Cranfield University

Through-life Engineering Services

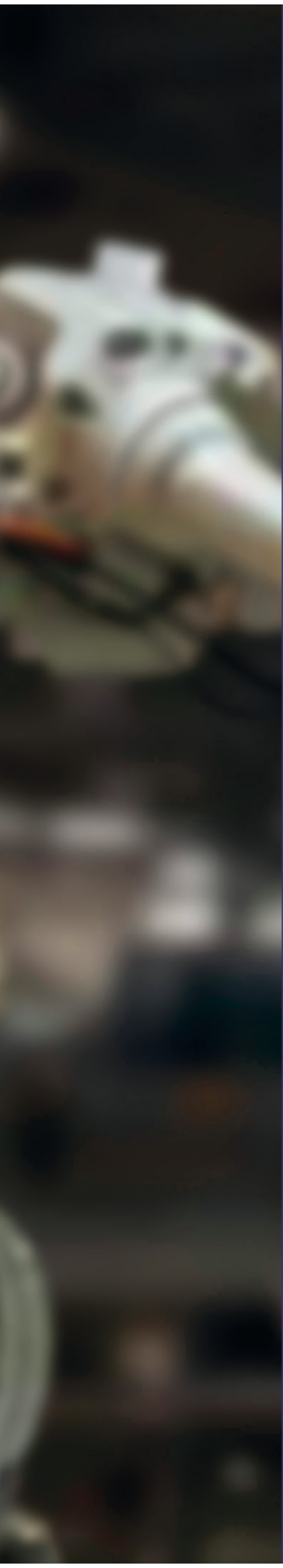
WMG THE UNIVERSITY OF WARWICK

CATAPULT High Value Manufacturing

Through-life Engineering Services for Mobility as a Service (TES for MaaS)

Maximising the UK opportunity in automotive manufacturing, supplies and service

Contents



Through-life engineering services (TES) will be essential for securing a leadership position in mobility as a service (MaaS) for the UK. TES addresses all aspects of a vehicle, from concept to retirement, aided by technologies that ensure maintenance becomes more prescriptive and breakdowns a thing of the past. Unique British solutions must be supported in the form of an open source platform for ‘MaaS for Life’. This must be supported by skills development, both in innovation and in operating competitive ‘MaaS for Life’ offers.

Chapter 1
Executive Summary

The way people travel on our roads is changing.

In the middle of the 20th Century, people dreamed of the day they would own their own vehicle and, when they secured one, would happily devote significant hours and resources to its care and upkeep.

But the dream is changing. Although 90% of vehicles are privately owned, they are in use for just 5% of their lifespan[i]. Today's dream is of being able to travel or to transport people and goods at will without the hassle or cost of vehicle upkeep and, when at home, to live without the sight of a largely unused asset depreciating at the kerbside. Today's generation wants to buy the journey not the vehicle.

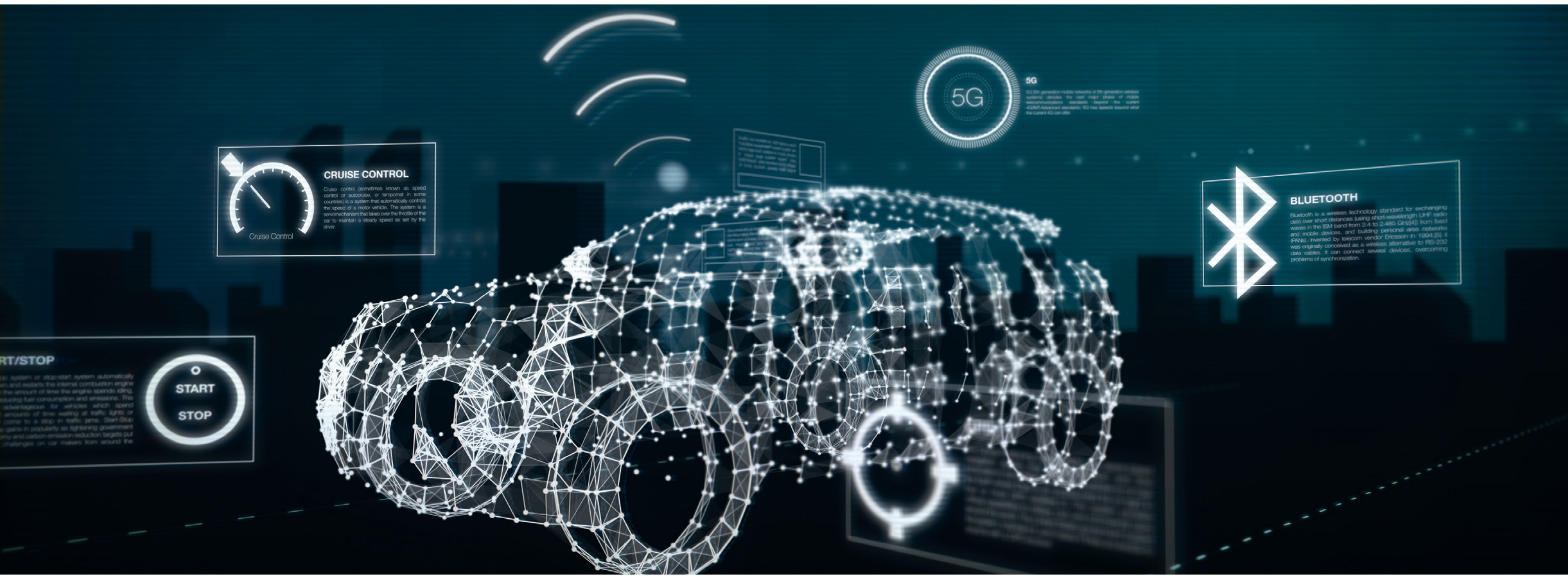
That change in mindset is creating both challenges and opportunities for industry.

To reap the benefits of changing customer demands, industry must be ready to provide vehicles engineered to cope with much higher levels of use, fleet operators must be able to access the data and through-life engineering services (TES) that keep them running sweetly, and retailers will need to refocus their business models as the traditional timeline of trade-in and purchase fades. The value of the automotive industry will shift from the design and manufacture of cars to the control and management of 'mobility as a service' (MaaS).

The challenges are significant, but the change is coming and the opportunities it creates are sizeable. Estimates vary widely but one estimate predicts that the global market for MaaS will grow to £275 billion by 2025[ii]. In the UK, the Engineering and Physical Sciences Research Council (EPSRC) working with Cranfield University estimates that the market for the through-life engineering services needed to support the vehicles could be as much as £13.5 billion by 2030[iii]. We know that the global car giants have MaaS on their radars. If the UK can develop a strategic response to the coming revolution, it will not only ease an inevitable transition but seize the competitive advantage.

So what might that strategic response include? Research by Cranfield University, the Warwick Manufacturing Group and the High Value Manufacturing Catapult identifies seven things the UK could do now to make sure we master the change:

- Make sure that the IT systems needed for MaaS and TES can talk to each other.
- Make sure that the UK has access to the skills needed to support TES.
- Set up a National Advisory Board to guide supply chain development.



TES for MaaS is forecast at up to

£13.5 billion

a year by 2030

- Invest in the research and development that will allow the UK to build on its already strong through-life engineering track record and spur the development of the digital technologies needed for MaaS.

- Support the development of a common open source operating platform.

- Make it easy for users to pay by creating a data-sharing platform that enables a single ticketing payment system across different modes of transport.

- And, crucially, join the dots: promote TES as an enabling technology and business model for the 'Future of Mobility' strand of the Industrial Strategy.

Our world is changing. This report looks at how we can maximise the UK opportunities flowing from one part of that change and make the UK stronger.

> Industry must be ready to provide vehicles engineered to cope with much higher levels of use and fleet operators must be able to access the data.

Chapter 2
Context

Over the past decade, the transport sector has evolved tremendously. Now, with the emergence of connected and autonomous vehicles and disruptive mobility technologies, a paradigm shift is about to happen in the way we move people, goods and services.

The Government's Industrial Strategy, released in November 2017, acknowledged this rapid transformation by including the Future of Mobility as one of its four Grand Challenges. This includes the need to prepare for it in terms of the regulatory framework, infrastructure investment, innovation acceleration (through more investment in R&D) and addressing the skills gap in the UK's workforce[iv].

