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# Disruptive technology and innovation in transport

Policy paper on sustainable infrastructure



**European Bank**  
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# Executive summary

A key objective of the European Bank for Reconstruction and Development (EBRD), especially in the transport sector, is to support the promotion of innovative new technology in the economies where the Bank operates to improve competitiveness and provide demonstration effects. The purpose of this paper is to provide an overview of the current state of the market and opportunities for the implementation of a range of (disruptive) digital technologies capable of revolutionising the transport sector in the EBRD regions. These technologies include:

- **the internet of things (IoT)** – a system of objects, processes, data and people connected with each other via sensors, and controlled remotely using the internet
- **big data** – complex data characterised by high volume and requiring the use of advanced analytics for processing
- **artificial intelligence (AI)** – computer science which enables machines to function like a human brain
- **drones** – unmanned aerial vehicles (UAVs) or flying robots.

The paper outlines a range of digital technologies and concepts (Section 2), introduces various technology application areas with supporting case studies and cost-benefit analysis (Section 3) and discusses a policy roadmap for their successful implementation (Section 4).

The summary of the technologies presented in Section 2 demonstrates that IoT, big data and AI do not operate in isolation but instead represent highly complementary technologies. Big data is collected most effectively using IoT systems and drones and then processed most efficiently using AI algorithms and optimisation techniques. The main applications of these particular technologies in transportation focus around demand forecasting and traffic optimisation resulting in better traffic management, asset management, travel planning and operation of autonomous vehicles (AVs). The

key challenge in the development of the identified disruptive technologies and their applications will be their successful integration into new business and governance models, maximising their combined benefits to support the end goal.

The four applications of the disruptive technologies that Section 3 reviews in detail are as follows:

- **Traffic management using intelligent transport systems (ITS)** – using new technologies to predict future traffic demand more accurately and optimise road networks accordingly, providing a wide range of social and economic benefits, including reduced congestion and pollution, improved safety and travel experiences for all road users.
- **Personal travel planning and public transport** – analysing available information on travel demand and travel patterns of the population, to facilitate the optimisation of planning, programming and operation of public transport systems, as well as improving personal journey planning for the public.
- **Autonomous and connected vehicles for mobility** – developing applications for AVs which can contribute to increased safety, a better user experience, economic savings and reductions in congestion, by facilitating car sharing and “mobility as a service” (MaaS).
- **Unmanned aerial vehicles/drones for monitoring** - using technology to revolutionise the way we undertake asset management, maintenance and inspections (bridges, tunnels and construction sites) and providing an efficient means to deliver packages (logistics).

These technology application areas were reviewed in the context of their contribution to the following policy objectives: (1) transport efficiency, (2) safety and security, (3) environment and climate change and (4) socio-economics. From the analysis of these policy objectives we concluded that the technology application areas which have the most profound (disruption) potential impact were new smart mobility (AVs/MaaS and drones) and intelligent transport systems (ITS), each requiring and leveraging different digital technologies.

The key challenge in the development of the identified digital technologies and their applications will be to integrate the business and governance models for new mobility technologies, services and systems successfully. The following challenges are critical to this process:

- Harmonising existing and new policies related to the legal framework for use and operationalisation of such technologies.
- Facilitating interoperability and data sharing.
- Promoting vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication.
- Ensuring data security and addressing risk-sharing/liability concerns.
- Identifying requirements for facilitating necessary enabling “public” infrastructure and forms of economic regulation to enable widespread adoption.
- Developing cost-benefit analysis methodologies and the supporting evidence base to promote adoption.
- Launching analytical work and developing innovative operating models.
- Developing integrated mobility systems.
- Sharing data and digital infrastructure.
- Supporting capacity-building, education and awareness-raising.

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# 1. Introduction

## 1.1. Objectives

One of the EBRD's key medium-term priorities is “digitisation and digital development”. An important aspect of this objective is the promotion of new technology and innovation that can improve the competitiveness of key sectors and businesses in the EBRD regions. The Bank is now considering a range of new technologies and innovations that are being developed and adopted in many parts of the transport sector. It seeks to understand the opportunities for EBRD clients to adopt and implement such technologies, including overcoming potential barriers to entry and adoption, with the Bank's support.

This paper provides an overview of the current state of the market and opportunities for the implementation of specific digital technologies in the transport sector. It discusses a range of potential application areas including an assessment of the potential costs and benefits of digital technologies capable of “disrupting” the transport sector. As such, the paper will be of direct interest to the EBRD's in-country transport teams, but also to municipalities and regional/national transport authorities, illustrating the potential (and successful) application of selected disruptive technology in different contexts within the transport sector, and a roadmap towards leveraging such technologies better. The following technologies are introduced and discussed in the context of the transport sector:

- **Internet of things (IoT)** – system of objects, processes, data and people connected with each other via sensors, and controlled remotely using the internet.
- **Big data** – complex data characterised by high volume and requiring the use of advanced analytics for processing.
- **Artificial intelligence (AI)** – computer science which enables machines to function like a human brain.
- **Unmanned aerial vehicles (UAVs/drones)** or flying robots.

These technologies were selected because:

- their technological applications have specific relevance to the transport sector
- they have potential to provide benefits from structural change, through addressing congestion and pollution to improved safety and a wide range of social and economic benefits
- they have the most potential to revolutionise how we live, work and travel in the next 10-20 years
- they primarily rely on the use of digital technology
- they have active programmes of implementation with test programmes in Europe and in Central Asia

Conversely, the following technologies, while they are very relevant to transport and have the potential to significantly disrupt the sector, are not discussed in detail. This is because they are deemed to rely less on the digital transformation of the fourth industrial revolution, and would require engineering transformation to be fully captured by the EBRD policy and business model. Further information is available elsewhere on:

- electric vehicles (EVs)
- advanced materials
- energy storage technologies (for example, lithium batteries)
- advanced robotics and manufacturing.

## 1.2. Structure

The structure of this paper is as follows:

**Section 2** provides a summary of different digital technologies and concepts, covering (1) internet of things, (2) big data, (3) artificial intelligence and (4) drones. These technologies are summarised in terms of potential application areas, components, barriers to implementation, technology and policy enablers and opportunities for further development and implementation.

This section provides a qualitative description of the various technologies considered in this paper and a discussion of areas of commonality and complementarity. Indeed, many of the technologies considered here are typically applied in combination

as technology stacks. This is because cost-benefit information is not readily available for discrete technologies, but rather for areas where these technologies, when applied in combination, can yield significant economic and environmental benefits.

In **Section 3** we introduce different application areas, related to the transport sector, to help frame each of these technologies, focusing on their potential impacts and implications. We explore several case studies for each of the application areas from Europe, Central Asia and elsewhere, together with information on the costs and benefits of those applications and specific schemes implemented around the world.

These case studies provide practical examples of some of the challenges and opportunities associated with the implementation of these technologies, and an outline of their disruption potential. After reviewing the most prominent disruptive technologies and potential application areas in transport, we identified several areas of public policy that might warrant further examination. This is discussed in more detail in Section 4. A roadmap for implementation is presented, comprising a range of applications that can build on these disruptive technologies, as well as potential barriers, bottlenecks and opportunities.

### 1.3. Background

Traditional methods of overcoming critical transport and infrastructure challenges are increasingly subject to technology-based disruptions, creating new opportunities. We are now in the fourth industrial revolution – but this one is happening much faster than any of its predecessors. The accelerating pace of technology diffusion and its updates, the convergence of multiple technologies towards human-centric goals, or common applications, and the emergence of global platforms are disrupting traditional transport and infrastructure development models.

In transport, demand continues to grow each year, with Europeans, on average, travelling around 35,000 passenger kilometres per year; with a clear majority (64 per cent) of these trips being made by

car. However, the situation is changing rapidly: since 2002, the number of kilometres driven per person has fallen by 8.5 per cent (Deloitte, 2015). Meanwhile, use of public transport has increased. This trend suggests that urban residents are becoming more likely to consider new ways of travelling and to move away from the traditional car ownership model in favour of new forms of transport such as car sharing, electric vehicles, autonomous cars and mobility-as-a-service (MaaS) solutions (Deloitte, 2015).

The past 100 years have also been characterised by significant growth in car ownership, which has been linked with global drivers of suburbanisation as well as increasing incomes and consumer purchasing power. The proportion of the global population living in urban areas continues to rise faster than the capacity of roads and public transport. The pressure on transport infrastructure is significant and cannot be resolved by simply building more infrastructure. New, innovative solutions and approaches are required to address these problems. The use of new digital technologies is a key part of addressing this challenge and can help to ensure more efficient and sustainable use of existing infrastructure. At the same time, it can encourage the public to abandon their cars in favour of walking, cycling and shared mobility solutions (Webb, 2019).

These new forms of transport rely increasingly on exploiting the use of digital technologies, which are revolutionising the way we travel and communicate. The ability to collect vast amounts of data (“big data”) and process it in real time using advanced analytics and AI will allow us to predict transport demand better and, as a result, improve our ability to manage existing infrastructure. Ensuring that assets are connected and communicate with each other through internet-of-things protocols and platforms will provide new ways to organise traffic, travel and logistics, while permitting the remote control and management of assets and networks. The use of robots, such as drones, is already revolutionising how we manage our assets and undertake infrastructure inspections and surveys, as well as supporting logistics and deliveries of consumer goods and services in many established and emerging global markets.



The digital age has the potential to bring with it a range of disruptive technologies. Indeed, the pace and the scale of the changes is expected to increase due to the rapid development in digital technologies. In the past, disruptive technologies would have been viewed as unknown and unproven, often considered impractical for real-world application. In many cases these disruptive technologies would displace established firms in existing markets. For example, mainframe computer manufacturers in the 1970s and 1980s underestimated the potential demand for personal computers. As a result, companies like Apple and Microsoft disrupted the market with their new products, while major manufacturers dismissed personal computers and overlooked a market that did not yet exist (Baker et al., 2016).

Today the term “disruptive” is often used to describe technological advancements which are new, evolve rapidly and have a significant impact on how we live and work, as well as on our economy. To ensure that society is ready for these new technologies, governments, policymakers and lawmakers will need to gain a good understanding of how the future is going to unfold and make the right investment decisions in infrastructure and education so that societies continue to prosper. In today’s society, digitisation and disruptive technologies such as big data, IoT, AI and drones have the potential to change the way the transport sector is organised and managed, paving the way for new services and business models.

## Economics of new technology

The transformative nature of disruptive technologies makes their economic and financial analysis challenging. By definition, disruptive technologies make more fundamental changes and affect deeper structures – changing the way existing markets operate, creating new players and displacing old ones. The analysis of their impacts requires a corresponding economic and financial methodological approach that considers broader outcomes than those typically applied to transport projects and investment.

The types of disruptive technologies proposed here have a wide range of potential applications and impacts across society generally. Furthermore, changes due to the deployment of, for example, big data solutions can have significant implications across a range of sectors at once. As such, these technologies change the context for transport as well as transport itself and result in a changing economic and financial landscape. In the World Economic Forum’s study *Deep Shift: Technology Tipping Points and Societal Impact* (20), three of the technologies considered are identified as the subject of “tipping point” considerations – big data for decisions (expected to be common by 2023); driverless cars (by 2026); artificial intelligence and decision-making (also by 2026). For these, cost-benefit analysis is only a partial guide to their feasibility as the structural changes they both cause and require depend on a wider range of factors.

For the transport sector, the economic impacts of new technology will occur through several mechanisms affecting the demand and supply sides of the economy: (a) reducing the need for travel through substitution; (b) improving the efficiency and convenience of travel by creating new modes, improved route planning, more efficient vehicles, and in vehicle services and so on; (c) improving the efficiency of infrastructure construction, operation and management; (d) improving the efficiency of transport operators and other businesses (through more competition, new services and new market structures); and (e) externalities such as reduced emissions, productivity gains, better information for public planning and so on.

The increasing capability of virtual technologies will reduce the need to travel by allowing remote observation and communication, but will also contribute to changes in the relative economic values of both new and old goods and services, changing incentives for travel and transport. Closely related to changes that affect overall demand are changes that are fundamental to a certain sub-sector of the transport network. A clear example is the retailer Amazon's proposed use of drones for "final mile" delivery to customers which would completely substitute an existing part of the limited capacity of the current terrestrial distribution system.

Cost-benefit analyses of these technologies show that their economic viability is often clear, but their development is inhibited in practice by many barriers to market developments (detailed for each technology and application in the next section of this report). These barriers mainly fall into three categories – lack of transparency over the potential benefits of the technology; the distribution of costs and benefits, which may mean that the benefits are not captured by those bearing the costs; and regulatory barriers that prevent the adoption of new technology due, for example, to perceived safety risks.

For instance, at the technical level, the inability to capture and use relevant data from multiple streams generated by different systems (ITS or IoT) is the result of several organisational, technical and commercial barriers. In some cases, a lack of understanding of the potential to use data has led to a failure to invest in deploying tech-enabled solutions. But there are also technical challenges, including finding efficient ways to transmit and store data. The most fundamental challenges are in data transmission and storage. Many IoT applications are deployed on remote or mobile equipment. Real-time transfer of all the data being generated by the sensors on aircraft engines would require more bandwidth than is currently deployed. If data can be collected and stored, the next obstacle is aggregating it in a format that can be used for analysis. Limited standardisation of data means that substantial systems integration work is needed to combine data from multiple sources. This challenge is accentuated by connectivity and storage challenges.

Issues of data ownership within and across organisations can complicate aggregation. Owners of data from one system might not find it in their own commercial interest to have their data combined with data from other systems (see website link 23 at the back of this report). Another example lies in the provision of infrastructure that often is or has aspects of natural monopoly. It is complex to develop solutions using disruptive technologies that address this, are timely and coordinated, and permit the benefits of competition. With common and widespread infrastructures in place, such as roadside or in-vehicle sensors, a range of value-added services becomes feasible. However, the need for, and revenue generated from, any one service may be insufficient to cover the costs, thus making the implementation of risk-sharing arrangements and associated financing structures substantially more complex.

In the construction industry, developers in worksite industries are working on two potential applications that are too nascent to reach their market potential today, and present too many barriers for development at this stage: fully robotic worksites and 3D printing of replacement parts on-site. Given the labour intensity, unpredictability and danger of some worksite environments, being able to remove employees from the site entirely would offer substantial productivity and safety benefits, particularly for assets that are difficult to reach. Many barriers to full automation remain, including the need for more sophisticated robotics and safety concerns about unmanned operations (especially for bridges and tunnels). The ability to 3D print replacement parts on demand could greatly reduce downtime caused by equipment failure and could raise asset utilisation and output. However, this would require equipment that produces parts that meet performance standards. If this challenge could be resolved, worksites would be able to reduce substantially the cost of carrying a spare parts inventory and could avoid delays caused by out-of-stock parts.

