300 fewer kilotons of CO_2 being released into the atmosphere by road and rail operations.

It should be noted that with lower carbon fuels expected to power construction equipment in future, the exact scale of carbon emissions, and particularly tailpipe emissions is uncertain, but likely to be lower than estimated below. Nonetheless, any reduction in fuel used of whatever type, will lower emissions.

Results summary

Road and rail sector	Central		High		Low	
	Nominal (to 2050)	Per annum	Nominal (to 2050)	Per annum	Nominal (to 2050)	Per annum
Additional GVA in UK (£m)	75,831	2,809	94,263	3,491	72,432	2,683
Road and rail sector	14,406	534	17,481	647	11,158	413
Broader Economy	61,425	2,275	76,782	2,844	61,274	2,269
Additional GVA, broader economy	61,425	2,275	76,782	2,844	61,274	2,269
Direct: Orders of CAP equipment	26,665	988	33,331	1,234	26,665	988
Indirect: Supply Chain stimulus of CAP orders	19,313	715	24,141	894	19,285	714
Induced: Increased earnings > increased demand	15,447	572	19,309	715	15,323	568
Cost Savings construction sector (£m)	40,907	1,515	48,667	1,802	32,384	1,199
Productivity improvements	24,704	915	28,609	1,060	20,097	744
Fuel Savings	10,251	380	12,920	479	7,597	281
Injury Costs	5,953	220	7,139	264	4,691	174
Distribution of Cost Savings (£m)	40,907	1,515	48,667	1,802	32,384	1,199
Profits	891	33	1,103	41	676	25
Value for Money for Clients	32,865	1,217	39,027	1,445	26,067	965
Investment Costs	891	33	1,103	41	676	25
Increased Wages	6,260	232	7,434	275	4,965	184
Value for money, Road and rail (£m)	32,865	1,217	39,027	1,445	26,067	965
Extra GVA p.a. by 2050	1,618	60	1,894	70	1,304	48
% extra GVA p.a. by 2050	9.9%		11.6%		8.0%	
Workforce changes (000s)	29.4		39.4		33.5	
Road and rail sector	-25.4		-29.1		-21.0	
Broader Economy	54.8		68.5		54.5	
Salary changes, construction sector						
Average salary, baseline (no CAP), £	49,043		49,043		49,043	
Average salary, with CAP, £	54,937		56,312		53,528	
Change, £	5,894		7,269		4,485	
% gain	12.0%		14.8%		9.1%	
Safety						
Deaths Avoided	31	2	37	2	24	1
Non-fatal accidents avoided	28,000	1,000	34,000	2,000	22,000	1,000
Reduction in in CO_2 emissions (kt CO_2)	19,330	880	24,363	1,102	14,325	658

Table 9 - Results summary across all scenarios

Annex G: Data sources

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Annex H: Contributors

List of stakeholders interviewed for the purposes of this market analysis; through whose contribution the production of this report would not have been possible.

- Action Sustainability
- Bomag
- Construction Equipment Association
- Content With Media
- Costain
- Dynamic Ground Solutions
- Eiffage, Kier, Ferrovial Construction and BAM (EKFB) joint venture on behalf of HS2 Ltd
- Finning (Caterpillar)
- Flannery Plant Hire
- High Speed Two
- Hitachi Construction Machinery
- JCB
- Komatsu
- Leica Geosystems
- L Lynch Plant Hire & Haulage
- National Highways
- Network Rail
- Sany
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[l] Workers produce value, not revenue, so the level of GVA that the new output level implies needs to be calculated, and this depends on the changes in input costs resulting from fuel savings and injury costs.