As the concept of 'mobility as a service' (MaaS) becomes widespread, vehicle usage patterns will change drastically. Today, 90% of vehicles are privately owned but they are in use for only 5% of the time[i]. By contrast, in future, when connected and autonomous vehicles (CAVs) are ubiquitous, less than 10% of vehicles will be owned privately[v], with the majority of cars being used to provide shared mobility on demand – a shift that is expected to bring enormous societal and economic benefits.

The MaaS model isn't just about cars: people will be able to choose from a wide range of modes of transport and mobility services to match their needs at any time. However, CAVs will not only enable and accelerate MaaS, but will also become the major platform for land transportation.

When connected and autonomous vehicles (CAVs) are ubiquitous, less than

of vehicles will be owned privately

Given the inexorable rise of autonomous vehicles and opportunities afforded by TES, the question is:

“How can the UK maximise its share of the opportunities arising from this transport revolution?”

> **Vehicles used by MaaS customers will have very high usage rates** (over 50%) and will therefore need to be engineered in very different ways.

Vehicles used by MaaS customers will have very high usage rates (over 50%)[vi] and will therefore need to be engineered in very different ways. At the same time, the established model of selling a new car to a buyer every 3 to 5 years will no longer be valid. The value of the automotive industry will be centred on the control and management of the whole MaaS system instead of just the design and manufacture of cars.

This will have a profound impact on manufacturers and their supply chains, and supporting services. Global car giants already have this matter on their agendas. However, any strategic response to this revolution is a competitive advantage and unlikely to be shared widely. Supply chains and governments therefore need to work out likely future scenarios for themselves and determine how to ensure a seamless transition to MaaS.

This could be seen as a serious threat to realising the benefits of MaaS, but it is also an opportunity for those willing to adapt and secure substantive, technology-driven positions in the new world of autonomy. As such, the 'servitisation' of engineering and manufacturing presents a substantial opportunity for the UK.

Benefits of through-life engineering services (TES)

Any industry that manufactures complex engineering products and where the manufacturer can consider the returns over the whole product lifecycle (such as automotive) is one in which through-life engineering service (TES) principles and associated business models may apply. TES provides capabilities and opportunities for companies to move to servitised business models.

In the automotive sector, new car stock is already extensively enabled for TES and elements of the TES concept are in use, but the term is not commonly used. Nevertheless, new service models are already appearing as autonomous vehicles are introduced. As a result, automotive OEMs will change their business models to become more service oriented, such as building and managing fleets for MaaS providers.

By 2025, the rise of new MaaS offers based on CAVs is likely to have penetrated the sector by between 20% and 90% (of gross value added, GVA)[vii]. As an early adopter of TES, the UK is uniquely positioned to profit from this shift, given that the automotive sector produces UK GVA of approximately £20.3 billion (1.24% of total GVA)[viii]. The UK autonomous vehicle market value will reach £25 billion in 2030[ix]. The average aftermarket value (maintenance, repair, overhaul and spares) in the UK is already 12% of the value of vehicle sales[x], which gives a lower bound for TES penetration in future. Together, these give an equivalent TES for MaaS market value by 2030 of between £3 billion and £13.5 billion[iii].

Given the inexorable rise of autonomous vehicles and opportunities afforded by TES, the question is: "How can the UK maximise its share of the opportunities arising from this transport revolution?"

> 'Servitisation' of engineering and manufacturing presents a substantial opportunity for the UK.

Chapter 3
TES: Enabling the Shift to a Servitised Future

With increasing awareness of the 'circular economy', in which we keep resources in use for as long as possible, extract the maximum value from them while in use, then recover and regenerate products and materials at the end of each service life, there is increasing need for alternative, sustainable business models. The growth of internet of things and big data, and the emergence of data-led 'industry 4.0', also feed into this.

In an economy where customers would rather pay for service or functionality than buy products, engineering companies will have to transition to service-centric business models to survive or remain profitable. Those who made that switch in the 1990s to early 2000s now derive over 50% of their revenue from these activities (for example Rolls-Royce), with much higher margins than from selling products alone, making their businesses sustainable[viii, xi].

Through-life engineering services (TES) provides the capabilities and opportunities for companies to make the transition to a servitised business model.

The value of TES

Through-life engineering is about optimising the design and manufacture of vehicles based on usage information in order to minimise unit travel costs and maximise customer experience.

TES allows companies to stay in touch with the value they physically create in their products throughout their lives and allows the creation of other, less traditional, value streams[xii]. In a TES transaction, the customer pays for a service or functionality rather than an asset, and doesn't distinguish between products and services. Maximising the service value throughout the expected operational life of the product or system, while minimising cost, therefore becomes the central driving force.

TES is also important as it allows owners and operators to get best value from their assets, and lets manufacturers and maintainers capture value by actively supporting the outcomes that a user desires (such as performance, reliability, availability and/or experience)[vii].

Relatively few companies have adopted a service-led model, with leaders in TES predominantly found in the aerospace, defence, information and communication technology (ICT), and rail sectors. Yet in the UK, which is currently a global leader in TES, around £275.2 billion (16.8%) of the economy is attributable to sectors that could be influenced by engineering services, and of this at least £31.6 billion (1.9%) is potentially associated with the application of TES[vii]. This highlights the opportunity for growth if more manufacturers and sectors were to adopt TES principles.

The TES framework

TES provides a framework that guides organisations on the technologies and capabilities required to deliver such services. The framework helps organisations develop and establish specific policies and processes, define or establish their TES organisational capabilities, identify potential value streams and determine what execution processes are required to achieve TES offerings. It also helps organisations assess where they are on their journey from product seller to service provider, from a knowledge, tools and technology perspective[xiii].

There is currently no TES framework for the automotive sector, but some guidance already exists in the example TES framework created by the Aerospace Technology Institute (ATI) (Figure 1) based on experiences gained in the aerospace sector.

> Through-life engineering services comprise the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high quality information to maximise their availability, predictability and reliability at the lowest possible through life cost.
>
> **EPSRC – TES Centre[vii]**