The analysis reported in the literature to date has taken a variety of approaches to the definition of scope for cost-benefit analysis. Skeete (2018)

notes that “there is no universal, valid definition to acceptance nor a single approach, but a broad range of theoretical constructs”. In practice, the authors choose a fixed set of mainly transport-related assumptions. For example, a study on autonomous vehicles notes that “most studies conduct micro-technical examinations of specific components within the autonomous vehicle” (Skeete, 2018).

While this reduces the complexity of the analysis in each study, assumptions are often particular to the individual themes of the studies and this can reduce their comparability. Furthermore, a focus on applications (how alternative technologies might solve the same problem) as opposed to individual technologies (the many ways in which each technology can contribute) widens the number of situations addressed by each technology, correspondingly increasing the number of cost-benefit ratios that are relevant to each. This makes comparison difficult.

The scope of economic and financial analysis tends to be tied to fixed aspects of the existing transport system, notably the volume of trips. Using a benchmark of a fixed volume of trips, it is possible to compare disruptive technologies to more traditional ways of achieving the same impacts. For example, technological solutions can reduce congestion, avoiding the need to increase road capacity to maintain or improve trip times. There can be associated benefits of reduced fuel consumption and emissions. The methods for valuing these benefits are already established using traditional methods. The estimation of the costs, arguably the more uncertain element, can nevertheless be based on detailed knowledge of the new technology. While the costs and benefits can be defined, overcoming the issues of transparency, distribution (allocation) of costs and benefits and regulation may be the greater challenge. Overall, these factors, and their ultimate influence on the level of uptake, are likely to be those that determine the overall viability of a new technology. Fagnant (2015) identifies that, among a range of missing research, “one of the most pressing needs is a comprehensive market penetration evaluation”.

The scope of cost-benefit analyses in the literature has typically not sought to represent the costs for overcoming these factors. However, expenditure on lobbying, for example to change regulation, would typically be part of corporate behaviour.

In the assessment of costs and benefits, the types of benefit commonly considered are the following:

- Time savings to individuals (for example, from reduced congestion).
- Savings from fewer automobile accidents (health, less disruption).
- Energy savings (from reduced trips and from more efficient use).
- Environmental benefits (mainly related to greenhouse gases and improved air quality).

Less commonly considered benefits are as follows:

- Maintenance savings (on roads and vehicles) from lower use or fewer trips.
- Environmental benefits not related to emissions (such as noise).
- Savings in the supply chains (for example, reduced demand for road materials) (20).

The types of cost considered are relatively clear in the specific studies but subject to variability when considered across the studies as a group. In general, studies focus more on financial than economic savings, with elements such as road costs being excluded (reflecting current charging structures, where road networks are free at the point of use), rather than full economic costs. Similarly, elements such as mobile phones may be assumed to be available at zero additional cost because they are assumed to have already been purchased. While this has some impact on the structure of the analysis, it also reflects particular perspectives on the availability and ownership of pre-existing infrastructures which are often key to the incentives for future participation and collaboration.

# 2. Disruptive technologies

## 2.1. Internet of things – a data collection and management tool

The internet of things (IoT), often referred to as the “internet of everything” is a system of objects, processes, data, people and even atmospheric phenomena, connected with each other via various types of embedded sensors, and controlled remotely using the internet (Witkowski et al., 2017). The applications of the IoT play an increasingly important role in smart transport and more recently in the “smart cities” agenda, helping to control traffic, monitoring weather and safety risks, providing information about the state of the roads and monitoring accidents. IoT platforms help manage, analyse and compile data from a wide variety of sensors, including proximity, infrared, image and motion detection sensors.

IoT technologies have a number of applications in the transport sector, including intelligent transport systems (ITSs) which use data collected from sensors, actuators, cameras and micro-controllers to optimise public transport, reduce congestion, monitor the environment and run security applications (Hill et al., 2017). From the transport sector’s perspective, the IoT could significantly change the way government entities provide transport services by allowing transport infrastructure assets to be monitored and operated in real time from remote locations. For example, International Business Machines (IBM) has developed systems that aggregate data from infrastructure-based sensors and similar devices to identify and measure traffic speed and volume on city roads. This provides road agencies, and in some cases the motoring public, with real-time traffic conditions, which can assist in incident response and routing activities (Baker et al., 2016).

**Table 1. The internet of things – applications, barriers and opportunities**

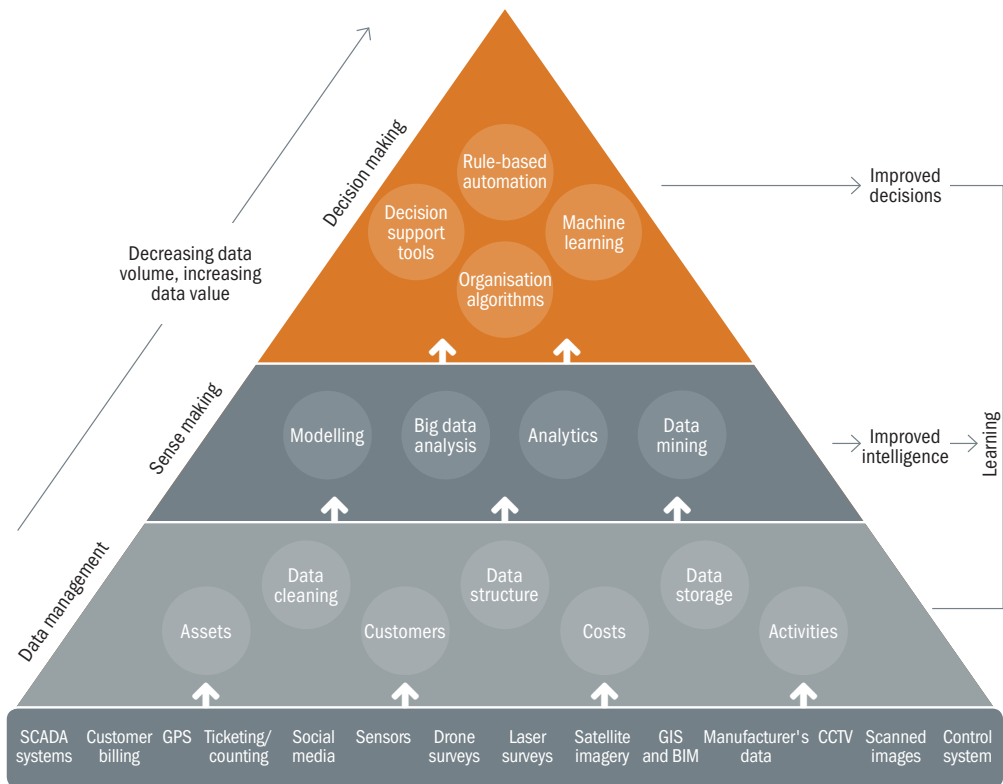
Applications	Barriers	Opportunities
<ul style="list-style-type: none"> <li>• Traffic management (ITS)</li> <li>• Demand modelling and forecasting</li> <li>• Asset management</li> <li>• Freight tracking</li> <li>• Logistics (tracking of deliveries)</li> <li>• Parking management</li> <li>• Personal travel planning</li> <li>• Public transport planning</li> <li>• Autonomous vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• High cost</li> <li>• Security and privacy concerns</li> <li>• IoT platforms</li> <li>• Interoperability and standards (integration inflexibility)</li> <li>• Legal issues around the internet</li> <li>• Requirement for technical skills</li> <li>• Requirement for infrastructure readiness</li> </ul>	<ul style="list-style-type: none"> <li>• Reducing congestion (savings in time, fuel, improved air quality)</li> <li>• Making transport safer and more efficient (vehicle tracking, travel planning)</li> <li>• More accurate forecasting (incident detection)</li> <li>• Logistics (deliveries tracking)</li> <li>• Social and economic benefits</li> <li>• Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication</li> </ul>
Components	Enablers	
<ul style="list-style-type: none"> <li>• IP (internet protocol) software platform</li> <li>• Computers</li> <li>• Device-to-device communication (Bluetooth, Z-Wave, ZigBee)</li> <li>• Device-to-cloud communication (Ethernet, wi-fi)</li> <li>• Device-to-gateway (application layer gateway service)</li> </ul>	<ul style="list-style-type: none"> <li>• APIs</li> <li>• Ubiquitous (low-cost or high-speed) connectivity</li> <li>• IP-based networking</li> <li>• Computing economics</li> <li>• Miniaturisation</li> <li>• Artificial intelligence</li> <li>• Advances in data analytics</li> <li>• Enhanced computing capabilities</li> <li>• Cloud computing</li> <li>• IPv6 IP protocol development</li> <li>• Blockchain</li> </ul>	

## 2.2. Big data – the data

“Big data” refers to complex data that is characterised by high volume (ranging from 1,000 gigabytes to 1 petabyte, equivalent to 1 million gigabytes in size), high velocity (in order to be useful, it needs to be analysed rapidly in “real time”) and high variety (normally comprising several different sources of data). The rapid increase in the availability and complexity of data has led to the term “big data”, although it does not have a universally agreed definition (Houses of Parliament, 2014). However, it is generally accepted that big data tends to be too complex to be analysed using traditional methods and requires the use of advanced analytics and computational algorithms.

The transport sector has always collected and analysed large quantities of data, including traffic surveys, data from timetables, and, more recently, data from traffic cameras, mobile phones and sensors. Historically, quantitative urban research has relied on data from surveys and censuses. All of these data sources are expected to continue to play a vital role in urban analysis. However, recent developments in the quantity, complexity and availability of big data, together with advances in computing technology, are presenting new opportunities to create more efficient and smarter transport systems. Figure 1 shows the main big data sources and the three component layers required to support smart infrastructure (Hill et al., 2017).

**Figure 1. Big data basic layers for smart infrastructure connected by the IoT**



Source: Hill et al. (2017).

In the context of the transport sector, big data is mostly associated with map data, vehicle location data, traffic control information, personal location data, payment or transaction data and public transport information. Big data can be collected from a number of sources and using a variety of methods, such as GPS or satnav, mobile devices (Bluetooth or wi-fi), cameras and sensors (for example, RFID2). The IoT often acts as an enabler for big data collection, providing an ecosystem of sensors and data platforms, capable of collecting and processing a vast amount of information quickly and efficiently.

### 2.3. Artificial intelligence – a data tool for processing complex datasets

Artificial intelligence (AI) refers to computer science and algorithms that enables machines to function like a human brain, analysing complex datasets for trends and patterns. Examples of AI methods that are being increasingly applied in the transport sector include artificial neural networks, genetic algorithms, simulated annealing, and fuzzy logic models (Abduljabbar et al., 2019). By modelling a relationship between the cause and effect of different real-life scenarios, AI helps bridge uncertainties and gaps within the data that cannot be resolved using traditional methods.

**Table 2. Big data – summary of applications, barriers and opportunities**

<b>Applications</b>	<b>Barriers</b>	<b>Opportunities</b>
<ul style="list-style-type: none"> <li>• Traffic management (ITS)</li> <li>• Strategic planning</li> <li>• Demand modelling</li> <li>• Asset management</li> <li>• Travel planning</li> <li>• Route guidance</li> <li>• Disruption alerts</li> <li>• Infrastructure management</li> <li>• Operational insight</li> <li>• Autonomous vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Data availability and openness of data</li> <li>• Data usability or accuracy</li> <li>• Data processing</li> <li>• Lack of technical skills for advanced data analytics</li> <li>• Privacy issues</li> <li>• Data storage</li> <li>• Mobile data</li> <li>• Willingness to share</li> <li>• Lack of information on private sector data available</li> </ul>	<ul style="list-style-type: none"> <li>• Reducing congestion (savings in time, fuel, improved air quality)</li> <li>• Making transport safer and more efficient (vehicle tracking, travel planning)</li> <li>• More accurate forecasting (incident detection)</li> <li>• Integrated cashless payments on public transport</li> </ul>
<b>Components</b>	<b>Enablers</b>	
<ul style="list-style-type: none"> <li>• Map data</li> <li>• Weather data</li> <li>• Personal location data</li> <li>• Public transport schedules</li> <li>• Vehicle location data</li> <li>• Fare and pricing data</li> <li>• Payment or transaction data</li> <li>• Smartphone sensors (GPS, accelerometer, camera)</li> </ul>	<ul style="list-style-type: none"> <li>• Internet of things</li> <li>• Artificial intelligence</li> <li>• Machine learning</li> <li>• Advanced analytics (predictive and real-time)</li> <li>• Blockchain</li> <li>• Enhanced computing capabilities</li> <li>• Cloud computing</li> <li>• Social media</li> </ul>	

The application of artificial intelligence in the transport sector centres around road and public transport planning, traffic incident detection and predicting traffic conditions. The intelligent computational analytics of these systems are able to represent uncertainty, imprecision and vague concepts, hence can be used for route optimisation problems in transport, including dynamic traffic

situations and events. An area where AI applications have also seen rapid development is intelligent transport systems (ITSs), where AI and machine learning (ML) techniques are used to find patterns and features in the captured data to allow real-time optimisation of traffic control policies and to achieve more connected transport systems.

**Table 3. Artificial intelligence – applied solutions, barriers and opportunities for the transport sector**

Applications	Barriers	Opportunities
<ul style="list-style-type: none"> <li>• Big data analytics</li> <li>• Corporate decision-making, planning and managing</li> <li>• Accurate prediction and detection models</li> <li>• Traffic flow/volume forecast</li> <li>• Traffic conditions forecast</li> <li>• Improvements in public transport</li> <li>• Traffic incident prediction</li> <li>• Traffic management (ITS)</li> <li>• Smart highways</li> <li>• Smart rail</li> <li>• Traffic signal control</li> <li>• Asset management</li> <li>• Travel planning</li> <li>• Logistics</li> <li>• Robotics</li> <li>• Autonomous vehicles</li> <li>• Drones</li> <li>• Customer analytics</li> <li>• Predictive maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of infrastructure</li> <li>• Dependent on the quality or reliability of data</li> <li>• “Black box” effect – limited understanding of the relationship between input and output</li> <li>• Not capable of forecasting under unexpected events and adverse weather conditions</li> <li>• Computation complexity of AI algorithms</li> <li>• Lack of advanced analytics skills</li> <li>• Lack of technological infrastructure to support AI</li> <li>• Fragmentation and incompatibility of data</li> <li>• Data privacy issues</li> <li>• Impact of automation (jobs displacement or loss)</li> </ul>	<ul style="list-style-type: none"> <li>• Better detection and prediction of travel patterns</li> <li>• Better traffic forecasts</li> <li>• Improvements to public transport (enhanced reliability)</li> <li>• Integration with shared mobility (Uber)</li> <li>• Enabling MaaS</li> <li>• Enabling smart city initiatives</li> <li>• On-demand public transport services</li> <li>• Improved productivity</li> <li>• Creation of new jobs</li> </ul>
Components	Enablers	
<ul style="list-style-type: none"> <li>• Knowledge-based system</li> <li>• Artificial neural network systems</li> <li>• Machine learning</li> <li>• Deep learning techniques</li> <li>• Genetic algorithm</li> <li>• Simulated annealing algorithm</li> <li>• Ant colony optimiser algorithm</li> <li>• Artificial immune system algorithm</li> <li>• Bee colony optimisation algorithm</li> <li>• Swarm intelligence systems</li> <li>• Fuzzy logic model</li> <li>• Logistic regression model</li> <li>• Agent-based software engineering</li> </ul>	<ul style="list-style-type: none"> <li>• Big data</li> <li>• Internet of things</li> <li>• Blockchain</li> <li>• Computing power and speed</li> <li>• Algorithmic improvements</li> <li>• Talent and skills</li> <li>• Investment and funding</li> </ul>	

## 2.4. Drones – an alternative data collection and exploitation tool for monitoring

A drone, in technological terms, is an unmanned aircraft. Drones are more formally known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UASs). Essentially, a drone is a flying robot that can be remotely controlled or fly autonomously using software-controlled flight plans in their embedded systems, working in conjunction with on-board sensors and GPS. There are two main types of drones: rotor (tricopters, quadcopters, hexacopters and octocopters) or fixed-wing, which include the hybrid VTOL (vertical take-off and landing) drones.

