CREATE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 636573

Project acronym: **CREATE**

Project title: **Congestion Reduction in Europe - Advancing Transport Efficiency**

Project website **www.create-mobility.eu**

Deliverable 6.2: Potential impacts of technological and other changes

		Date of preparation:	**29th May 2018**
Start date of project:	**1st June 2015**	Duration:	**36 months**
		Version:	**1**
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		Status:	**Final**
		Dissemination level:	**PU**

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1 Introduction

The goals of CREATE's Work Package 6 (Future Developments) were set out as follows in the grant agreement:

> This work package looks beyond the current set of policies being implemented by Stage 3 cities, to consider future challenges and opportunities, with a focus on assisting cities where projected rapid increases in population and employment (e.g. in Copenhagen and London) are likely to lead to significant mobility densification and risk undermining the improvements in network performance and reducing levels of car use that have been achieved in recent decades. This aim is addressed through a set of four objectives and associated tasks.
>
> **Objectives**
>
> 1. Identify likely future population and employment trends and resulting pressures on city transport networks
> 2. Assess the scope for advances in transport technologies and management strategies to address these challenges
> 3. Assess the scope for harnessing non-transport technologies to change underlying patterns of demand for mobility
> 4. Explore the nature of a future 'Stage 4' city and the set of policies that might be implemented there.

This deliverable arises from two tasks within Work Package 6 (Future Developments) which align with Objectives 2 and 3 above:

- Assessing the scope for using advances in transport technology and management (Task 6.2); and
- Scope for advances in non-transport technologies and changing underlying demand patterns (Task 6.3).

In the CREATE grant agreement, two complementary deliverables were envisaged:

- Potential contributions of advances in transport technologies and new management systems (D6.2); and
- Potential contributions of non-transport technologies and changes in social and business practices (D6.3).

As the project progressed, it became increasingly apparent that the overlap between the two was so great as to justify combining them into a single deliverable. The principal reasons for this are that "transport" and "non-transport" advances tend to arise from the same underlying changes (see Section 2) and that the questions of how to respond to them have the same set of answers. Having said that, there are differences and, for this reason, they are presented in separate sections (3 and 4).

As will be seen, we look at both the positive (potential benefits) and the negative (potential harms) arising from technological and other advances in the context of a broader survey of how to interact with change.

This deliverable should be read in conjunction with D6.4 ("Deliverable 6.4: Developing strategy – working with uncertainty) and an emerging 'Stage 4'" which discusses, amongst other things, the governance of change.

1.1 Structure of this deliverable

This section concludes with a short glossary of terms relevant to the remainder of this deliverable. Following that:

- In Section 2, a range of fundamental changes (underlying more specific changes such as drones or mobility as a service) is introduced and discussed;
- In Section 3, after a brief discussion of the ways in which technological advances can affect the transport policy maker, a set of a transport advances is examined;
- An equivalent exercise is undertaken for a set of non-transport advances in Section 4;
- Section 5 presents some practical considerations concerning the management of advances, technological and otherwise; and
- The deliverable concludes with a short discussion and a set of recommendations.

1.2 Glossary

A recurring theme in this deliverable (and, indeed, in this work package) is the relationship between technology and society and the governance of this relationship. We present here definitions of a small number of relevant terms, in order to support the discussion that follows.

1.2.1 Socio-technical system

The term "socio-technical system" derives originally from research into on coalmining practices in the 1950s (Trist and Bamforth, 1951). The term "socio-technical" refers to the interrelationship between the technical and social aspects of society as a whole. Where transport is concerned, the overall term "socio-technical system" reminds us that technology interacts with society and, therefore, that we must be careful not to think about any technology as if it is separate from the society into which it may be introduced. Instead, they shape each other over time.

1.2.2 Technological determinism

This term is attributed to Thorstein Veblen and describes the theory that society's structure and values are determined by its technology (Smith and Marx, 1994). Though widely discredited today, it is useful to keep this theory in mind as we think about technological change. Much of the narrative concerning automated vehicles, for example, suggests that change will be "one way" – that the technology will arrive and that society will adapt to it.