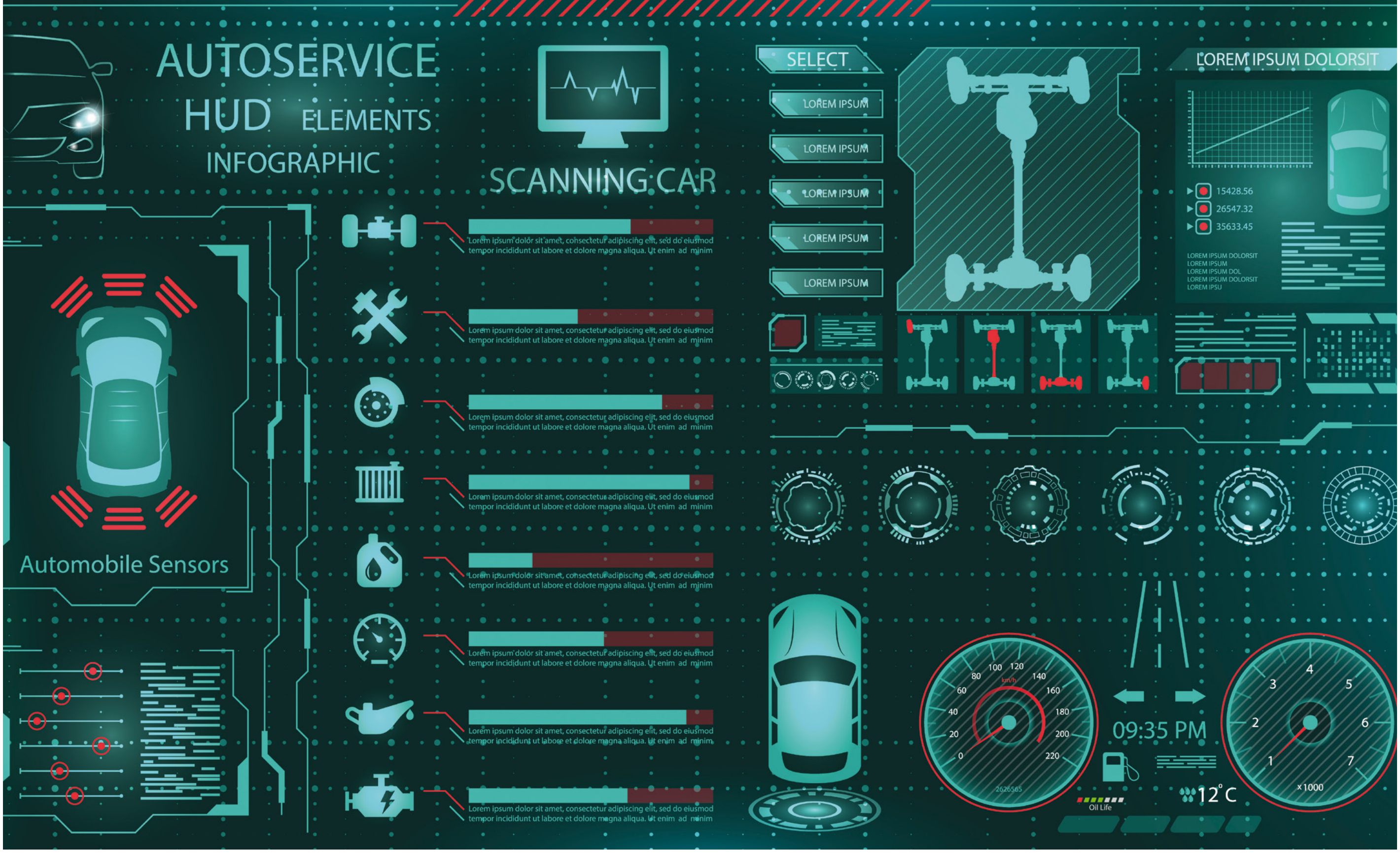
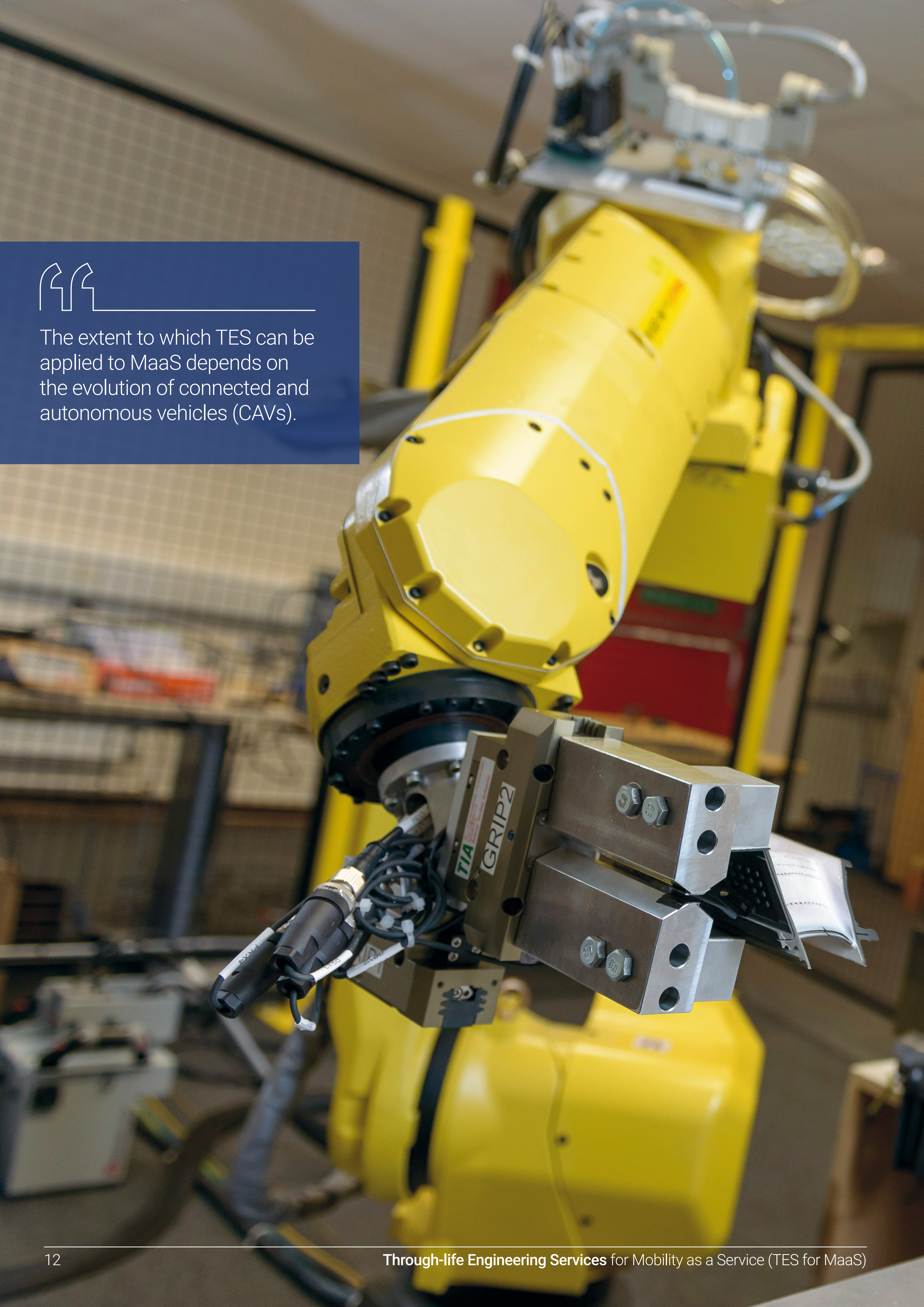


Figure 1: The TES Framework

	Basic (Product)		**Intermediate** (Output)		**Advanced** (Outcome)
	Basic Services	Preventive & Corrective Maintenance	Predictive Maintenance	Real-Time Condition Based Services	Advanced As-A-Service Provision
OFFERINGS	• Break down response • Insurance inspections • Upgrades • Spare Parts	• Scheduled MRO • Inspections based upon estimated wear and life interval (time based) • Planned repairs	• Reliability Centred Maintenance • Diagnostics and emerging prognostics	• Condition Based Services • IVHM • Real-time data	• Availability / Capability as a Service • Fleet / Asset Management • Maintenance Planning • Operations planning and management • Other asset and business management services including training, finance etc
KNOWLEDGE	• Knowledge of in-service issues • Knowledge of means of repair / repair techniques • Knowledge of spares	• Knowledge requirements for Basic + • Knowledge of product life / hours of in-service use	• Requirements for preventive maintenance + • Knowledge of Use • Knowledge of degradation and failures • Knowledge of Repair	• Requirements for predictive maintenance + • Knowledge of diagnostics and prognostics aligned to failure / degradation mechanisms	• Requirements for Real-time condition based services + • Knowledge of product design and functionality • Knowledge of customer business operations
TOOLS	• Maintenance / repair manuals • Inspections / logbooks / defect reports • Issues databases		• Library of standards, methods and algorithms to support service related decision making, including decision optimisation tools, uncertainty models, degradation / deterioration models, repair methods, and common data and interoperability standards		
TECHNOLOGIES	• Standard / prescribed tools and equipment for inspections, testing and repair • Maintenance planning and management platforms		• Technologies required to deliver advanced service capabilities and support new business models, including Internet of Service Things, Data Analytics, Advanced Sensors, Digital Twins and Robotics amongst others		

← Data sharing / ownership, Intellectual Property, Mind-set, Regulations, Security of data, Skills, Standards, Quality of data, Infrastructure, Logistics →