Drones are being increasingly used in the transport sector to improve operational efficiency, save money and time and increase safety. The technology has been used to inspect bridges and tunnels, as well as monitoring traffic and in logistics delivery. Infrastructure can be inspected and made more resilient through remote inspections and multi-spectral imagery, with drones providing an interoperable platform capable of more frequent and precise measurements. Furthermore, drones have several potential applications in logistics. Transporting vital goods through the air has been a staple of international commerce for decades, but a revolution is taking place at low altitudes, on demand, for last-mile connectivity (World Economic Forum, 2018).

Maintaining roads, bridges and tunnels at the optimum level can be very costly. Inspecting the deck of a bridge, for example, could take four workers an entire eight-hour shift to complete. This would also involve heavy-duty equipment and could cost nearly US\$ 5,000. In addition, a traditional bridge inspection would need to take place during the daytime and would require the re-routing of traffic, which would have additional cost implications. Using a drone to inspect the same bridge would require only two people, no heavy-duty equipment and limited traffic control and monitoring, with the entire process taking about two hours. This would provide significant savings on staff and equipment and improve efficiency and safety (14).

The summary of the disruptive technologies presented above shows that IoT, big data and AI do not operate in isolation. Instead, they are highly complementary technologies. Big data is collected most effectively using IoT systems and drones and then processed for optimisation and forecasting using AI. The main applications of the three technologies in transport centre around demand forecasting and traffic optimisation resulting in better traffic management, asset management, travel planning and operation of autonomous vehicles (AVs). A more detailed explanation of the four applications of big data, IoT and AI, supported by case studies, is presented in Section 4.

Drone operations are also inextricably linked with IoT and big data. They can act as data collection devices and perform tasks that are remotely controlled by humans, using IoT. The one application of drones that is transforming the transport sector is in logistics and deliveries, which Section 4 discusses in more detail, with supporting case studies.



**Table 4. Drones – applications, barriers and opportunities**

<b>Applications</b>	<b>Barriers</b>	<b>Opportunities</b>
<ul style="list-style-type: none"> <li>• Asset inspections and maintenance (tunnels, bridges)</li> <li>• Infrastructure maintenance</li> <li>• Design process (provision of geospatial data) - integration with building information modelling (BIM)</li> <li>• Construction site monitoring</li> <li>• Enhancing construction site safety</li> <li>• Traffic monitoring</li> <li>• Logistics (deliveries)</li> <li>• Warehousing and inventory maintenance</li> <li>• Remote delivery</li> <li>• Disaster response</li> </ul>	<ul style="list-style-type: none"> <li>• Regulatory concerns</li> <li>• Safety</li> <li>• Security</li> <li>• Privacy</li> <li>• Anonymity and traceability</li> <li>• Misuse (for example, terrorism, drug smuggling)</li> <li>• Insurance implications</li> <li>• Impact of automation (job losses)</li> <li>• Aviation risk (potential for collisions with other aircrafts)</li> </ul>	<ul style="list-style-type: none"> <li>• Improved traffic management</li> <li>• Cost savings and/or increased efficiency</li> <li>• Creation of new jobs</li> <li>• Increased safety (engineering inspections)</li> <li>• Improved resilience of infrastructure</li> <li>• Enhancing data processing and accessibility</li> <li>• Supports BIM</li> </ul>
<b>Components</b>	<b>Enablers</b>	
<ul style="list-style-type: none"> <li>• Predator drone (military)</li> <li>• VTOL drone (vertical take-off and landing)</li> <li>• Global navigational satellite systems (GPS and GLONASS)</li> <li>• Flight controller (central brain of the drone)</li> <li>• Inertial measurement unit (IMU)</li> <li>• Electronic speed controllers (ESC)</li> <li>• Ground station controller (GSC) - smartphone app</li> <li>• Internal compass</li> <li>• First-person view (FPV) video transmission technology</li> <li>• High-performance cameras</li> <li>• Multispectral, LIDAR, photogrammetry, low-light night vision and thermal sensors</li> </ul>	<ul style="list-style-type: none"> <li>• Automatous drones</li> <li>• Battery technologies</li> <li>• Logistic configurations</li> <li>• Internet of things</li> <li>• 3D modelling</li> <li>• Augmented and virtual reality (AV/VR)</li> <li>• Video editing software</li> </ul>	

# 3. Applications in transport

As Section 2 shows, the four disruptive technologies (IoT, big data, AI and drones) have several applications in transport. This chapter discusses the technologies and applications that have the greatest potential to fundamentally change the way traffic flow is organised and managed, and as a result to bring the most significant economic and social benefits to the EBRD regions. These applications have been identified as areas that bring the four technologies together, to showcase how they can enable and complement each other to provide optimum solutions for the transport sector. The four applications of the disruptive technologies reviewed in detail in Section 3 are as follows:

- **Traffic management using intelligent transport systems (ITSs)** – using new technologies to predict future traffic demand more accurately and optimise road networks accordingly, providing a wide range of social and economic benefits, including reduced congestion and pollution, improved safety and travel experience for all road users.
- **Personal travel planning and public transport** – using the available information on travel demand and travel patterns of the population to facilitate optimisation of planning, programming and operations of public transport systems, as well as improving the public’s personal journey planning.
- **Autonomous and connected vehicles for enhanced mobility** – developing applications for AVs that will contribute to increased safety, better user experience, economic savings and reductions in congestion by facilitating car sharing and mobility as a service (MaaS).
- **Unmanned aerial vehicles and drones for monitoring** – using the technology to revolutionise asset management and inspections (bridges, tunnels and construction sites) and delivery of packages (logistics).

## 3.1. Traffic management using intelligent transport systems

### Overview

ITSs are an emerging field driven by digital technologies, aimed at improving the efficiency, safety and environmental performance of road transport. An ITS enables vehicles to interact directly with each other and with the surrounding road infrastructure. It typically involves communication between vehicles (vehicle-to-vehicle, V2V), between vehicles and infrastructure (vehicle-to-infrastructure, V2I) and/or infrastructure-to-infrastructure (I2I) and between vehicles and pedestrians or cyclists (vehicle-to-everything, V2X).

Big data can be collected using a variety of techniques and is already used all over the world to combat congestion, including through the use of inductive loop detection (insulated cables embedded in the streets), video analysis and infrared sensors (detecting the heat emitted by objects), GPS and social media. ITSs have been developed since the beginning of the 1970s, however the recent widespread emergence of big data has allowed the development of new applications for the transport sector. Over the past decade, there have been remarkable new developments in technologies that facilitate ITSs; however, these are far from being used to their full potential, as this section will detail.

Big data is a disruptive technological change, following cloud computing and the internet of things, which enable large data volume and large data type, with high commercial value to be processed at a lower cost and higher speed. In the transport sector and ITSs, all traffic monitoring, data treatment and applications can be done at a much lower cost and higher frequency. Big data analytics can improve the ITSs’ operational efficiency. Many subsystems in ITSs that need to handle large amounts of data to give information or provide traffic management decisions will be less expensive to operate. Through fast data collection and analysis of massive amounts of current and historical traffic data, traffic management departments will be able predict traffic flow in real time. Public transport big-data analytics

can help management departments to learn journey patterns in the transport network, which can be used for better public transport service planning.

## Enablers, barriers and opportunities

### Technical analysis

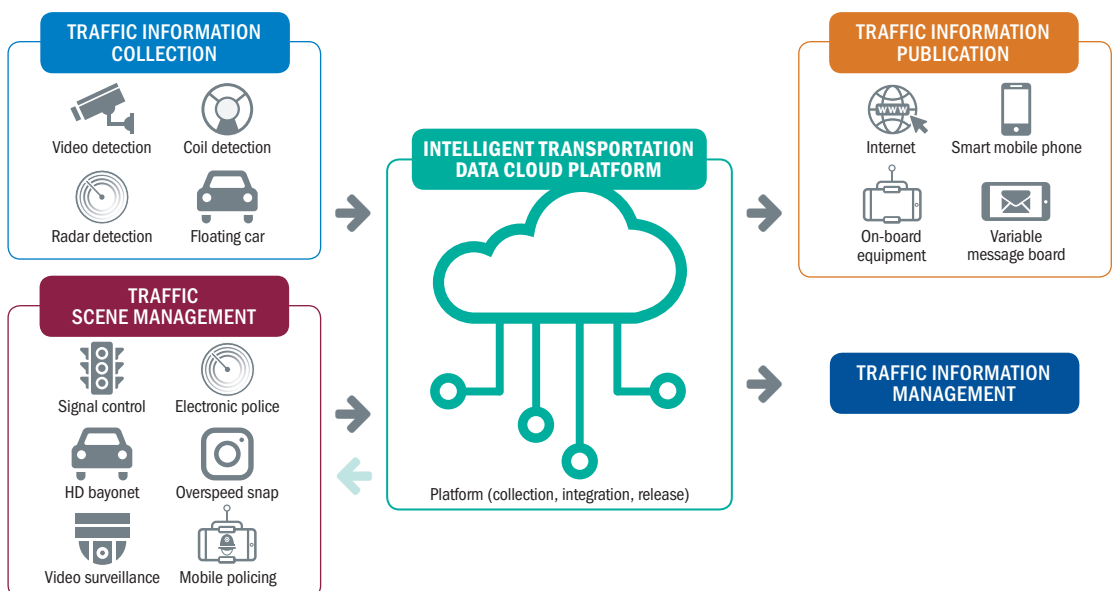
The use of big data, IoT and AI in traffic management systems allows for more detailed and accurate predictions in relation to future traffic demand, traffic flow and any unexpected events or incidents on the road network. Having this wealth of real-time information allows for more efficient optimisation of traffic signals and reducing congestion, improving traffic safety and preventing or reducing damage to the infrastructure, as well as reducing traffic emissions, enhancing mobility, increasing service reliability and supporting economic development.

Despite significant advances in the use of big data in traffic management, there are still some problems. These difficulties include a lack of integration of traffic data, low utilisation rate,

limited dissemination of traffic information, and a lack of experience in using advanced intelligent data analysis methods to provide real-time and accurate traffic information to travellers and to traffic management departments to deal with unexpected events and illegal traffic behaviour. AI and other technologies of big data analysis, together with increased computing power and storage capacity, bring new opportunities for the development of ITSs.

The ITS big data analysis cloud platform consists of a basic service layer (data collection), data analysis layer (data integration) and terminal publishing layer (data release). The basic service layer is the basis for data analysis and its main purpose is to use cloud computing technology to integrate data from different systems (IoT). The data analysis layer's function is to process the data in real time, using advanced analytics and potentially AI to then help the decision-making process by providing trend predictions and forecasting. The main function of the terminal distribution layer is to communicate the available information by releasing it in real time via cloud services and smart devices (mobile phones, PCs) (Hu et al., 2017), as Figure 2 shows.

**Figure 2. An ITS in real time**



Source: Market analysis (Support study for Impact Assessment of Cooperative Intelligent Transport Systems, European Commission (2016) and Hu et al. (2017)).

The uptake of ITSs has been uneven across Europe. In 2016, the C-Roads Platform was formed to provide a single point of contact for cooperation between the automotive industry manufacturers and the European Union (EU) member states. Initially, eight member states were included, which increased to 16 as of October 2017. The C-Roads Platform aims to facilitate harmonised and interoperable ITS deployment across the EU, encouraging cooperation and harmonisation between the projects:

- C-Roads InterCor (2016-19), Belgium, France, the Netherlands, the United Kingdom. The project links European ITS initiatives with the aim of creating a continuous ITS network that can serve as a testbed for ITS services deployment and development.
- NordicWay (2015-17), Finland, Denmark, Norway, Sweden. The pre-deployment pilot project aiming to test interoperable cellular communication for ITS services, enabled through roaming between different mobile networks and cross-border services.
- C-The Difference (2016-18), France, the Netherlands. The partners involved in this pilot project have been working on bringing ITS services to the market for the past 10 years, investing significantly in the development and deployment of ITS.
- C-Roads (2016-20) Austria, Belgium, the Czech Republic, France, Germany, Slovenia. The project outlines the rationale and objectives for ITS development, including coordinated deployment across borders.

## Cost-benefit analysis

The claims about the benefits of traffic management are varied but, in general, high. A typical set of claims is provided in a summary by Transforming Transport, an EU-funded project of a consortium of 48 leading transport, logistics and information technology stakeholders in Europe (22). They highlight the following points:

- A 10 per cent efficiency improvement can lead to cost savings of €100 billion from big data, as fast data collection and analysis of current and historical traffic data has helped traffic management departments with operational efficiency.
- Improvements in operational efficiency empowered by big data are expected to lead to US\$ 500 billion savings worldwide in terms of time and fuel, as well as savings of 280 megatonnes of CO2 emissions.
- The McKinsey Global Institute concluded that in 2013, US\$ 400 billion a year globally could be saved by “making more of existing infrastructure” through improved demand management and maintenance.
- “The Internet of Things has changed the business performance of many organisations and is predicted to cut the emissions from trucks in the US by 25 per cent” (21).

In a specific study in the Netherlands, the social costs of congestion on the main road network in 2015 (2010 prices) are estimated to be between €2.3 and €3 billion annually. Traffic management systems (ITSs) contribute to a 9 per cent improvement in overall travel time, which is worth €210-€272 million (on a *pro rata* basis). The associated system costs are €164 million, giving a benefit-cost ratio of between 1.3 and 1.7.

In a more recent study by the European Commission (20), annual benefits of approximately €15 billion in 2030 are compared with costs of €2.5 billion, giving a ratio of benefits to cost of 6:1. This further corresponds with other studies, which have estimated benefit-cost ratios in the range of 1.5 to 6.8 shown in the EasyWay and DRIVE C2X studies (20).

This study bases the estimates of costs on the installation of four types of hardware and software:

- In-vehicle information sub-system fitted either by the vehicle manufacturer or retrofitted to the vehicle and attached to the vehicle communication buses.
- Personal sub-systems such as mobile phones, tablets, personal navigation satnav-type devices, and other handheld devices not attached to the vehicle's information bus.
- Roadside ITS sub-systems such as beacons and smart traffic lights.
- Central ITS sub-systems, which may be part of a centralised traffic management system.

These provide a range of communication and control services (V2V or V2I) but do not provide the more advanced capability for autonomous and connected vehicles discussed below. While the costs for autonomous driving are estimated as eventually falling to between US\$ 1,000 and US\$ 1,500 per heavy goods vehicle (HGV) per year (see below), the upfront costs to consumers of these four simpler systems for new vehicles are estimated at approximately €275 per car and €315 per HGV (with ongoing annual costs of €20 and €30 respectively). By 2030, these are estimated as potentially falling to €180 per car and €200 per HGV.

The study estimates the benefits of 25 individual types of improvement that are possible with this equipment, with some providing more than one type of benefit. Of the total number, 15 provide safety-related benefits, 10 provide efficiency benefits such as savings in travel time, 8 relate to managing traffic operation such as smoothing the patterns of traffic flow and 8 provide environmental benefits. Each independent improvement is relatively simple, with examples including “warning of slow or stationary vehicle”, in-vehicle signage and speed limits, information on weather conditions, signal violation at intersections, off-street parking and park-and-ride information, zone access control for urban areas and protection for vulnerable road users.

Over 86 per cent of the costs relate to the hardware required within vehicles and a further 10 per cent to “aftermarket” devices. Three elements make up approximately 99 per cent of benefits estimated, with reduced travel times and increased efficiency accounting for 66 per cent of total benefits, reduced accident rates for 22 per cent and fuel consumption savings 11 per cent. As with all the disruptive effects assessed here, the assumptions on uptake are of great importance, as essentially the same hardware enables all 25 services. Where services are limited by regulatory and other constraints, benefits fall commensurately.

This study primarily addresses what can be seen as marginal changes from enhanced driver aids to adapting existing systems. The advantage of the approach is that the changes assessed are specific and realistic and occur within a relatively short timeframe (by 2030). The level of costs and benefits are less than an order of magnitude smaller than those from autonomous vehicles and can be considered indicative of the benefits of “low hanging fruit” on a first stage towards the fuller use of automation and information systems. Nevertheless, they show that high benefit-cost ratios approaching six are plausible even when based on marginal changes to existing systems enabled by a disruptive technology.

## Case study – “Talking Traffic” in the Netherlands

**Overview** (Source: ITS in the Netherlands Progress Report, 2017)

In the Netherlands, €90 million is being invested up to 2020 into a smart mobility system that will upgrade 1,250 traffic lights (a quarter of the total number in the Netherlands). The project has been named the “Talking Traffic” partnership.

The partnership between the Dutch government, local authorities, mobility experts and ICT businesses will target the busiest traffic hotspots,

using IoT to communicate to individual drivers, providing in-vehicle guidance via smart phones and GPS navigation systems.

Users will be able to access real-time information on weather conditions, roadworks, parking information, lane closures and stationary or slow-moving traffic, allowing anticipation and avoidance of traffic issues, therefore improving traffic flows. The aim is to improve both the safety and sustainability of Dutch road networks.

**Table 4. Netherlands initiatives, costs and results**

Initiative	Description	Cost	Results
“Talking Traffic” Partnership	Real-time, personalised messages to drivers through ITSs. Data collected from light installation systems.	€90 million (joint partnership)	By the end of 2017 approximately 1,250 traffic control systems had been upgraded. Partnership supports safer and better optimised traffic flows.
Use of information services during roadworks	Service providers “Innovactory” and “Be-Mobile” identify locations of road users in proximity to roadworks. Notifications are sent to the road users in the run-up to and during the works.	€250,000-300,000	Limits disruption. Makes road users aware in advance. When used on busy corridors, approximately 10 per cent of users clicked on the link for further background information.
Social media as a data source	Use of open social media data on traffic situations, for example, hazardous situations, debris on roads and incidents	€40,000 (southern Netherlands)	Open source data contain information of value for road traffic controllers. Every month 10,000 reports were automatically analysed. Of these, 10 per cent were potentially relevant to traffic controllers (approximately 15 reports per shift).
Neutral Logistic Information Platform	All parties pass information through one data platform. Cooperates with market parties. Used for trucks at terminals and business premises.	€6 million annually (public-private)	An integrated, more efficient management platform with one single controller. Makes logistics chains more manageable, reliable, flexible, cost-effective and transparent.
Blue Wave for Waterways	Supply of information between waterway managers, shipping traffic and road traffic in real-time; opening times of bridges and locks, availability of moorings, clearance heights, unplanned restrictions.	€300,000 (from Dutch government and regional party contribution)	Information passed on to existing traffic data flows and data distribution platforms to provide more integrated and efficient information sharing.
Smart cameras on the A2	Use of algorithms to analyse video images from traffic cameras. Detects vehicles or objects in the road and can suggest decisions to road traffic controller.	€186,000 (southern Netherlands)	Algorithms are not currently smart enough to take on routing work without a road traffic controller. However, support from smart cameras reduces analysis time. Improves traffic flow and safety.

Source: ITS in the Netherlands Progress Report (2017).

## Case study – City parking

The IoT is playing a progressively important role in the management and enforcement of parking facilities in cities. As space becomes more finite, cities are looking towards IoT and big data to manage and operate parking provision effectively through the use of integrated sensory systems, centralised data units known as “gateway” devices, and data analytical software.

An example of this can be seen through the uptake of equipped in-ground vehicle detection sensors located within parking bays. These

sensors use radio frequency identification readers (RFIDs) to detect occupied or vacant spaces. IoT gateway devices are often used to gather this data into larger centralised systems via wireless communication. This information is then transmitted to cloud-based big data analytical software for processing and responding in real time (Das et al., 2018).

An example of this in application can be seen in Westminster in London through the launch of its Smart Parking initiative. Westminster City Council

**Figure 3. Applications of IoT and big data in cities**



Source: Redrawn based on Bibri (2018).

## Case study – City parking (continued)

(WCC) has been faced with increasing demand for parking spaces, with occupancy levels in some parts of the district frequently exceeding 80 per cent. As of October 2014, WCC went live with ParkRight, an app which allows users to identify available spaces through the use of RFID parking sensors. Some 3,400 sensors were installed, using a “SmartSpot” gateway to transmit live information to SmartRep, a software tool for car parking management. This tool can analyse large amounts of information quickly, communicating with the ParkRight app to navigate users to vacant spaces via GPS directions (10).

Instantaneous benefits of using RFID sensors and gateway devices such as this include reduced traffic congestion on the road network, improved air quality, more efficient and targeted parking enforcement, historical data that can be used in monitoring and future planning, and easier and safer payment for users.

Looking towards the future of parking and traffic management, “gateway” devices installed at the roadside can be used to gather and transmit a wide variety of data, beyond that which we currently see in the “vacant/occupied” scenario in Westminster.

For example, RFID “tags” on moving vehicles can be used to transmit information to these gateway devices. RFID tags are becoming more common among newer vehicle models and are usually attached to windshields, containing wirelessly readable information about the car model, registration plate and permit information. Countries such as China and India have enforced mandatory RFID tags in recent years on all new registered vehicles, with the aim of better managing and monitoring traffic.

Although issues arise around data protection and citizen “tracking” through use of this technology, opportunities also arise from the use of gateways as platforms of communication within smart city environments. For example, wireless information picked up from WiFi and GPS signals can be used to monitor activities such as pedestrian footfall and public transport services to create fully integrated intelligent transport systems, as illustrated in Figure 3, giving an indication of where IoT and big data application could drive cities in the future (Bibri, 2018).



## 3.2. Personal and public transport travel planning

### Overview

The use of big data in public transport can help analysts to understand the existing demand, as well as travel patterns of the population and what mode of travel they may choose, in order to plan public transport services better. This, in turn, allows for service improvements and satisfying the increasing demand of transport customers for timely and accurate information about their journeys. The use of the IoT in infrastructure could lead to the development of traveller information hubs, which could replace traditional traveller information systems. The processed big data recorded using a distributed IoT sensor network and central platform would allow for optimisation of planning, programming and operation of infrastructure by transport agencies (Baker et al. 2016).

Big data analytics can be used in transport apps to provide passengers with real-time information on traffic, the most suitable driving routes and arrival or departure times of public transport services, leading to better overall satisfaction and reduced travel times, which could also generate an economic benefit if reduced travel time means that employees can spend more time working.

### Enablers, barriers and opportunities

**Technical analysis** (Source: Study of ITS Directive, Priority Action A: The Provision of EU-wide Multimodal Travel Information Services, European Commission)

Multi-modal travel planning is a key element of ITS deployment. Data standards are a key enabler for the development of large-scale services by facilitating the interoperable exchange of data between different travel information services and reducing both the costs and complexity of data management. The standards for multimodal traveller information and planning services (MMTIPS) need to be suitable for international use and include the necessary metadata, such as version identification.

Big data, IoT and AI provide the new tools and processes needed for the large-scale collection, analysis and processing of data. These data are needed to provide useful travel planning services include timetables, real-time data on passenger transport road travel time data, road tolls/charging, pollution levels, fare data and prices, personal journey data and information service demand data (anonymised logs of end-user queries).

Some of the economic, legal and technical barriers for MMTIPS uptake include:

- the cost of collecting, managing and aggregating data
- the cost of linking to third-party data sources
- lack of certainty about continuity of data supply
- lack of equal access to data
- lack of clarity on data ownership and conditions for re-use
- lack of tools to collect and manage data
- lack of data available in common formats
- low quality of data.

The main enablers for MMTIPS are software tools for capturing and managing data, as well as policy measures that encourage existing suppliers and promote new participants.

**Market analysis** (Source: Study of ITS Directive, Priority Action A: The Provision of EU-wide Multimodal Travel Information Services, European Commission)

In Europe, travel information services are provided by both the public and private sectors, with local authorities or transport operators often also acting as the travel information service provider. The services provided by local authorities and transport operators concentrate on a specific region, with the pan-European services providing more extensive travel information. Multimodal travel information services are currently available at regional and national levels in many parts of the EU; however, there is the need to develop pan-European information services which is likely to be a long-term process, currently constrained by economic factors, technology and user demand. The cost of data and

systems must be low enough to make the business model viable. The new technologies (IoT, increasing computation power, big data, consumer mobile devices) are radically changing what is possible, with user demands and habits also changing.

Europe has always been at the forefront of travel and traffic data and has many advanced urban real-time systems. Some major cities such as Amsterdam, Barcelona, Copenhagen, Helsinki and London provide a wide range of travel information services such as Google Transit and Citymapper. In Europe there is considerable variation in both the existence of data between modes and in the policies on its availability, as well as in access to the desired form of data. For example, data for public transport modes typically exist for large urban conurbations, but not necessarily outside of them.

### Cost-benefit analysis

Personal transport planning (PTP) is a *behaviour change intervention* that encourages individuals to adopt new travel patterns. The changes are expected to lead to an overall outcome that is cost beneficial for society and for all, or the great majority of, individuals. Once the change has been made the net benefits can be realised. A clear additional cost is the upfront cost of explaining the benefits of the behaviour change to individuals and this cost is often directly linked to the level of uptake. It is eventually offset against the net benefit from the change in choice of transport mode. For example, the EU's "Ad Personam" direct marketing programme for public transport targeted a group of 2,521 citizens across seven European cities with an individual tailor-made travel plan and offered free use of public transport during a promotional week (24).

A number of PTP projects were studied as part of *Intelligent Energy Europe programme – The Economic Benefits of Sustainable Transport Actions Independent Review of Evidence, 2015* (24). In the Sustainable Travel Towns PTP programme in the UK, 90,000 households were targeted, and 40,927 households contacted across three towns to receive a range of intervention materials to encourage more sustainable travel, with typical costs of £16 per individual contacted.

The change in the level and type of transport demand and associated savings can be compared with the costs of making the initial contact and the ongoing costs of maintaining information programmes. The review-of-evidence study quotes recent results from integrated UK programmes including PTP, which have shown benefit-cost ratios of 1.4 to 4.5, based on economic benefits from reduced traffic congestion. It also references an early UK study from 2004 where car driver trips from targeted populations fell by 71.5 per cent in urban areas and a later 2009 study across eight urban areas of England showing a mean reduction in trips of 11 per cent (min 4 per cent to max 13 per cent), for 11 PTP projects. Longer-term benefits of PTP are uncertain as reinvestment may be required in an area as new populations move in.

## Case study – Personal travel planning in Perth, Australia (Source: <https://www.wa.gov.au/service/transport>)

### Overview

- The government of Western Australia successfully delivered residential PTP projects to 284,000 people in 2007. By 2008, the full programme was scheduled to target 450,000 residents.
- In addition to the residential PTP aspect, a travel behaviour-change programme (TravelSmart) also includes school and workplace travel planning.
- Perth is a heavily car-dependent city, with approximately 75 per cent of all trips made by car. It has a city population of 1.5 million, covering 30 local government areas.
- Research carried out prior to the implementation of the PTP programme showed that 39 per cent of trips were constrained to the car, while 20 per cent were undertaken by sustainable modes. The remaining 41 per cent of trips were classified as a potential area to convert car travel to more sustainable modes.

### Technology

Big data – Using a large data collection process, summarised here:

- Random sample survey, which established background population characteristics and baseline travel behaviours.
- Contacting participants by phone and discussing their travel behaviour, as well as providing an invitation to participate in the programme.
- Where required, provision of cycle training and public transport information for each participant.
- Monitoring of participants and collection of validation data from public transport ticketing systems.

### Cost-benefit analysis

Delivering the PTP programme to 450,000 residents over eight years cost AUD 15 million in total.

A combined dataset consisting of more than 6,000 households and 48,000 trips was drawn from the surveys. A target population of 128,000 residents was engaged, providing an opportunity to explore behaviour changes by trip characteristics and demographics.

An individual resident would on average each month make six fewer car trips, three extra walking trips, one extra bike trip, one extra public transport trip and do one and a half hours more physical activity.

Each household that took part in the programme would save AUD 500 per year in car running costs. The combined community benefits per year include:

- 20 million fewer car trips
- 200 million fewer car kilometres
- 60,000 fewer tonnes of greenhouse gases
- 2.6 million extra public transport “boardings”
- 5 million hours of physical activity
- 20 million fewer litres of fuel, a saving of AUD 25 million.