SOURCE: Aerospace Technology Institute 2017

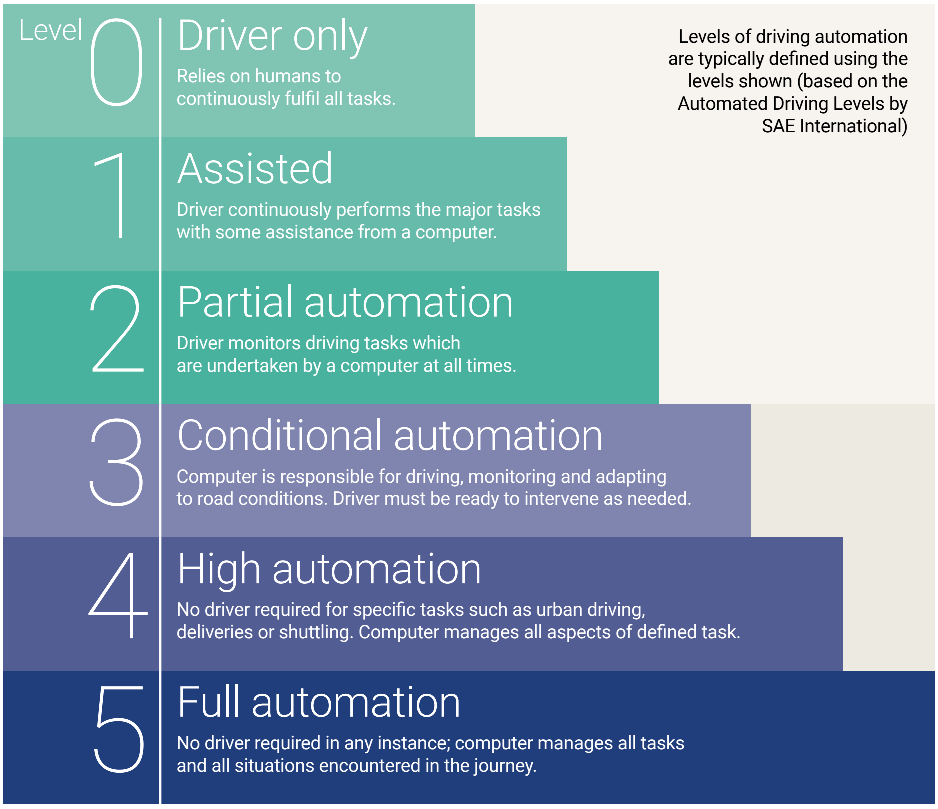


> The extent to which TES can be applied to MaaS depends on the evolution of connected and autonomous vehicles (CAVs).

Chapter 4
Applying TES to MaaS

The Transport Systems Catapult defines the concept of mobility as a service (MaaS) as: "Using a digital interface to source and manage the provision of transport related services which meet the mobility requirements of a customer"[xiv].

Figure 2: Levels of driving automation



In the MaaS model, people will choose and buy mobility services from a range of types of transport, based on their needs, which will be cheaper than owning their own vehicles. This requires vehicles to be both autonomous and connected. However, automotive OEMs, including Nissan, Ford, Volvo, BMW and Audi, have all announced plans to launch fully connected and autonomous vehicles (CAVs) by 2021, indicating that some form of MaaS will happen soon.

The extent to which TES can be applied to MaaS depends on the evolution of CAVs. CAVs can communicate with the surrounding environment, including infrastructure and other vehicles, and self-drive without human input. There are six levels of driving automation, according to the SAE International standard J3016[xv], with levels 3 and above being those in which the vehicle can drive dynamically, with or without human intervention, as shown in figure 2.

There are six themes in which TES can be applied in MaaS, which vary in complexity and will change as MaaS develops through the now commonly accepted phases[xvi]:

- **MaaS 1** (2018-2020)
  Level 3 autonomous vehicles (AVs) in production
- **MaaS 2** (2020-2025)
  Level 3 and 4 AVs in production
- **MaaS 3** (2025-2030)
  Level 3, 4 and 5 AVs in production

01

TES basic services

MaaS 1 Monitoring of in-service issues and more data collection by OEMs.

MaaS 2 More fleet-based data sharing, and capture of failure and degradation data. New standards will be needed to collect and analyse the data, and protect privacy and intellectual property.

MaaS 3 24/7 maintenance service for fleets, with autonomous or remote insurance inspections.

04

Real-time, condition-based services

MaaS 1 TES is already building on emergent internet of things (IoT) technologies to provide more real-time services.

MaaS 2 Real-time vehicle health and usage monitoring, feeding into diagnostics and prognostics, with self-diagnostics and calibration becoming more common.

Maas 3 Limited remote repairs.

05

Advanced TES as a Service provision

Over time, some through-life engineering services will themselves be provided by third parties, resulting in 'TES as a Service'.

MaaS 1 Over-the-air upgrades of vehicle software.

MaaS 2 A 'digital twin' of a vehicle will allow a virtual in-vehicle simulation of any upgrade before it is applied.

MaaS 3 Outcome-based contracts between MaaS providers and customers, with a 'pay-per-use' model available outside urban areas. Self-engineering vehicles will reduce maintenance costs significantly, reducing unit travel costs.

Use of self-healing materials and technologies, contributing to significantly improved availability of autonomous vehicles, in spite of higher levels of utilisation.

02

Preventive and corrective maintenance

MaaS 1 TES is currently applied to MaaS vehicles though annual servicing and breakdown maintenance.

MaaS 2 Start to see benefits from maintenance decision-making based on data analytics.

MaaS 3 Use of self-healing materials and technologies, contributing to significantly improved availability of autonomous vehicles, in spite of higher levels of utilisation.

03

Predictive maintenance

MaaS 1 Limited TES is applied with on-board diagnostics in current vehicles used in MaaS.

MaaS 2 More diagnostics to predict failure and manage reliability and condition-based maintenance. Along with car performance monitoring, there will be more interest in internal environment monitoring and control for better customer experience.

MaaS 3 More closed loop maintenance management systems, such as advanced vehicle health management, plus limited self-repair capability.

06

Feedback to design and engineering

Maas 1 Some 'design for service' studies are underway, in which likely future service challenges are taken into account at the design stage, but they are limited. BSI's TES PAS standard is a welcome development.

MaaS 2 Needs further standards development; possibly producing something akin to the Building Information Modelling (BIM) standard[xvii] used within construction, in which the physical and functional characteristics of a building are modelled digitally. Through-life modelling of performance over time will be more common and that will support the automation of maintenance.

MaaS 3 Real-time, condition-based capability contracting will become a reality supported by a BIM-like standard for transport infrastructure. End-of-life management of the vehicles will be done by MaaS providers in collaboration with OEMs (original equipment manufacturers).

Real-time, condition-based capability contracting will become a reality supported by a BIM-like standard for transport infrastructure.

Chapter 5
Seizing Opportunities for the UK

The social and economic benefits of mobility as a service (MaaS) are well documented[xviii], but the long-term outcomes for the UK will depend on decisions made now regarding the rate of adoption of MaaS and through-life engineering services (TES) for connected and autonomous vehicles (CAVs). There are many challenges to be overcome before we can seize the opportunities it affords.

Real-time vehicle health and usage monitoring that feed into

diagnostics

and

prognostics

will be essential to extend their lifecycles.

Economic forecast

The Transport Systems Catapult report on the 'Market Forecast Growth for Connected and Autonomous Vehicles'[ix] considered four scenarios for the growth in sales of CAVs (including cars, vans, HGVs and buses). The two middle ground 'Central' scenarios both assume rapid technology development and moderate global CAV uptake, with Europe ahead of the rest of the world as a result of factors including a supportive regulatory framework. However, projected UK market sales for CAVs are predicted to be far higher if the UK can take a leading position globally, clearly showing the benefit of addressing factors that would boost the sales of CAVs, such as through-life engineering services (TES).

Table 1: Projected UK market sales for CAVs (levels 3 to 5)

Scenario	2020	2025	2030
Central	£240m	£750m	£1,000m
Central, UK Lead	£350m	£1,370m	£1,800m

Source: Transport Systems Catapult report on the Market Forecast for Connected and Autonomous Vehicles

The UK has been a leading pioneer in TES. Yet we have failed so far to translate this success across the full range of industrial sectors.

TES value chain

A range of business and market opportunities will emerge from adopting TES for MaaS, as shown in figure 3. A primary set of opportunities directly linked to MaaS will appear in the short-to-medium term, while a secondary set will emerge from these, creating even more value overall.

TES has been proven to enable the profitable provision of product-centric services, as demonstrated by Rolls-Royce in the UK aerospace sector. The biggest challenge relating to MaaS for the automotive industry is creating the right business model for the 'software-defined car'.

With predicted usage rates of over 50%[vi], reliability is key in a MaaS scenario. Real-time vehicle health and usage monitoring that feed into diagnostics and prognostics with be essential to extend their lifecycles. Lessons learned from aerospace and rail sector applications of TES will give the UK an advantage, building on our strengths and closing the gap between our best and worst performers. The UK has been a leading pioneer in TES, originating many of the innovations in the field through our industries and academia. Yet we have failed so far to translate this success across the full range of industrial sectors. The opportunity for knowledge sharing and acceleration of competitiveness across sectors is immense.