## Case study – Public transport in Singapore

Singapore is renowned as a global hub for technology, innovation and transport, being voted the “most technology-ready” nation by the World Economic Forum in 2015 and 2016 (16). The Singaporean government and industry practitioners are increasingly providing commuters with more advanced on-demand and point-to-point alternatives to private vehicle travel through integrated public transport facilities and technology. This is combined with a highly effective vehicle electronic road pricing tolling system to encourage behaviour change.

Singapore uses mobile apps to help communicate transport information to the public. These apps can personalise travel information and produce individual travel plans based on data given by the user, such as location-sharing and user preferences. Some key apps that are driving Singapore forward in its bid to be a “smart nation” are as follows:

- MyTransport: the app was launched in 2010 by Singapore’s Land Transport Authority and allows users to customise and select favourite transport services. MyTransport has access to traffic cameras throughout the city which allow users to view and track traffic in real time at specific points along the highway network. The app also includes MyConcierge, which allows users to customise which traffic news they would like to see. Other features of the app include Electronic Road Pricing locations and rates, parking availability, park-and-ride car parks, Mass Rapid Transit/Light Rapid Transit stations and taxi call numbers (17).
- Grab: a transport company that offers taxis, car-sharing, food delivery, eScooter rentals and shuttle services (18). The company is based in Singapore but operates across Southeast Asian countries such as Malaysia, Indonesia and the Philippines. The app assigns taxis to nearby travellers through a location-sharing system and holds an in-house payment system.
- Gothere.sg: an app aimed at connecting transport with leisure activities such as shopping facilities and eating experiences. The app helps users find the nearest bus stops or driving routes to get to the desired location as well as providing them with store directories and available discounts at various malls around Singapore.
- SG Buses: a dedicated app for travellers who rely on buses for travel. The app provides users with bus stop locations, arrival times, routes and seat availability.
- Locomole: an exploration app primarily targeted at tourists or visitors to the city. The app provides detailed trails that allows users to embark on self-guided walking tours of the major attractions. The app includes features like augmented reality and game challenges to interact with the users. Locomole can be paired with the above apps to help users navigate between attractions and sites.

### 3.3. Autonomous and connected vehicles for mobility

#### Overview

Connected vehicles have been widely touted as the future of safe and highly optimised transport. Many car makers are eager to develop vehicles with connected features including tracking cameras, radar sensors, laser scanners, ultrasonic sensors, LIDAR and GPS, all aimed at creating an intelligent vehicle that can communicate, not only with other vehicles (V2V), but infrastructure and landscape around it (V2I) (Bagloee et al., 2016).

These connected vehicle systems provide automated vehicles with information that may not be available through internal sensor equipment alone. For example, V2V applications would warn vehicles about a vehicle suddenly braking in front of them. Similarly, roadway-based sensors in a V2I application might detect the presence of a pedestrian, about to cross the road, who is in the vehicle's sensory blind spot (Baker et al., 2016). Furthermore, AVs rely on AI software based on deep learning techniques. This approach works by teaching the vehicle how to drive while maintaining safe headways, lane discipline and control during testing (Abduljabbar et al., 2019).

#### Enablers, barriers and opportunities

##### Technical analysis (Source: Bagloee et al., 2016)

AVs operate on a three-phase design known as “sense-plan-act” which is the premise of many robotic systems. The main challenge for AVs is understanding, and reacting appropriately to, the complex and dynamic driving environment. To this end, the AVs are equipped with a variety of sensors, cameras, radar and so on which obtain raw data from the surrounding environment (IoT). These data then serve as the input for software which would recommend the appropriate course of action (AI) such as acceleration, lane changing or overtaking (Bagloee et al., 2016). The levels of automation can vary from partial to full automation.

Some of the key technologies used in AVs are:

- video cameras (tracking of lane markings and reading road signs)
- radar sensors (detecting objects ahead)
- side laser scanners
- ultrasonic sensors
- differential GPS
- mapping
- infrared cameras
- LIDAR (detection of objects in 3D).

Some of the potential advantages and opportunities of AVs include:

- optimisation of traffic flows (reducing congestion, saving fuel, improving air quality)
- making transport safer and more efficient
- driver convenience and quality of life
- more travelling opportunities for those unable to drive
- reduces land required for parking.

Some of the disadvantages and potential barriers for implementation include:

- large investment in infrastructure required
- high cost of autonomous driving systems
- liability issues, for example insurance claims
- regulatory changes required at all levels (national, regional, local)
- public perception – giving up control, trust
- current limits in AI technology – AI's ability to react effectively to all scenarios
- safety risks associated with testing self-driving vehicles.

## Market analysis

In 2015, the EC launched a call for proposals to push “the uptake of IoT in Europe and to enable the emergence of IoT ecosystems supported by open technologies and platforms”. The call set out five large-scale pilots including Pilot 5 on “Autonomous vehicles in a connected environment” (Hill et al., 2017).

Pilot 5 included a €20 million budget from the EU and worked with European governments and stakeholders, as well as involving international IoT cooperation from China, Japan, South Korea and Brazil.

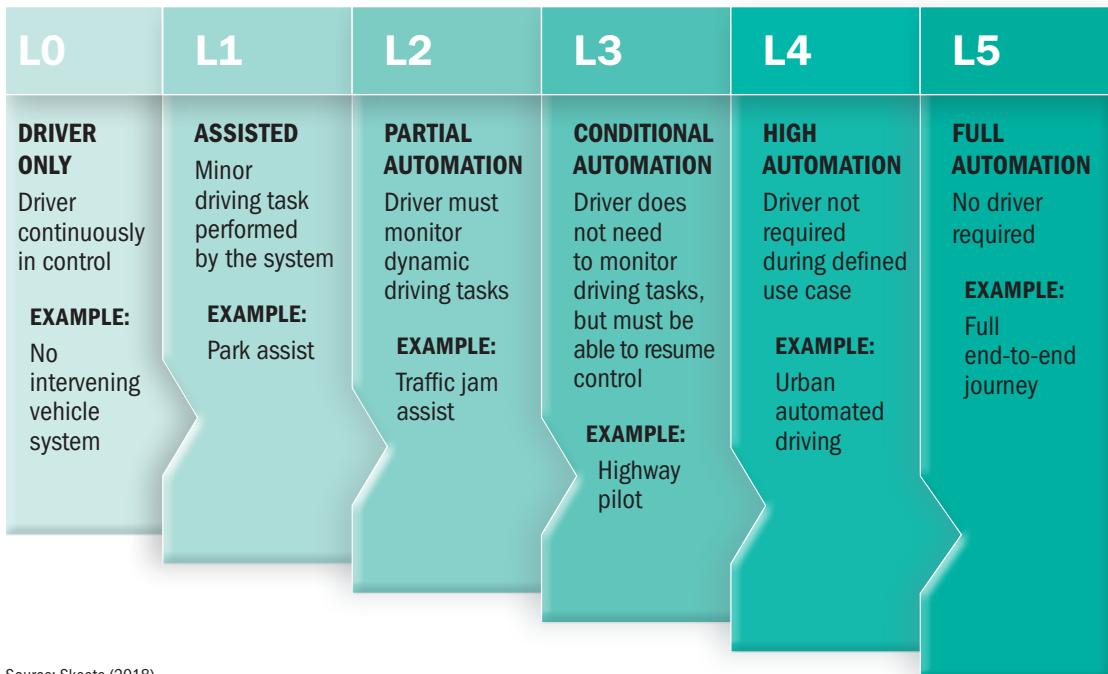
The pilot was used to test scenarios for the integration of highly and fully autonomous vehicles (up to level 5) safely and efficiently using advanced technology, information communication and artificial intelligence. The pilot aimed to bring together all manner of stakeholders involved in the development of connected and autonomous vehicles (CAVs), such as:

- technology (manufacturers, app developers)
- industry (car manufacturers, insurance companies, certification bodies)
- pilot hosts (public authorities, infrastructure providers)
- users (drivers, rental car companies, taxi firms).

At present Europe is lagging behind both Asia and, to a lesser extent, the United States of America, in the roll-out of 5G. It is estimated that it could be 2021 before the 5G data networks are fully up and running in Europe. There is also a fierce debate taking place on the choice between two potential technologies to be considered (7):

- Wifi – car manufacturers such as Volkswagen and Renault are in favour, based on it being “sufficiently tested and fully standardised”.
- C-V2X (cellular-vehicle-to-everything) technology, which can warn vehicles about obstacles outside of the range of cameras and radar.

**Figure 4. Level of AV automation**



Source: Skeete (2018).

- C-V2X only works with 5G but its proponents say that the data it delivers would increase the safety of AVs. The technology is already being used in AVs in Asia, including in China, which, unlike Europe, is already benefiting from 5G connectivity. Europe will soon need to make the decision on its preferred technology. The Munich-based 5G Automotive Association is a consortium of some 70 car companies including Audi, Daimler, Nissan, Volvo and BMW, trying to develop C-V2X.

Despite Europe lagging behind the US and China, there is no doubt that AVs are anticipated to grow significantly in the future in Europe, based on the importance of the automotive sector and the interest of foreign companies. Germany in particular is home to many of the world's largest car manufacturers and its economy relies heavily on the automotive sector. The companies that in the past were more "hardware"-focused are beginning to form partnerships to drive the AV revolution (8).

Europe's approach to pioneering AVs is likely to focus more on their use in public transit and multimodality, rather than personally owned AVs. Many European cities and transit agencies are, for example, testing driverless buses (Estonia, Sweden and Switzerland). The risk of focusing on privately owned AVs is that they will only exacerbate current congestion problems. In terms of legislation, Europe is ahead of the USA, with Germany and the UK most advanced, along with South Korea and Singapore.

### Cost-benefit analysis

Digital connection of vehicles is a technology distinct from autonomous driverless cars but advantageous when the two are combined (Skeete, 2018). The World Economic Forum's study *Deep Shift: Technology Tipping Points and Societal Impact* (19) identifies the benefits and costs of driverless cars as follows:

#### Positive (benefits)

- Improved safety.
- More time for focusing on work and/or consuming media content.

- Effect on the environment.
- Less stress and road rage.
- Improved mobility for older and disabled users, among others.
- Adoption of electric vehicles.

#### Negative (costs)

- Job losses (taxi and lorry drivers, car industry).
- Decreased revenue from traffic infringements.
- Less car ownership.
- Legal structures for driving.
- Lobbying against automation (people not allowed to drive on freeways).
- Hacking/cyberattacks.

A University of California, Berkeley, Working Paper "Intelligent Transportation Systems and Infrastructure: A Series of Briefs for Smart Investments" (25) highlights the following benefits:

- Intelligent transport systems and technology provide a high return on investment (ROI), especially when incorporated as part of ongoing construction activities.
- The ROI (measured in safety, travel time reliability, throughput and quality of life) takes less than six months in highly congested corridors.
- The cost to acquire and install this technology is roughly five per cent of the overall construction budget if installed during construction.
- Transport networks are now ready to support advances in automated and connected vehicles and in shared demand management approaches.

The two technologies combined go beyond services involving simpler sensors and responders used for traffic management and other ITS-based services described above. Several stages of operational practice can be defined from fully human-driven cars, to assisted driving, to various forms of partial and conditional automation and finally full automation covering a full end-to-end journey (Skeete, 2018). Cost-benefit approaches can, in principle, be applied when upgrading incrementally

from one stage to another or to changes covering more than one stage. Individual US states have been developing regulation in a correspondingly incremental manner (Center for Information and Society, 2012), but at federal level only testing is currently permitted.

As Skeete (2018) identifies, traditionally, in road transport, technological design has followed regulation (Foxall and Johnston, 1991) and the benefits of connected vehicles would also depend on regulatory change. Furthermore, once permitted, the most disruptive implication of connected vehicles is to increase their currently very low level (4 per cent as estimated by D. Morris, 2016) as one self-driving taxi can replace between 6 and 10 privately owned cars (Hars, 2016).

From a cost-benefit perspective increasing the utilisation of a vehicle by a factor of six implies a similar increase in the ratio of benefits to costs compared to existing provision, noting that this factor would be lower (than six) as only capital costs, not fuel and some maintenance costs, would be saved. However, it would not be substantially lower as because the assets are already underutilised, the capital costs are already a substantial proportion of the current total. Where vehicles are already highly utilised, such as a freight fleet, the same type of benefit is not available to the same degree. Furthermore, Hensher (2006) disputes the cost advantages of the sharing model for cars and based on a quoted comparison with the Uber taxi service finds that car ownership may still be lower cost to the user unless the cost of the driver (the Uber) can be avoided.

**Table 5. Estimates of annual economic benefits from AVs in the USA**

Annual economic benefits	Assumed market share 10%	Assumed market share 50%	Assumed market share 90%
Crash cost savings from autonomous vehicles			
Economic cost savings (US\$ billion)	5.5	48.8	109.7
Comprehensive cost savings (US\$ billion)	17.7	158.1	355.4
Economic cost savings per AV (US\$)	430	770	960
Comprehensive cost savings per AV (US\$)	1,390	2,480	3,100
Congestion benefits			
Travel time savings (million hours)	756	1,680	2772
Fuel savings (million gallons)	102	224	724
Total savings (US\$ billion)	16.8	37.4	63.0
Savings per AV (US\$)	1,320	590	550
Other AV impacts			
Parking savings (US\$)	3.2	15.9	28.7
Savings per AV (US\$)	250	250	250
Annual savings: economic costs only (US\$ billion)	25.5	102.2	201.4
Annual savings: comprehensive costs (US\$ billion)	37.7	211.5	447.1
Annual savings per AV: economic costs only (US\$)	2,000	1,610	1,760
Annual savings per AV: comprehensive costs (US\$)	2,960	3,320	3,900

Source: Fagnant (2015).



In the USA, the annual economic cost of crashes (of US\$ 277 billion) has been estimated as over double that of congestion, and technology to connect vehicles has the potential to reduce this substantially (Cambridge Systematics, 2011). It has been suggested that motor-vehicle fatality rates per person-mile travelled could eventually approach those in aviation and rail, about 1 per cent of the current rate (Hayes, 2011) and implying benefits of almost the full US\$ 277 billion.

The study including this estimate (Fagnant, 2015) modifies the potential savings based on uptake, quoting values for 10 per cent, 50 per cent and 90 per cent uptake of US\$ 17.7 billion, US\$ 158 billion and US\$ 355 billion respectively. As an illustration of potential structural changes in the economy, these changes are assessed in other literature in terms of the loss of healthcare revenue, though as a relatively minor effect (approximately 1 to 2 per cent of overall healthcare budgets (Clemets et al).

Benefits are also assessed and monetised for congestion (travel time and fuel) and for parking and are also presented for different levels of uptake. Overall, the sum of the annual economic savings across these categories of benefit ranges from US\$ 25.5 billion to US\$ 201 billion, according to uptake. In addition, there are possible savings from effects that are more difficult to monetise to give an overall estimate, for comprehensive costs, of between US\$ 38 billion and US\$ 447 billion. Expressed on a per-connected-vehicle basis, economic costs range from US\$ 1,760 to US\$ 2,000 and comprehensive costs from US\$ 2,960 to US\$ 3,900.

Compared to these potential benefits, the costs of enabling technologies are unknown as connected vehicles are not currently deployed in all equivalent situations and evidence of their performance is limited to current testing. However, forecast costs are estimated as falling over time to values of US\$ 3,000 per vehicle, based on expert judgement of the price the market would bear (Erik Coelingh, quoted in *Economist Technology Quarterly*, 2012), and to US\$ 1,000 to US\$ 1,500 per vehicle (KPMG and CAR, 2012). However, the sensor systems based on LiDAR installed in test vehicles currently

cost from US\$ 30,000 to US\$ 85,000 (Fagnant, 2015) and it is clear that economies of scale are required and must be assumed for benefit-cost ratios to be greater than one.

In a study of potential benefits (Montgomery et al., 2018) the authors estimate aggregate benefits which correspond well with the study quoted above, in the range of US\$ 275 to US\$ 800 billion annually, assuming 100 per cent of passenger vehicles are fully autonomous and there is no change in aggregate transport demand (total personal and freight vehicle miles). These include:

- congestion reduction (estimated US\$ 71 billion annually from savings in time and fuel)
- reduced accidents (US\$ 118 to US\$ 503 billion)
- energy security and environmental benefits (US\$ 13 to US\$ 58 from reductions in gasoline and fuel consumption from reduced congestion and platooning).

Private benefits are identified separately, resulting from ownership of an AV, independent of the number of other AVs on the roads) and include:

- time savings (US\$ 69 billion to US\$ 153 billion annually)
- self-driving taxi and Uber-type services (US\$ 3.9 billion to US\$ 10.6 billion).

Table 6 shows a summary of benefits.

In a study of costs (Bosch et al., 2017), autonomous vehicle costs are estimated to average US\$ 0.80-1.20 per vehicle-mile over the next 10 to 30 years, potentially reducing to US\$ 0.60-1.00 per vehicle mile. In comparison, vehicles with human drivers have average costs of US\$ 0.40-0.60 per vehicle mile (Stephens et al., 2016). The costs of shared, electric, autonomous taxis cost will decline from about US\$ 0.85 per vehicle mile in 2018 to US\$ 0.35 per mile by 2035, while shared autonomous rides have even lower costs of US\$ 0.20-0.40 per passenger-mile, assuming that they average 3 to 6 passengers (see Figure 5).

The main constraints to autonomous and connected vehicles have been identified as: (1) the broad question of liability, (2) data access (ownership, privacy and security) and (3) the approval of autonomous technologies that are currently operating in unregulated environments (Skeete, 2018). At a practical level, the uptake of autonomous vehicles is likely to be geographically limited because of the need for very detailed and carefully validated digital maps of all the locations where they can operate, along with electronic

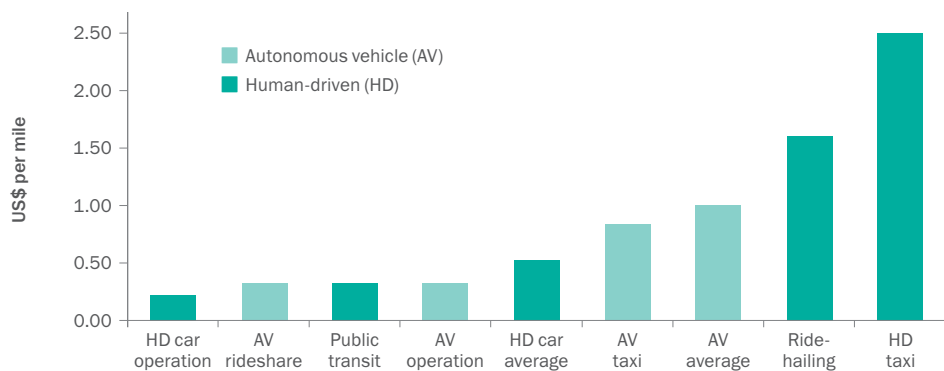
and marking changes, physical changes to urban roads, and high-speed freeway changes (25). These changes to roadside infrastructure highlight the issue of the distribution of costs as the benefits, at least in the short term, would be gained only by those sections of society using the driverless technology. This might not be easily justified from government budgets unless uptake was appreciable and potentially leads to a “chicken and egg” situation, which impedes the overall development of the technology.

**Table 6. Summary of benefits (annual US\$ billion, with 100 per cent AV penetration)**

Category	High	Low
Public benefits at 100% of VMT (annual)	633	202
Congestion	71	71
Accidents - repair and medical expense	118	118
Accidents - pain and suffering	385	-
Reduced oil consumption	58	13
Private benefits at 100% of VMT (annual)	163	73
Value of time	153	69
Reduction in cost of taxi/Uber/Lyft service	10	4
Total annual benefits in personal transport	796	275
Freight cost reduction	298	92

Source: Montgomery et al. (2018).

**Figure 5. Cost comparison of autonomous and human-driven vehicles**



Source: Bosch et al (2017) and Stephens et al (2016). Note: This comparison shows AVs are predicted to cost less than human-driven taxis and ride-hailing services but more than human-driven personal vehicles (HVs) and public transit services.

## Case study – CAVs on a freeway in Antwerp modelling study

This study, carried out by the Directorate for Energy, Transport and Climate, European Commission in Italy and the Faculty of Civil and Environmental Engineering, Transportation Research Institute in Israel, looked at how automation can impact on transport systems, and in particular on road capacity, in freeway scenarios (Makridis et al., 2018).

The simulation focused on a scenario where AVs and CAVs would coexist with manually driven vehicles and was carried out using the Aimsun transport modelling software, using the ring road of Antwerp in Belgium for the case study. Antwerp's ring road is used by heavy-duty vehicles carrying goods, as well as commuters travelling to and from the city and is characterised by high levels of congestion, particularly during peak periods.

A number of different scenarios were tested to account for different penetration levels of CAVs

and AVs, as well as for different levels of traffic demand. The results showed that AVs increased congestion on the network and manually driven cars outperformed AVs due to their nature of taking more risks and maintaining smaller headways than those programmed into AVs. CAVs, on the other hand, proved to be beneficial to the network under some conditions, particularly with higher penetration rates. With higher demands and high penetration rates, CAVs were able to accept smaller gaps while cruising or manoeuvring on the network, which resulted in improved network performance and prevented bottlenecks from disrupting the traffic flow.

These preliminary results confirmed the effectiveness of the strategy put forward by the European Commission to consider vehicle connectivity as the first necessary step in the transition towards the automation of the entire transport sector.

## Case study – Port of Rotterdam

The Port of Rotterdam, in the Netherlands, handles more than 461 million tonnes of cargo and more than 140,000 vessels annually (13). In January 2018 it announced its collaboration with IBM, Cisco, Esri and Axioms on a multi-year digitisation initiative to transform the port's operational environment using IoT and AI technologies in the cloud, with a view to optimising traffic management to improve efficiency and become the model for ports of the future. By 2030, the port authority wants to allow autonomous ships in port to unload goods.

Sensors ("Digital Dolphins") are being deployed across 42 kilometres of land and sea to collect and process the information through a centralised dashboard application. The data collected are

analysed by IBM's cloud-based IoT technology to manage vessel traffic efficiently in order to maximise cargo loading by helping to make decisions that reduce waiting times for ships to dock, load and unload, and enable more ships into the available space. The port operators will also be able to view the operations of all different parties at the same time, making that process more efficient.

The port has not publicly announced the cost of the overall project, but analysts expect the smart port to cost many millions of euros in both capital and operating costs. The expected savings for the ship operator will be in a region of US\$ 80,000 per hour and will allow the port to dock more ships each day.

## Case study – autonomous vehicles (providing mobility as a service)

The use of car-sharing, either be it by pool-sharing or shuttle service, has gained momentum over the past decade as road space becomes ever more restricted and single occupancy vehicles (SOVs) are gaining stigma for being environmentally and economically unsustainable. As the development of self-driving and autonomous vehicles continues, an opportunity is arising in the form of autonomous car-sharing services as a way of delivering “mobility as a service” (Maas) (Bert et al., 2016).

Car-sharing programmes, such as short-term vehicle rental companies Car2Go and ZipCar, or shared taxi services such as Uber car-pooling, seek to move away from asset ownership into a MaaS-driven economy.

In recent years, researchers have highlighted the potential for high reductions in fleet size as a result of shared AVs. Current research on queue modelling, scenario testing and demand simulation indicate that potential reductions of up to 90 per cent are achievable in city centre locations against current car fleet sizes (Spieser et al., 2014).

Spieser et al. (2014) compared current demand in Singapore against an “automated mobility-on-demand system” indicating that up to 40 per cent of current vehicles would be sufficient to meet demand. Similarly, the International Transport Forum used demand models to look at AV car-sharing potential in Lisbon. The findings indicated substantial ride sharing potential exists for AV fleets, with a possible fleet size reduction of 90 per cent (International Transport Forum, 2015).

Even in larger regions away from high-demand city centres, reductions are still achievable. For example, in Zurich, one AV sharing service has the potential to replace 10 current vehicles on the roads based on a maximum 10-minute wait time (Bosch et al., 2016).

While the research shows clear benefits to the use of this technology, barriers such as increased journey times and lack of sufficient AV technology at present mean this form of MaaS is unlikely to become a reality until around 2027 (15).

### 3.4. Unmanned aerial vehicles/drones for monitoring

#### Overview

The use of drones and other unmanned aerial vehicles (UAVs) has increased in recent years for surveying, facility management and other relevant fields. However, more recently, the technological progress in the design and navigation of low-weight and autonomous drones and UAVs has resulted in their more practical and cost-effective operation in the fields of construction management and monitoring. This section provides an overview of the current progress towards the development of a fully automated smart construction monitoring and reporting system based on real-time data obtained from drones and UAVs. The data in terms of drone images from multiple locations and point clouds (from 3D scanning of construction sites) can be used to construct a 3D model using photogrammetry techniques. This so-called “drone model” can be compared to BIM models at various construction stages to monitor construction progress. Aside from construction scheduling and costing, this comparison can be expanded to include real-time recording, reporting, billing, verification and planning. With the growing world population and its concentration in urban areas in developed and developing countries, long-term urban transport and construction planning strategies will have to look beyond using technology to improve the operation of the existing transport and urban development systems.

The UAV/drone market for commercial use is estimated to grow to reach over US\$ 1.2 billion by 2020, with 150,000 jobs in the EU potentially being created by 2050 (Marsh, 2015).

#### Enablers, barriers and opportunities

##### Technical analysis[Level 4 heading – bold only?]

The main advantages and opportunities of the implementation of UAVs are (Welch et al., 2015 and Marsh, 2015):

- high speeds
- removes vehicles from the highway network (reduces congestion, fuel reduction, improves air quality)
- cost-effective in comparison to road trips
- opportunity for more integrated logistics
- faster disaster relief response to more remote locations
- surveillance opportunities.

The main disadvantages and barriers include (Welch et al., 2015 and Marsh, 2015):

- regulations required around airspace
- potential conflict of airspace with aviation, other drones, infrastructure
- difficulty around locations of “landing mats” for deliveries
- additional costs – software, robotics engineers, maintenance, insurance, upgrades, drone delivery stations
- security and privacy issues
- weight or size limits for deliveries.

##### Market analysis

In 2018 a number of European cities joined the Urban Air Mobility (UAM) initiative (9). The initiative aims “to contribute to the creation of a market for urban air mobility that brings together cities and regions with companies, allows innovative urban mobility solutions to be showcased, and supports, where possible their replication at scale.”

The expectation over the next year is to set up city demonstration projects to study and evaluate drone traffic management in European cities. In line with the European Commission’s U-space vision, which aims to develop safe and secure airspace for the deployment of drones, the UAM initiative will help demonstrate the benefits of drones within the

aviation market to citizens, industries, small and medium-sized enterprises, researchers and local and regional authorities.

Key projects have already begun in UAM member cities, with an opportunity emerging for drones not only to address mobility needs, such as emergency services and traffic alleviation, but also to provide economic benefits.

Key cities delivering UAM-driven demonstrations throughout 2018 and 2019 include:

- Ingolstadt - developing a pilot scheme for air taxis
- Ghent – project aimed at designing a prototype for an ambulance drone
- Plovdiv - signed the UAM Manifesto with an innovative goods transport system for the integration of urban-rural territories
- Brussels - leads the application of drones for use in emergencies
- Euregio (cities of Enschede and Munster) - cross-border project looking to provide quicker emergency services
- Antwerp - pioneering smart security solutions
- The MAHHL-cities (Maastricht, Aachen, Hasselt, Heerlen, Liège) – improving public services and connectivity in the region through air mobility
- The region of Northern Hesse – third-dimension smart logistics for its urban and inter-urban areas.

Other participating cities that have joined the UAM initiative and are looking to develop their own demonstration projects include Geneva, Hamburg, Toulouse and the region of Nouvelle-Aquitaine.

### Cost-benefit analysis

Drones, as aerial vehicles, are a subset of robotic vehicles, with the military prominent in sponsoring their early and subsequent development over many years (Marsh, 2015). Recent developments, particularly advances in computing hardware and software, have sufficiently reduced their costs to enable wider commercial use, and, when combined with appropriate management and support, to enable probable commoditisation of the information and services they can eventually supply.

As with other aerial vehicles, guidance is a critical issue, and establishing a safe, reliable and sufficiently rapid system for control greatly affects their costs. Ultimately, automation of guidance systems will be key to low costs. While larger aerial vehicles have established guidance protocols, these are not yet in place for widespread commercial use of unpiloted drones.

A cost-benefit analysis of Amazon's drone delivery service highlights the potential if such guidance systems were in place (Welch, 2015). While it can be argued that the basis of the cost comparison presented is missing key components, the contrast between the calculated US\$ 0.06 per delivery by drone with US\$ 1.20 by UPS (delivery lorry) indicates the potential benefits of drones for local delivery. Where there is no road-based alternative, such as in remote districts or after natural disasters, the benefit-cost ratios would be very high if deliveries, for example of essential medical supplies, could be made.