Safety margins must be high too. The principle challenge for a vehicle maker

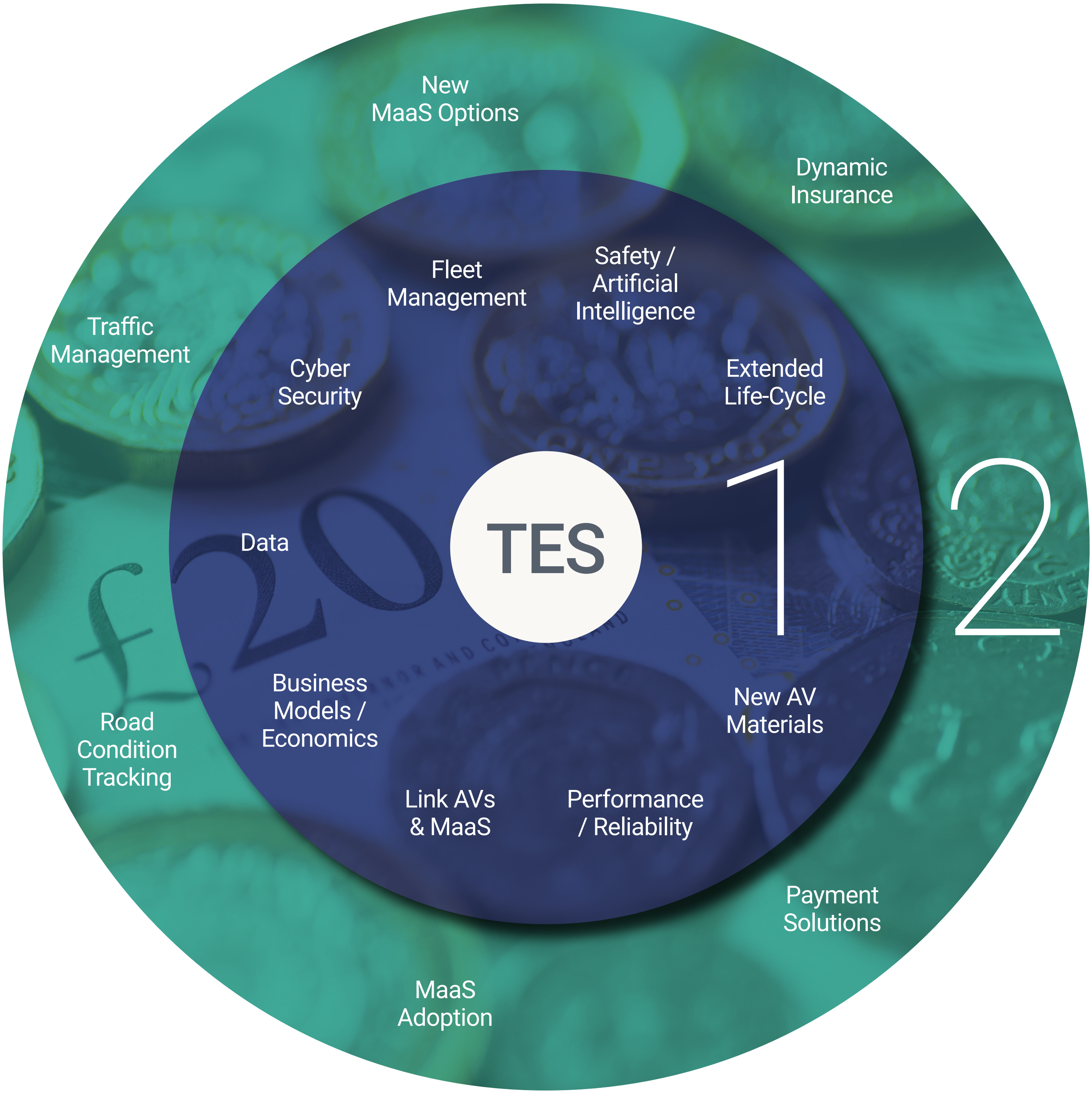


Figure 3: TES Value Creation Ecosystem.
1 - Direct value, 2 - Indirect value

is not so much capturing the world around CAVs, but making sense of the information gathered. The latest developments in AI can support such advanced capability, but industry needs to carefully select which areas to build on, based on growth potential.

Degradation modelling will enhance lifecycle prediction and development of self-healing materials will facilitate self-engineering and reductions in maintenance costs. On the other hand, 'vehicle-to-everything' (V2X) communication will increase the safety of CAVs and provide a valuable source of data to MaaS providers.

This extra data will give rise to revenue opportunities for data brokerage services, which will be able to take data generated from CAVs, process it and sell it on. Some of this may be on sectors of the population that currently cannot travel easily but will be able to do so using AVs, such as older people who are no longer able to drive. It is predicted that companies will be able to gain huge financial value from automotive data, including connectivity – of the order of US$450-750 billion globally by 2030[xix].

However, there has also been a steady rise in digital manipulation of data stolen both from inside and outside cars, including user information taken from the service providers. Data privacy and integrity therefore remain two of the biggest challenges to the digital industry and potential brakes on rates of adoption.

Opportunity highlights:

Develop long-term research and education to build on the existing collaborative environment between academia, industry, government and other stakeholders.

Build a 'MaaS for Life' brand at national level to help to promote and enhance the adoption of MaaS.

Encourage collaboration between data science, material science, design and maintenance ecosystems in UK research and development, and public-private partnerships.

How the UK can gain the lead

UK stakeholders have a wealth of knowledge in this area, which they shared with us in a series of structured workshops and interviews in late 2017 and early 2018 (see Appendices), adding to the information we obtained from an extensive literature review. From this, we identified many opportunities for the UK to gain a leading position in TES for MaaS:

- Create a centre of excellence on cross-sector TES for MaaS to leverage the opportunities offered by improved TES models. Pilot studies on implementation should be carried out, with adequate support provided for implementing the findings.
- Academia and industry need to collaborate on through-life degradation models. This would provide opportunities for optimising MaaS in terms of extending vehicle life and reducing the cost of MaaS for customers.
- Develop long-term research and education to build on the existing collaborative environment between academia, industry, government and other stakeholders, such as the Automotive Council, TES Council and Aerospace Technology Institute.
- Build a 'MaaS for Life' brand at national level to help to promote and enhance the adoption of MaaS. This should support a competitive MaaS offer with optimum through-life cost and be designed in a socially inclusive manner.

Other opportunities include:

- Create more agile standards and architectures for MaaS overall and for TES for MaaS, and legislation supporting TES for MaaS development involving CAVs.
- Encourage TES and MaaS owners (fleet owners and mobility service providers) to work towards an open platform.
- Make the most of the Industrial Strategy's Grand Challenges focusing on Artificial Intelligence and the Future of Mobility.
- Secure data centres could support service providers across different transportation modes.
- Encourage collaboration between data science, material science, design and maintenance ecosystems in UK research and development, and public-private partnerships.
- Involve the public in the design of MaaS offers.
- Apply lessons learned in TES for the aerospace and defence sectors and Formula 1 cars.
- Reskill the workforce to apply TES technologies and business models to CAVs and then to MaaS.

Chapter 6
Creating an Environment for Success

The Government and organisations such as Innovate UK and the Transport Systems Catapult all have roles to play in creating an environment in which UK businesses can flourish and become leaders in both mobility as a service (MaaS) and through-life engineering services (TES).

Regulation is vital, but must not hinder innovation or protect incumbents.

One immediate requirement is for the Government to boost the UK's position by promoting collaboration, both within industry and between industry and Government. Industry, in turn, should create an agile supply chain and servicing capability, with better collaboration between OEMs and lower tier suppliers and SMEs. Industry also needs to communicate its problems and engage with bodies such as the Catapults in order to maximise the opportunity to retain service, technology and software IP in the UK.

Innovate UK and the Transport Systems Catapult can promote and encourage UK organisations to compete with non-UK mobility players. This could include providing more backing for small competitors, including start-

Lack of innovation is not an issue, but how to leverage it to maximise the output is.

Stakeholder feedback

ups, incubators and universities, thus creating an ‘enabling ecosystem’ which promotes entrepreneurship.

Regulation is vital, but must not hinder innovation or protect incumbents. For example, data will be an essential part of a successful MaaS concept, but a distinction will need to be made between vehicle and passengers’ personal travel data. The Government, working with industry, will need to clearly define related rules and how they are enforced, taking into account the benefit of sharing aggregated and/or anonymised data on an open platform. Other regulations will be needed to cover safety standards and immigration for skilled labour, which may be required to address any skills shortages after Brexit.