When they are used for delivery, drones release capacity on existing roadways and, in the face of the fourfold increase in freight volumes forecast for 2050 by the Organisation for Economic Co-operation and Development (OECD), offer a solution to constraints that might otherwise act as a brake on economic growth (Marsh, 2015). The mitigation of these capacity constraints is an additional benefit that drones offer over and above their direct use, which, while positive, is difficult to estimate in cost-benefit analysis as the benefit depends on the level of congestion arising from other causes. It also highlights the missing costs included in the UPS delivery charge, which is unlikely to include a specific element to reflect the use of the local road network, currently uncharged at the point of use.

Where drones are used primarily to transport sensors, the benefits will relate to the value of the information collected. This includes its real-time availability as well as deep supporting services, which allow, for example, comparison of differences between data observed on drone flights on different occasions. In these applications, drone technologies overlap with and compete with other technologies such as Earth observation.

## Case study – Amazon Prime Air

Amazon has continued to push the boundaries in terms of the application of digital technologies, which it is investing in to enhance their delivery services for its customers (2). The company is well known for its successful e-commerce business and, over the last few years, has striven to come up with different methods to deliver its products.

December 2016 saw Amazon complete its first delivery by air and by drone in Cambridge, Massachusetts. This service, known as Amazon Prime Air, will aim to deliver packages of up to five pounds (approximately 2.2 kg) in weight within 30 minutes of the customer pressing the order button (2).

Currently the building and testing of different models of drones are underway but the potential barriers are issues around safety and security. Based on the segregation of airspace between the ground and 500 feet, Amazon has suggested that certain standards should be applied, to follow set rules for the flying of drones. Drones would be connected within this airspace to online networks that would “directly communicate with each other, allowing for the automated control of flights in real time” (3).

Allowing the drones to be connected to the internet to allow for flight control, management and communication between drones identifies a clear overlap between drone-use and the internet of things. “The key here is to simplify the airspace, not complicate it” (3).

Amazon has suggested that drones fly below 400 feet with the airspace between 400 and 500 feet designated as no-fly zones. Areas between 200 and 400 feet would be reserved for a “drone highway” where the drones would be travelling autonomously at high speeds and out of the line of sight of any operator. Amazon has assurances over the use of “sense and avoid” technologies that will allow the drones to dodge other vehicles, other drones and stationary objects,

as well as potential hazards such as birds and tall buildings (3). Integrated GPS and sophisticated navigation tools would put the drone back on track after any unexpected avoidance manoeuvres (4).

Areas below 200 feet would be reserved for lower speeds, where drones could be used, for example, to map fields, scan bridges or film videos, services typically carried out in the asset management industry. Drones would also be completing the final stages of their delivery at these operating heights, as they land near homes to drop off packages. Some sources (4) have indicated that a “delivery mat” would be required that would help guide the drone to its destination, where it can safely deliver the package. A mat allows for flexibility in moving the landing destination for the drone but requiring a mat could be problematic for more urban dwellers living in houses with smaller gardens, or for those living in apartment blocks.

Ultimately, for safe operation, a US government aviation body suggested that commercial drones would only be able to fly during the day and within the plain view of a licensed operator from the ground (3). These restrictions would obviously limit the use of the drones, but it has by no means stopped Amazon from progressing with this innovative alternative to deliveries.

A cost-benefit analysis of Amazon Prime Air (Welch, 2015) in Chattanooga concluded that a cost of a single delivery by a drone would be US\$ 0.06 per trip, so clearly more cost effective than US\$ 1.20 per package when delivered by UPS, when considering drone capital input alone. Based on 60,000 trips carried out over five years, the total cost would be US\$ 3,600, as opposed to US\$ 72,000 with UPS. However, there might be additional costs required to run drone delivery stations, such as computers and monitoring software, robotics engineers for maintenance and upgrades to drones, potential insurance and legal fees associated with drones and buildings, and land acquisition associated with drone stations.

## Case study – Elios indoor drone for bridge inspection in Minnesota

The Flyability Elios is a collision-tolerant drone designed specifically for inspection and exploration of inaccessible or potentially hazardous places (12).

The Flyability Elios drone is used for two different types of missions: flying under small bridges and flying in the confined spaces of box girders on larger bridges.

Minnesota has nearly 13,000 bridges that need to be inspected regularly to detect issues such as cracking concrete, problems with bearings or movement of the bridge, as well as corrosion, paint loss and rust. Without a drone, inspecting the underside of structures or confined spaces can be prohibitively expensive.

The inspectors at Collins Engineers use Flyability's Elios drone to fly underneath bridges and in other areas difficult to reach using traditional methods, which provides major savings for the company and allows it to provide more information at more frequent intervals to their clients. The drone requires no traffic control to transport, no additional time to reach the site, and can be operated by a single

inspector. The savings add up to approximately US\$ 3,000 on a small bridge inspection. That number could add up to US\$ 3 million of annual savings, in a road network that includes 1,000 bridges. Minnesota currently has 830 structurally deficient bridges, representing 6.4 per cent of the state's 12,961 bridges. Those 830 bridges represent a looming crisis for the state. Inspecting the 830 deficient bridges with drone technology could save the state about US\$ 2.5 million. Inspecting all the bridges with drones could save the state the substantial amount of US\$ 38 million. In addition, the drone allows better access to hard-to-reach areas, like the spaces between beams, which would normally be very difficult to inspect.

Drone inspections provide bridge inspectors with significant savings in time and costs, while providing customers with more thorough data for effective resource allocation.



# 4. Policy roadmap

## 4.1. Policy objectives

This paper has reviewed the application of disruptive technologies in transport in the context of their contribution to the main policy objectives identified (see Annex A), including:

- transport efficiency
- safety and security
- environment and climate change
- economy.

We also identified the maturity level for each of the technologies:

- 1 – Technology application currently in testing or development phase and limited implementation.
- 2 – Technology application being implemented on a small scale, further development required.
- 3 – Technology application well tested and routinely implemented with headline conclusions. Further development areas easily identifiable.

### Transport efficiency policy objective

It appears that the objective of **transport efficiency** can be best achieved by prioritising the following disruptive technology applications:

- **Traffic management (ITS)** – to include traffic flow and condition forecasting and travel planning as they provide the most benefit in terms of reducing congestion on both urban and inter-urban corridors, facilitate strategic planning and improve the operation of freight and public transport.
- **Autonomous vehicles (MaaS)** – have the potential to reduce the number of privately owned vehicles on the transport network, and as a result reduce congestion on both urban and inter-urban corridors, improve accessibility, urban mobility and public transport.
- **Drones** – particularly when used in logistics, they have the potential to drastically reduce the number of vehicles on the road network currently being used for deliveries and, as a result, reduce congestion on both urban and inter-urban corridors.

### Safety and security policy objective

The objective of **safety and security** can be best achieved by prioritising the following disruptive technology applications:

- **Traffic management (ITS)** – incident detection and prediction using IoT, big data and AI can significantly improve safety by allowing traffic authorities to react promptly to any issues identified and react accordingly by reassigning traffic and providing the necessary emergency response.
- **Autonomous vehicles** – the research suggests that they have the potential to reduce the number of collisions by 99 per cent (technology maturity level 1).
- **Drones** – particularly when used for asset maintenance and inspection and construction site monitoring, they have the potential to significantly reduce the risk involved relative to using more traditional methods (technology maturity level 1).

### Environment and climate change policy objective

The **environment and climate change** policy objective should be addressed by prioritising the following disruptive technology applications:

- **Traffic management (ITS)** – improving transport efficiency will inherently have a positive impact on a reduction in vehicle emissions, improving air quality, reducing noise and overall benefiting public health and well-being.
- **Autonomous vehicles (MaaS)** – providing that their implementation is in line with the principles of MaaS, there is potential to significantly reduce the number of vehicles on the transport network and have a positive impact on the environment.
- **Drones** – particularly if used in logistics on a large scale, they have the potential to remove a significant number of vehicles from the roads and, as a result, have a positive impact on the environment.

## Socio-economic policy objective

The **socio-economic** policy objective should be addressed by prioritising the following disruptive technology applications:

- **Traffic management (ITS)** – improving transport efficiency will have an inherently positive impact on direct cost savings (time savings, increased productivity and efficiency), increased economic output, as well as wider social benefits to include increased leisure time and improved health and wellbeing, resulting from time savings and an improved environment.
- **Autonomous vehicles** – have the potential to provide significant time savings, with the time currently spent driving being distributed between work and leisure which would result in increased productivity and efficiency alike, and improved health and well-being.
- **Drones** – direct cost savings by providing a cheaper alternative to the traditional tools used in logistics, site inspections and asset maintenance. In a wider context, if successful in replacing a significant number of vehicles on the roads, drones can contribute to time savings by reducing congestion and improving the environment, and as a result have a positive impact on public health and wellbeing.

## 4.2. Policy recommendations to assist with barrier removal

From the analysis of the policy objectives it can be concluded that the disruptive technology applications having the most profound impact on transport efficiency, safety, environment and socio-economics centre around new smart mobility (AVs/MaaS and drones) and smart transport systems (ITS).

These new smart mobility and transport systems promise to contribute to improved transport efficiency, safety, environment and to provide socio-economic benefits. However, innovations in technologies and use need to optimise the whole transport system to make a long-term contribution to achieving these objectives.

In spite of modest evolutionary innovations, transport continues to represent over 20 per cent of CO<sub>2</sub> emissions and is projected to continue to rise significantly to 2050 even in benign scenarios. Most significantly, transport's share of overall CO<sub>2</sub> emissions continues to increase in current linear projections. Recent scenarios offer little confidence that the policy mix currently deployed towards mitigation will have sufficient decarbonisation impact. Projections towards 2050 appear to offer a stabilisation of current absolute CO<sub>2</sub> emissions from global transport at best and a rather more probable increase of CO<sub>2</sub> emissions, albeit with a reduced rate of increase (Lennert et al., 2016).

The aim of this policy roadmap is to identify priorities for further research and development into smart mobility and transport system measures and to propose a set of guiding recommendations for the future. It was developed in line with the EU's Strategic Transport Research and Innovation Agenda (STRIA) (Lennert et al., 2016) and the United Nations Economic Commission for Europe (UNECE) "Road Map for promoting ITS – 20 global actions 2012-2020" (UNECE, 2016).

The key challenge in the development of these disruptive technologies and their applications will be to successfully integrate the business and governance models for new mobility technologies, services and systems in order to remove the barriers and transform them into potential enablers. The following are the main priorities in this process.

### Barrier 1: Legal and regulatory framework

#### Enabling policy 1: Harmonising existing and new policies

The lack of harmonised policies for the development of digital transport applications can hamper the implementation of existing solutions and constitute a real barrier to market development. A structured policy framework would ensure that the activities around promoting innovation in the transport sector are more effectively planned and coordinated and efficiently implemented both in terms of technical regulations and legal instruments. A common deployment strategy would be more effective when developed through harmonised national policies.

### Barrier 2: Data fragmentation and multiple platform development

#### Enabling policy 2: Facilitating interoperability and data sharing

The design and development cycle of innovative technologies in the transport sector is shorter than the policy cycle and as such the regulatory authorities often lag behind. This is particularly evident at the international level and can lead to technical fragmentation and interoperability issues across countries. Through the sharing of data, services and information, the overall cost of providing each of the components of the new transport systems will be reduced and will enhance the ability of the private sector to operate effectively.

The EU has launched major initiatives to help develop ITSs in road transport, leading the way in creating a clear path and providing the necessary tools to deploy ITSs widely. Efforts should be made

to speed up development and implementation of regulations and agreements on technical and technological compatibility. Advanced driver assistance systems (ADAS) technologies, for instance, are important advances in vehicle safety and the optimisation of their potential benefits is crucial for the deployment of AVs. Further development of provisions for ADAS should be encouraged and special attention should be devoted to: (a) raising awareness of the benefits of V2I and V2V on road safety; and (b) infrastructure standards to promote V2I and V2V (for example, a convention on road signs and signals).

Companies, governments and public entities should be encouraged to provide user and urban data collected on the use of public space and infrastructures wherever it is available (ensuring that the privacy of the public is protected) so that users, cities, third-party apps, operators, developers and innovators can access it to develop innovative solutions. Only by making the big data “open” will third parties be able to integrate it into their systems and establish truly “cross-infrastructure” integrated mobility systems.

All disruptive technologies considered depend on the availability of an information and communication technology (ICT) policy, which enables the systems that constitute the core of ICT infrastructure. The capability to deliver the new technologies on a large scale does not grow in a linear direction with the augmentation of available technology. New operating models will need to be developed to allow for effective collaboration between cities, the public, science and industry, as well as the public transport and private operators and individual mobility providers to co-deliver sustainable mobility and transport systems. Municipal and regional institutions will need to be equipped with the strategic capacity to transform and develop stable operational frameworks for new urban mobility, which will require innovative approaches to cross-sectoral planning, public participation and procurement and the shared use of embedded physical and technical infrastructure.

### Barrier 3: Security, insurance and privacy concerns

#### Enabling policy 3: Ensuring data security addressing risk-sharing or liability concerns

Security and privacy concerns could become potential barriers to the deployment of big data, IoT, AI and drones. The applications need to be implemented using viable business cases that require consistent standards and regulations on liability and the highest levels of security for personal data. The 1968 Convention on Road Traffic states that “every driver shall in all circumstances have his vehicle under control...” (UNECE, 2016). AV systems that act on behalf of the driver or override the driver’s decision introduce new challenges. For example, in a system failure and accident situation it is not clear who is legally liable. A solution will need to be developed to allow for the implementation of AVs.

### Barrier 4: Prohibitive cost or lack of economic and financial evidence of return on investment

#### Enabling policy 4: Developing cost-benefit analysis methodologies and the supporting evidence base

A lack of harmonised methodology for cost-benefit analysis of the disruptive technologies hampers the deployment of innovative solutions and may encourage the retention of more traditional solutions that are less beneficial to the public. More work is needed in this area as it is commonly accepted that cost-benefit analysis has a major effect on future sustainable transport planning and provides a tool that is of special interest to governments and policymakers.

## 4.3. Cross-cutting issues and opportunities

The findings of this study suggest that disruptive technologies have the potential to significantly impact economic growth and the evolution of society through a process of “creative destruction” (Rosenberg, 1994). This observation is consistent with previous technology developments, for example the emergence and commercialisation of technologies such as the steam engine, electricity, automobiles, aircraft and, more recently, personal computing and communication devices (for example, smart phones) that simultaneously made old technologies redundant while creating opportunities for new markets to emerge. This in turn led to higher economic productivity, improved living standards and (positive and negative) societal and environmental impacts. However, in practice, new technologies must first undergo a process of invention, commercialisation and diffusion (Rogers, 1983).

While new technologies are continually being developed, their diffusion and uptake is highly variable and dependent on a range of social, economic and political factors. Opportunities and issues that could underpin or undermine the diffusion of digital technologies are discussed including implications for policymaking in the EBRD regions. An overarching policy statement is provided below, covering a range of topics with supporting information.