An additional benefit of TES for MaaS is that it could enable the dismantling of the current MoT structure, replacing it with self-testing autonomous vehicles (AVs). TES will also facilitate the introduction of innovative recycling opportunities and integrated data/analytics propositions.

TES and CAV skills

TES is already widely practiced within the aerospace and defence sectors. Nevertheless, today’s automotive technicians and engineers will need reskilling to deal with connected and autonomous vehicles (CAVs) and intelligent transport systems (ITS), and more skilled workers recruited/trained to counter the ageing workforce in the ITS and CAV sectors in time to meet commercial demand. The Government’s role should centre on promoting and enabling training and education within the automotive industry, with financial incentives for companies, through schemes such as Apprenticeships, at all levels from technician through to chartered engineer.

Chapter 7
Delivering TES for MaaS

Through-life engineering services (TES) will be essential for securing a leadership position in mobility as a service (MaaS) for the UK.

TES presents a broad range of opportunities – going beyond simply enabling cars to be used more frequently and for longer – which can be delivered faster and in an affordable manner by following a shared roadmap. Our roadmap shows how TES can be used for MaaS to increase its competitiveness and make it affordable. Table 2 outlines examples of TES options that will be valuable for MaaS across the three MaaS adoption phases (see chapter 4). This description should be the guide to identify the technology, business model and standardisation efforts necessary to accelerate MaaS adoption.

Table 2:
TES options for MaaS – a roadmap

TES options for MaaS
TES Basic service
Preventive and corrective maintenance
Predictive maintenance
Real-time, condition-based services
Advanced 'as a service' provision
Through-life engineering for example: • feedback to design and manufacturing • life extension • degradation modelling and compound degradation assessment

MaaS adoption phases for autonomous vehicles

MaaS 1 (2018-2020)	MaaS 2 (2020-2025)	MaaS 3 (2025-2030)
Service, spares and repairs Monitoring in-service issues Data collection	Sharing data in fleet operations Failure and degradation data capture Development of new standards	24/7 service and maintenance Autonomous/remote insurance inspections
Vehicle use and performance data collection	Use data analytics to feed back into maintenance regimes Scheduled maintenance based on use and wear Collect degradation data	Self-healing materials and technologies Preventative maintenance managed by AVs – improved availability
Diagnostic/predictive algorithms Feedback to design Degradation modelling Vehicle connectivity is an enabler	Diagnostics to predict failure and manage reliability-based maintenance Condition-based monitoring and maintenance Monitoring of cabin and internal environment/state	Closed loop condition based management strategy Closed loop integrated vehicle health management (IVHM) Self repair where possible
Emergent internet of things (IOT)	Real-time vehicle health and usage monitoring feeding diagnostics and prognostics Self-diagnostics and calibration	Remote assistance/fix
Over-the-air upgrades	Digital twin – integrated data	Fleet management Availability/outcome-based contracts Pay per use Self-engineering – reduced maintenance cost
Design for service Use TES expertise to build frameworks and standards Vehicle component degradation models Feedback directly to DFMEA	BIM-like standards for cars and fleets Through-life modelling of performance over time Automation of maintenance Improved data mining capability Less wastage – replace/repair	BIM-like standard for infrastructure Real-time, condition-based capability contracting Self-engineering in practice End-of-life management

NOTES: BIM – Building Information Management; DFMEA – Design Failure Mode and Effect Analysis

Chapter 8
Conclusion & Recommendations

Through-life engineering services (TES) can help prepare the UK automotive industry for future of transport based on the principle of providing mobility as a service (MaaS).

Our consultations with stakeholders, including vehicle manufacturers, and consideration of policy frameworks, infrastructure and data, lead us to a number of recommendations to the Government to enable the creation of a unique British MaaS offering using TES expertise.

01

Develop system integration capability for through-life of a MaaS offer

TES for MaaS offers unique opportunity to create a supply chain of OEMs, technology and service providers, Catapults and R&D organisations/universities that is focused on system integration with systems level thinking. The development of the right capabilities needs demonstrator projects that integrate the lifecycle of a MaaS offer using connected and autonomous vehicles (CAVs). Such project(s) should have multiple stakeholders to ensure every aspect of MaaS requirements is covered.

02

Set up a National Advisory Board

Set up a National Advisory Board to map the activities that need to be supported for an exemplar brand of MaaS, such as 'MaaS for Life in complex urban areas'. The Board should be chaired by an independent person with experience in TES and MaaS, and include members from city councils, Government, automotive OEM manufacturers, TES owners and providers, other mobility service providers, insurance associations, banks, Catapults and universities. The Board should look at the UK supply chain gap in MaaS and TES, and make recommendations for its development and capability enhancement. The Board should lead the development of a 'MaaS for Life' brand for the UK, nationally and internationally, and monitor the demonstrator projects.

03

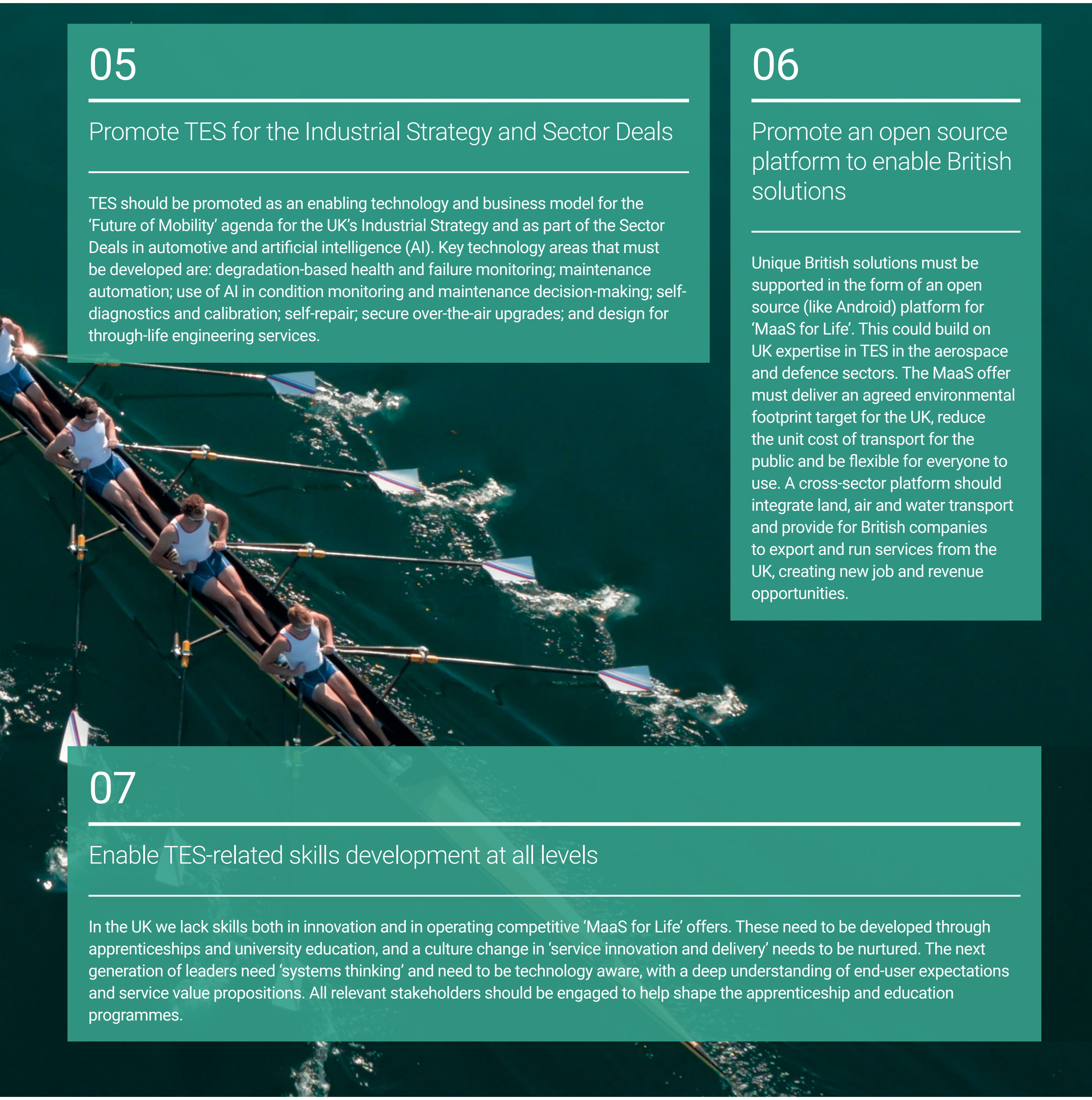
Invest significantly in R&D

Significant R&D investment could build on the UK's track record in TES, develop prognostics and digital technologies for MaaS, and contribute to the development of a 'MaaS for Life' operating platform. This platform could be the basis for service providers to offer innovative services within a complex urban environment. The investment could be overseen by the National Advisory Board.