***Policy statement 1: As for the barrier related to data fragmentation, digital technologies can significantly modify the effectiveness of existing assets (for example, cars operating better together) and innovations (for example, electric vehicles and smart grids). Integrating ICT with other technologies can yield significant co-benefits relating to data collection and processing, with a compounded potential for positive disruption.***

As this paper shows, the application of digital technologies is rapidly changing the form and function of the global transport sector. New and improved sensors, algorithms and data management platforms are positively impacting traffic management systems as well as contributing

to public policy, such as the implementation of shared bicycle schemes in urban areas across several countries (Funk, 2015). These developments have occurred at the same time as the growth of electric vehicles. Rapid improvements in the cost and performance of electronics, particularly power electronics, and gradual improvements in storage technologies have resulted in lighter vehicles and more abundant and efficient charging stations (Funk, 2015), opening up new markets and opportunities for digital technologies.

Digital technology improvements will also contribute to the development of smart networks and grids of various types, for example, charging of electric vehicles when they are parked in private and public settings, and enabling the export of energy back to the energy grid in real time (Huber, 2011). However, for this to be successful, new policies and business models will need to be developed that capitalise on network effects and support parallel investment in charging infrastructure and electric vehicles (Funk, 2015). Collectively, these examples demonstrate the potential for digital technologies to complement and enhance other technology innovations.

***Policy statement 2: Cost can be a prohibitive barrier to entry and market development. Infrastructure investment (such as dedicated roads for autonomous vehicles) will be required to realise the benefits of certain disruptive technologies. Without this potential benefits could be partially or fully negated, thereby reducing the overall economic viability of these technologies. However, sourcing and allocating of funding for such infrastructure remains a significant challenge.***

Many digital technologies are undergoing rapid development, for example improvements in cameras, microelectromechanical systems (MEMS), lasers and wireless communication are making autonomous vehicles more economically viable. Annual improvements (in the region of 25 to 40 per cent) in many sensors, could lower the cost of autonomous vehicles by 90 per cent in the next 10 years (Funk, 2015). Compared to conventional vehicles, autonomous vehicles can provide a range of benefits, notably improved safety, performance

and efficiency. However, the benefits are likely to be much larger when dedicated roads are provided for these vehicles. Indeed, for certain types of autonomous vehicles, dedicated roads are a prerequisite.

Dedicated roads enable these vehicles to travel at higher speeds and closer together, reducing congestion by improving the capacity of the network and improving individual vehicle fuel efficiency (Funk, 2015). The capacity and rate at which dedicated roads can be constructed to carry autonomous vehicles will directly affect the level of benefits as will any physical or regulatory limits on the ability to partition existing roads or otherwise make adaptations to the road network.

***Policy statement 3: Security of data and privacy are growing concerns for users and potential users. Smartphones can provide an abundant and highly valuable source of real-time geo-referenced information. This information can be used by operators to enhance public and private transport systems through better prediction of people movement. However, this source of information is highly vulnerable to both user exploitation and operator security breaches.***

The widespread availability and uptake of smartphones in the developed and developing world has provided an opportunity for new markets and services to develop. For example, improvements in ICT have fundamentally changed the way ticketing is managed on many public transport systems, with contactless payment using smart cards and smartphones becoming the dominant transaction method. Currently, about 90 per cent of bus and taxi travellers and 75 per cent of subway travellers in Seoul use smart cards for ticket payments, providing a more convenient and lower-cost solution for travellers (Pucher, Park et al., 2005; Pelletier, Trépanier et al., 2011; Turner and Pourbaix, 2014).

Furthermore, the use of smartphones creates more opportunities to crowdsource information, update maps and relay transport information and travel schedules in real time to improve service delivery (Xu and Dodds, 2015). Despite the range of potential

applications and benefits for users and operators, use of smartphones and geo-positional systems carries significant security risks. Data protection and sharing remains a significant concern and a potential liability risk if personal data is mismanaged or security breached.

***Policy statement 4:** The cost dimension can also deter adoption when costs and benefits are unknown. The successful commercial diffusion of new technologies requires an understanding of demand, an actual or emerging gap in the market as well as evidence of tangible derived benefits. However, these elements can be eroded by rebound effects, such as demographic, technological or regulatory changes leading to the adoption of alternative technologies.*

In terms of urban mobility, smartphones incorporating geo-locational positional systems are a key enabler of innovation in transport systems. This is aided by the high levels of use in many communities worldwide. For example, in London over 70 per cent of people regularly use their smartphone for travel purposes (Rode, Hoffmann et al., 2014). Smartphones can provide further opportunities to promote and disseminate information about shared mobility schemes covering different modes of travel such as the availability of bike, scooter and car-sharing schemes, as well as information on private taxi services such as Hailo, Taxibeat, TaxiForSure and Uber (Rode et al., 2017).

Linking these applications and technologies with e-payment solutions can also improve the overall convenience and experience for travellers. Evidence suggests that the provision of car-sharing schemes has been linked with a reduction in car ownership levels and total vehicle kilometres travelled (Martin and Shaheen, 2011), with travellers also being more receptive to public transport options. However, as an illustration of the interconnectedness of different technologies, such developments, which reduce overall traffic, may affect the need for and financial viability of other solutions, such as congestion management technologies. But it can also enhance other demand-management interventions by providing a means to relay information to individual travellers.

***Policy statement 5:** New types of data may need to be collected to support the diffusion and uptake of disruptive technologies in the transport sector. Generally, these data will need to be multi-dimensional, high-resolution and continually updated and validated to yield the largest benefits and ensure they are fit for purpose.*

Information availability and accessibility will be critical to the practical deployment of many of the disruptive technologies considered here. For example, the uptake of advanced autonomous vehicles, with the ability to operate without direct human control and input, will initially be constrained by the (non) availability of highly detailed and validated digital maps of locations, and by the terrain, as well as by the need for supporting operational infrastructure such as low-cost electronics (for example, 5.9 GHz dedicated short-range communication (DSRC)), and changes to road markings and road signage (that is, to support vehicle image recognition) (Bayen and Shastry, 2017). As seen in other sectors, the application of digital technologies is likely to be only partially successful and will either over- or underachieve. Without successful deployment, the expected potential benefits, for example improved safety and reduced congestion, are unlikely to be realised.

New types of information will almost certainly need to be collected and regularly updated to support the application of digital technologies, and this is where drones and other remote sensing technologies could prove very useful (Bayen and Shastry, 2017). It has been suggested that disruptive technologies can provide significant direct benefits (and opportunities for follow-on applications), however many of these technologies are still in their infancy; as such they require further development and testing, and are subject to other constraints such as consumer acceptance and regulatory barriers, which may affect the future market size. Furthermore, if such constraints are overcome and lead to low costs (for example, from economies of scale), there may be an incentive for consumers to overconsume, for example, by undertaking travel previously considered unnecessary, an example of the so-called rebound effect.



**Policy statement 6:** *Real-time data will be required for high-risk dynamic applications of disruptive technologies (for example, drones) in the transport sector. Traditional disciplines and approaches (for example, spatial planning) will need to be rethought and designed to accommodate these alternative technologies.*

Interest in drones has grown significantly in recent years, supported by projects such as Amazon Prime Air, Google's Project Wing, and Airbus's Project Vahana. As this paper shows, drones can provide a range of benefits and can be used for a variety of applications such as commercial package delivery, aerial surveillance, emergency supply delivery, videography and search and rescue. Drones are particularly beneficial for mapping and observation of terrestrial topographies and movements and therefore key to transport applications, potentially providing a prime feed of highly useful transport information. However, most drones will be likely to operate between 200-500 feet, meaning it is essential to manage this airspace carefully to ensure privacy and efficiency (Bayern and Shastry, 2017).

One way to maximise the efficiency of drone systems is to develop "highways of the air", which will need to be integrated with existing developments, adding an additional dimension to spatial planning. To accommodate many drones these air highways will need be managed in real time, updating virtual trunk networks and branches to reflect changes in the airspace. This model can be extended even further, adding additional levels of highways at different altitudes, thereby prioritising various types of air traffic. Last-mile operations will be particularly critical as they will involve drones flying near humans and other important assets (Bayern and Shastry, 2017). In these situations, real-time data, such as cellular and road traffic data, will be required to provide an indication of people movement and avoid unacceptable risks.

**Policy statement 7:** *The willingness to pay and initial concerns of consumers are critical to the success or failure of digital technologies. Uncertainties are expected to be gradually overcome through information provision, behavioural change and awareness-raising activities and structuring of costs including user and operator subsidies. However, several significant challenges remain.*

A critical consideration of any new disruptive technology, even if supported in full or part by public funding, is the willingness of consumers to pay. Previous studies have identified that a large proportion of consumers are likely to consider purchasing autonomous vehicles when they become more widely available (Power, 2012). However, whether this holds true in practice depends on consumers' appreciation of the benefits and incurred direct and indirect costs. From the individual consumer's perspective, fully autonomous vehicles can provide a range of benefits including (1) reducing the burden of driving, (2) automating parking in narrow spaces and (3) removing the need for driving licences (permitting wider access to travel) (Shin et al., 2019).

However, consumer concerns over higher up-front costs and regular maintenance, uncertainties relating to potential accidents and malfunctions, operator anxiety and concerns of data security represent potential detractions. Despite this, government action or incentives can go some way towards mitigating perceived negative factors, for example, direct financial support (by implementing subsidies or innovation support, promoting investment to reduce production costs), and thereby reducing the cost to the consumer (Shin et al., 2019). Ultimately, different consumer groups will weigh up positives and negatives differently. For example, evidence suggests that elderly people and those without driving licences strongly support the use of autonomous vehicles.

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# Annex A. Policy objectives

Policy objectives	Transport efficiency						Safety and security			Environment and climate change				Socio-economic						
	Congestion reduction	Inter-urban corridors	Urban mobility	Accessibility	Strategic planning	Freight transport	Public transport	Safety	Freight transport security	Public transport security	Environmental impact	Energy savings	Fuel savings	Air quality	Labour market	Efficiency/time savings	Productivity	Cost savings	Competitiveness	Economic output
<b>Disruptive technologies applications</b>																				
<b>IoT/ big data/ AI</b>																				
Traffic management (ITS)	3	Major	Major	Major		Major	Major	Minor			Major	Minor	Minor	Minor		Major		Minor		Major
Traffic flow/volume forecast	3	Major	Major	Major		Major	Major				Minor	Minor	Minor	Minor		Major		Minor		Minor
Traffic conditions forecast	2	Major	Major	Major		Major	Major	Major			Minor	Minor	Minor	Minor		Major		Minor		Minor
Asset management (vehicles and infrastructure)	2					Major	Major				Minor	Minor	Minor	Minor		Major	Major	Major	Major	Major
Freight tracking	1	Minor	Major			Major	Major		Major		Minor	Minor	Minor	Minor		Major	Major	Major	Major	Major
Logistics (tracking of deliveries)	1					Major	Major				Minor	Minor	Minor	Minor		Major	Major	Major	Major	Major
Parking management	2	Minor		Minor	Minor						Minor	Minor	Minor	Minor		Major		Minor		
Travel planning	3	Major	Major	Major							Minor	Minor	Minor	Minor		Major		Minor		Minor
Public transport real time information	3	Minor		Major	Minor		Major				Minor	Minor	Minor	Minor		Major		Minor	Major	Minor
Public transport operations planning	2	Minor		Minor			Major		Minor		Minor	Minor	Minor	Minor		Major		Minor	Major	Minor
Smart ticketing	2			Major			Major									Major		Minor	Major	Minor
Disruption alerts/incident detection	2	Minor	Major	Minor		Major	Major	Major	Major							Major		Minor		Minor
Pollution detection	2									Major			Major							
Autonomous vehicles	1		Major	Major	Major		Major	Major								Major			Major	Major
Autonomous vehicles – MaaS	1	Major	Major	Major	Major		Major	Major			Major	Major	Major	Major		Major		Major	Major	Major
<b>Drones</b>																				
Drones – logistics	1	Major	Major	Major	Major		Major	Major			Major	Major	Major	Major	Minor	Major	Major	Major	Major	Major
Drones – traffic monitoring	1	Major	Major	Major		Major	Major	Major			Major	Major	Major	Major	Minor	Major	Major	Major	Major	Major
Drones – disaster response	1			Major			Major	Major								Major		Major		
Drones – asset and construction site monitoring	2			Major			Major	Major			Major	Major	Major	Major	Minor	Major	Major	Major	Major	Major
Drones – BIM data	2				Major		Major	Major			Major	Major	Major	Major	Minor	Major	Major	Major	Major	Major

 Major impact  
 Minor impact

# Glossary of terms

<b>ADAS</b>	advanced driver assistance systems
<b>AI</b>	artificial intelligence
<b>ANN</b>	Artificial neural networks
<b>ANPR</b>	automatic number plate recognition
<b>AV</b>	autonomous vehicle
<b>BIM</b>	building information modelling
<b>C-V2X</b>	cellular-vehicle to everything
<b>CAV</b>	connected and autonomous vehicles
<b>DSRC</b>	dedicated short-range communication
<b>EBRD</b>	European Bank for Reconstruction and Development
<b>ESC</b>	electronic speed controllers
<b>EV</b>	electric vehicle
<b>FLM</b>	fuzzy logic models
<b>FPV</b>	first person view
<b>GA</b>	genetic algorithms
<b>GIS</b>	geographic information system
<b>GPS</b>	global positioning satellite
<b>GSC</b>	ground station controllers
<b>HD</b>	human-driven personal vehicle
<b>IMU</b>	inertial measurement unit
<b>IoT</b>	internet of things
<b>ITS</b>	intelligent transport systems
<b>LIDAR</b>	light detection and ranging
<b>MaaS</b>	mobility as a service
<b>MEMS</b>	micro electrical mechanical systems
<b>ML</b>	machine learning
<b>MMTIPS</b>	multimodal traveller information and planning services
<b>PTP</b>	personal transport planning
<b>RFID</b>	Radio frequency identification
<b>ROI</b>	return on investment
<b>SA</b>	simulated annealing
<b>SCOOT</b>	split cycle offset optimisation technique (a real-time system of adaptive traffic control)
<b>SOV</b>	single occupancy vehicle
<b>STRIA</b>	strategic transport research and innovation agenda
<b>UAM</b>	urban air mobility
<b>UAS</b>	unmanned aircraft systems
<b>UAV</b>	unmanned aerial vehicle
<b>UNECE</b>	United Nations Economic Commission for Europe
<b>V2I</b>	vehicle to infrastructure
<b>V2V</b>	vehicle to vehicle
<b>V2X</b>	vehicle to everything
<b>VIS</b>	vehicle identification system
<b>VMT</b>	vehicle miles travelled
<b>VR</b>	virtual reality
<b>VTOL</b>	vertical take-off and landing
<b>WCC</b>	Westminster City Council





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