04

Set up a common data sharing platform

Set up a data sharing platform (with common content and data formats) to support accurate planning of journeys between different modes of transport: this should have public organisation ownership, for example by city councils. Such a platform would enable a single ticketing payment system and promote the success of MaaS. The MaaS programme should be rolled out in phases, starting with cities with a strong public transport infrastructure.



05

Promote TES for the Industrial Strategy and Sector Deals

TES should be promoted as an enabling technology and business model for the 'Future of Mobility' agenda for the UK's Industrial Strategy and as part of the Sector Deals in automotive and artificial intelligence (AI). Key technology areas that must be developed are: degradation-based health and failure monitoring; maintenance automation; use of AI in condition monitoring and maintenance decision-making; self-diagnostics and calibration; self-repair; secure over-the-air upgrades; and design for through-life engineering services.

06

Promote an open source platform to enable British solutions

Unique British solutions must be supported in the form of an open source (like Android) platform for 'MaaS for Life'. This could build on UK expertise in TES in the aerospace and defence sectors. The MaaS offer must deliver an agreed environmental footprint target for the UK, reduce the unit cost of transport for the public and be flexible for everyone to use. A cross-sector platform should integrate land, air and water transport and provide for British companies to export and run services from the UK, creating new job and revenue opportunities.

07

Enable TES-related skills development at all levels

In the UK we lack skills both in innovation and in operating competitive 'MaaS for Life' offers. These need to be developed through apprenticeships and university education, and a culture change in 'service innovation and delivery' needs to be nurtured. The next generation of leaders need 'systems thinking' and need to be technology aware, with a deep understanding of end-user expectations and service value propositions. All relevant stakeholders should be engaged to help shape the apprenticeship and education programmes.

This report on through-life engineering services (TES) for mobility as a service (MaaS) was based on a step-by-step research process.

The rearch process included:

- a review of current literature
- workshops with stakeholders
- a SWOT (strengths, weaknesses, opportunities and threats) analysis that was validated using semi-structured interviews.

These led us to produce the roadmap for implementation of TES for MaaS and the set of recommendations to maximise the UK's opportunity in TES for MaaS.

Literature review

A literature review was undertaken to identify existing research that covers current and future directions and understand the opportunity. It also formed the basis for the workshop discussions and SWOT analysis. The literature review focused on MaaS and TES frameworks, and the relevance of the two concepts to the UK's automotive industrial strategy.

Workshops

In the initial stages of the study, it was important to understand the requirements and expectations of stakeholders in the mobility, TES and policy sectors. To do the initial scoping, we used a workshop format as this allowed stakeholders to focus on a specific issue at a time. The literature review informed the questions posed to workshop participants. Three workshops were conducted, lasting 3 to 6 hours each, depending on the workshop's focus.

SWOT analysis and validation interviews

The literature review and workshop results informed the SWOT analysis for MaaS in the context of TES. This was then verified via a series of semi-structured interviews with interviewees who represented different stakeholder groups, such as OEMs, Tier 1 suppliers, policy makers and mobility service providers. The semi-structured interview format provided a flexible platform for interviewees to speak about targeted questions[1]. Interviews were conducted by telephone, with all respondents asked the same set of questions and each session lasting 30 to 45 minutes.

[1] Robson; "Real world research: a resource for social scientists and practitioner-researchers", 2nd edition; Oxford: Blackwell; 2002.

The TES for MaaS project engaged automotive stakeholders in a series of workshops to understand the future potential scenarios for mobility as a service (MaaS) and how through-life engineering services (TES) can support the development of connected and autonomous vehicles (CAVs) for use in these scenarios, and offer a unique UK solution.

Engagement

The TES for MaaS project team engaged with the Department for Business, Energy & Industrial Strategy (BEIS) 'Disruptive Innovation in Automotive' project, which considered the possible impact of disruptive innovation on UK automotive manufacturing. This formed part of the industrial engagement and workshops process.

The aim was to understand the current state and future direction of MaaS and explore how TES can support the development of MaaS.

The RethinkX Disruption, Implications and Choices, Rethinking Transportation 2020 – 2030 Report, 2017[2] helped with defining the MaaS adoption phases for AVs. The Aerospace Technology Institute (ATI) TES Strategy document[3] provided a through-life engineering services framework (see chapter 3) based on the aerospace sector that outlines a set of knowledge, tools and technologies to deliver TES. (No equivalent was found in the automotive or AV context.)

- The scenario timings were based on three MaaS periods (1, 2 and 3) as used in PwC's report 'The 2017 Strategy & Digital Auto Report'[4]:
  - > MaaS 1 (2018-2020) – Level 3 AVs in production
  - > MaaS 2 (2020-2025) – Level 3 and 4 AVs in production
  - > MaaS 3 (2025-2030) – Level 3, 4 and 5 AVs in production

Workshop findings: Business scenarios

MaaS 1 (2018-2020)

OEMs will offer more in-vehicle digital services via built-in connectivity as a source of new revenue. These services will require major partnerships between OEMs and technology suppliers, especially for software product development: for example, Renault, Nissan and Mitsubishi are investing $1 billion in technology start-ups focussing on vehicle electrification, AV systems, connectivity and AI. New unusual market entry will be normal, such as BlackBerry's relationship with Chinese internet giant Baidu to develop self-driving car technology[5].

Successful servitisation business models already exist in 2018 in the Truck sector, with manufacturers such as MAN, Scania and Volvo supplying vehicles through fleet management contracts, but this business model will become more mainstream during the MaaS 1 period.

MaaS 2 (2020-2025)

Electric vehicle (EV) production will continue to grow. Ford has already forecast that it will have 40 electric vehicle models by 2022 (24 hybrid and 16 fully electric)[6] and Nissan says that Infiniti will become a purely electric vehicle brand after 2021.

All vehicles manufactured by this point will be either all-electric or a form of hybrid sometimes referred to as ePower[7] in which the battery is charged by a small gasoline engine. General Motors forecasts that it will launch two new EVs in the next 18 months and 20 electric or hydrogen-fuel-cell EVs by 2023 as part of an all-electric future.

Digital components and software services will attract major software companies: for example Toyota Connected is working in partnership with Microsoft, Nvidia's AI technology will be integrated into Uber's fleet of self-driving cars and freight trucks, and Magna's ICON RADAR (high-resolution automotive radar) will help companies jump from AV level 3 to level 5 autonomy.

There will be more opportunities for revenue generation through analytics of vehicle and customer data: this is forecast to grow to a $750 billion business by 2030[8].

In addition, redesign of the vehicle distribution channels will accelerate during this period.

MaaS 3 (2025-2030)

OEMs will build and operate fleets of vehicle for MaaS operators. The relationship with the passenger, as well as the brand value and profit potential, could shift to the MaaS platform provider. As a result, companies like GM, BMW and Ford are already investing in building capabilities to address these market opportunities.

Vehicles will be used as a platform to provide added value services, such as BMW CarData[9] and Park and Delivery apps via 'VW We'. Initiatives such as the Open Services Gateway Initiative (OSGi) will be essential, allowing service-providers, gateway operators, and device and car manufacturers to develop, deploy and manage network-based services.

Some stakeholders believe this stage could last until 2035.

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[2] J. Arbib and T. Seba; "Rethinking Transportation 2020-2030: The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries"; RethinkX Sector Disruption Reports, RethinkX California, US; 2017.

[3] Aerospace Technology Institute; "Through-Life Engineering Services technology strategy for the UK Aerospace Sector"; 2017.

[4] PwC; "The 2017 Strategy & Digital Auto Report"; 2017.

[5] Trefis Team; "Why BlackBerry's Autonomous Driving Deal With Baidu Is Significant"; 2018. [Online]. Available: https://www.forbes.com/sites/greatspeculations/2018/01/05/why-blackberrys-autonomous-driving-deal-with-baidu-is-significant/#449091ce40a1

[6] N. Carey and J. White; "Ford plans to spend $11bn on 40 new electric car models by 2022"; Independent, 2018. [Online]. Available: https://www.independent.co.uk/news/business/news/ford-electric-car-models-billions-2022-car-manufacturer-a8159431.html

[7] Automotive News; "Infiniti will go mostly electric by 2021, Nissan CEO says"; 2018. [Online]. Available: http://europe.autonews.com/article/20180117/COPY/301199997/infiniti-will-go-mostly-electric-by-2021-nissan-ceo-says

[8] McKinsey & Company; "Monetizing car data"; 2016.

[9] Telematics wire; "BMW car data"; 2017. [Online]. Available: http://telematicswire.net/tag/bmw-cardata/

A strengths, weaknesses, opportunities and threats (SWOT) analysis was carried out across the different mobility as a service (MaaS) timelines adopted in this report and used at the workshops. The output formed the basis for a suggested mitigation (weaknesses) and generation (opportunities) roadmap across the MaaS timelines.

The SWOT analysis considered four themes:

- Application – The elements that affect the MaaS ecosystem.
- Through-life engineering services (TES) owner – The organisation delivering through-life engineering in the service-centric business model that offers the product capability/ outcome/performance/availability.
- Infrastructure – Technologies and systems that enable autonomous driving and the delivery of aggregated mobility services.
- Data – Data collected from vehicles; customer information regarding their mobility requirements; data communicated between infrastructure and connected vehicles.

Strengths

- The regulatory platform for testing of autonomous vehicles (AVs) is open and flexible, and encompasses the development for connected AVs (CAVs) for MaaS and CAV test beds.
- In the UK, MaaS trials are taking place in several areas, supported by the required manufacturing know-how from major manufacturers, such as JLR and Nissan.
- Manufacturing capability is supported by a strong back-end services application development skills base.
- The Government's Industry Strategy has identified artificial intelligence as a focus: that is helping MaaS development and will support the application of TES for better MaaS offers.
- The Aerospace Technology Institute (ATI) has published a strategy to support TES technology development within civil aerospace, which is unique to the UK.
- The industry base in the UK is supported by strong academic and research teams in TES and integrated vehicle health management (IVHM), whose work includes research in self-healing materials, which will be needed for future CAVs and will contribute towards a more competitive MaaS market.
- The UK's dealer and maintenance network is well established, which is a benefit because it is likely that fleet owners will take ownership of TES for CAVs to support more reliable and competitive MaaS offers. OEMs are expected to own fleet services in the future: combined with their manufacturing knowledge, they will offer advanced TES services for the MaaS.
- The UK's infrastructure is complex, so learning how to adapt autonomous vehicles to this will be a strength that can be exported to other countries.
- The UK has the industrial capability to develop new business models to monetise the data accruing from TES and MaaS.

Weaknesses

- The UK lacks a major platform integrator in the automotive sector to accelerate the MaaS offer. There is a lack of joined-up thinking – who can put an overall solution together; who will be the UK's Elon Musk?
- There is a significant need to develop high value design capability with the system thinking in the UK. The design and skills development must engage the next generation of users in the debate.
- There is a lack of UK insurance models for CAVs.
- We need a comprehensive understanding about the likely impact of MaaS on a range of aspects, from car parking revenue to legal frameworks.
- The culture of data sharing among MaaS and TES stakeholders needs improving.
- There is a lack of unified ticketing facility nationally.
- Public perception of new technologies and new ways of working needs to change to adopt MaaS faster.
- Potential TES and MaaS providers are not thinking in a way that incorporates 'through-life' and they lack deep systems level understanding.
- There is a lack of investment available to scale up the adoption of MaaS and the industry base in this country.
- The value chain and translational models are not well understood.
- The supply chain needs to develop to create an ecosystem for TES for MaaS.
- Standards for TES and MaaS are essential to drive growth.
- Skills development across all levels needs significant improvement to support MaaS growth and to benefit from TES developments.

Appendix C *(continued)*
SWOT Analysis

- Integration of various transport modes is inadequate. Current road infrastructure and land use planning are not optimised for multi-modal transportation.
- There is a major weakness in the UK's communications network with the lack of 5G.

Opportunities
See Chapter 5.

Threats
- Other countries may develop MaaS offers faster, using the size of their internal market and available levels of investment.
- Other countries are setting relevant international standards potentially faster than the UK.
- Major companies, such as Google, Uber, Amazon and Apple, are setting the agenda, which could result in the UK losing out on market share.
- Slow regulatory change will affect TES for MaaS and its adoption in the UK.
- Lack of partnership development to support MaaS in the UK and lack of investment required to accelerate infrastructure development.
- A clear roadmap for CAV technologies is necessary to drive the infrastructure development.
- Cyber security of the new MaaS offers needs to be developed.
- More research and development in secure engineering is essential to protect the service and the infrastructure.
- The skills base in TES for CAVs and MaaS in general is lacking.

Detailed results from the SWOT analysis are available on request.

Appendix D
Contributing Stakeholders

Company/Organisation	Sector
Aerospace Technology Institute (ATI)	Research & technology
Ageas Insurance	Insurance
Barclays	Banking
Bosch UK	Automotive
BSI Group	UK national standards body
Centre for Connected and Autonomous Vehicles (CCAV)	Government organisation; part of Department for Transport and Department for Business, Energy & Industrial Strategy
Cranfield University	University
Department for Business, Energy & Industrial Strategy (BEIS)	Government department
E4tech	Consultancy
FiveAI	Autonomous technology
Hennik Group	Industry publishing group
High Value Manufacturing Catapult	Research centre
Horiba MIRA	Automotive engineering consultancy
Institution of Mechanical Engineers (IMechE)	Professional institute
Intelligent Transport Systems UK	Membership organisation
International Institute of Obsolescence Management (IIOM)	Professional institute
Jaguar Land Rover	Automotive
Lloyds Bank	Banking
MaaS Global	MaaS
NatWest	Banking
Nissan Motor Company	Automotive
Policy Connect	Cross-party think tank
Rolls-Royce	Engineering
TES Council	Membership organisation
The Real-Time Data Company Ltd	Engineering test & verification
Transport for London	Transport provider
Transport Systems Catapult	Not-for-profit consultancy
University College London MaaSLab	University
Warwick Analytics	Test analysis software company
Warwick Manufacturing Group	Part of Warwick University

[i] Reinventing Parking; "Cars are parked 95% of the time". Let's check!; 2013. [Online]. Available: https://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html

[ii] The Insight Partners; Mobility as a Service (MaaS) Market 2025 – Global Analysis and Forecasts by Service Type, Application Platform, Business Model & Vehicle Type; February 2018

[iii] Estimated TES for MaaS annual market value of £3 billion to £13.5 billion by 2030 calculated from:

UK autonomous vehicle market value of £25 billion in 2030. Source: Transport Systems Catapult; Market forecast for connected and autonomous vehicles; 2017

Average UK aftermarket value (maintenance, repair, overhaul and spares) around 12% of value of vehicle sales. Source: Marshall Motor Holdings plc; Annual Report & Accounts 2016

Penetration of new MaaS offers based on CAVs of 20% to 90% of GVA. Source: EPSRC Centre for Innovative Manufacturing, Through-life Engineering Services; A national strategy for engineering services: Delivering UK economic growth by making things work better for longer; Cranfield University 2016 [Online]

[iv] Department for Business, Energy & Industrial Strategy; Industrial strategy: building a Britain fit for the future; 2017

[v] P. Valdes-Dapena; Why own a car when you can subscribe to one instead; 2018. [Online]. Available: http://money.cnn.com/2018/05/01/technology/car-subscription/index.html

[vi] ABI Research; ABI Research Forecasts Global Mobility as a Service Revenues to Exceed $1 Trillion by 2030; 12 September 2016 [Online]

[vii] EPSRC Centre for Innovative Manufacturing, Through-life Engineering Services; A national strategy for engineering services: Delivering UK economic growth by making things work better for longer; Cranfield University 2016 [Online]

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[xvi] PwC; The 2017 Strategy & Digital Auto Report; 2017

[xvii] International Organization for Standardization; ISO/TS 12911:2012; Framework for building information modelling (BIM) guidance

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