1.2.3 Technological fatalism

This term is connected to, but distinct from, technological determinism. It describes the belief that technological change is inevitable and that its impacts are beyond society's control (Licker, 2001). Again, this is an extreme position and one that is not widely held; but it deserves inclusion because policy makers are sometimes guilty of adopting positions with respect to technology that could be described as fatalistic. The idea that automated vehicles are coming and that we ought to prepare for their arrival has a distinctly fatalistic tone.

1.2.4 Anticipatory governance

Though this term is not well defined (Guston, 2014), it describes the idea of catching a technology as it is emerging and guiding its development (as far as possible) towards socially desirable outcomes. Often cited as a positive example is the UK's approach to human fertilisation and embryology, where a carefully chosen regulatory path led to a situation in which the benefits of the technology are being enjoyed whilst the feared negative aspects have been largely controlled (Wilsdon and Willis, 2004). In the case of transport technology, the idea could prove powerful in a sector that is not typically quick to intervene: catching a technology early, before it has become embedded (cf socio-technical systems), and establishing governance systems that enable society to enjoy its benefits.

1.2.5 Precautionary governance

This too is a term which lacks a single definition (Reber, 2018) but we shall use it here to describe an approach to governance based on minimising the risk of harm. More specifically, in cases of uncertainty (as is almost inevitable where new technology is emerging), a precautionary approach implies avoiding situations where a risk has been identified of some harm occurring and choosing, instead, interventions which keep this risk minimised. The significant point here is that precautionary governance can lead to the loss of *benefits* because they would only have been available if a path had been followed that implied some level of avoidable risk.

2 Fundamental technological changes

Section 4 provides a series of examples of technological and associated advances that can be expected to have a noticeable impact upon the transport sector. In this section, we discuss a set of more fundamental technological changes that lie beneath the majority of the more specific changes discussed in Section 4. The reason for doing this is to enable the transport policy maker to be circumspect about the next “big thing”, by understanding where it is coming from. The impression from the media can be that there is a constant stream of revolutionary developments. This is not actually the case. Instead, a small number of fundamental shifts (as discussed in this section) are enabling various developments (as described in Section 4) to occur. And, on closer inspection, these are not necessarily the revolutions that they are painted; they are instead evolutions. A close study of automated driving, for example, will remind us that experiments were being carried out as early as the 1940s and that cars have been gradually carrying out a growing proportion of the driving task for many years. If automated vehicles are to prove revolutionary, this will be not because of the technology but because of the way society chooses to adopt them.

The circumspection that this section is intended to help foster will help us to remain *calm* about technological advances. It will also remind us that the impact of technological advance is to a great extent a matter of choice.

Note that this section is not intended to provide (and indeed cannot provide) an exhaustive survey of these topics and that some simplification has been necessary in order to cover the topics sufficiently briefly.

2.1 Ubiquitous computing

This term is sometimes used interchangeably with *pervasive computing* and the *internet of things*. We prefer *ubiquitous computing* (UC) because, of the three, it seems to convey most accurately what it describes – the increasing prevalence of computers in our world. Ever more objects contain computers and ever more types of object contain computers, including items, such as fridges, that do not obviously need to contain one.

People increasingly own not one but multiple computers – a laptop, a tablet, a mobile phone, a smart TV – and also own various objects that contain computers – cars, fitness-monitoring devices etc. And it is significant, from the perspective of transport, that people habitually carry at least one of these computers around with them.

2.2 Ubiquitous sensing

Though not as established a concept as UC, we use *ubiquitous sensing* to convey a complementary thought: that ever more objectives are gathering ever more data, be that images, sound, temperatures, vibration, air composition etc. Much of the time, the object that collects data also contains a computer that can process them but, if not, it will probably be able to transfer the data in raw form and, failing that, store them for retrieval at a future time. One reason for the proliferation of sensors is that they have become a great deal cheaper over time; another is that they have become smaller such that it is easy to fit them into arbitrarily small packages. For instance, a typical mobile phone will, apart from naturally having a microphone, also contain a camera, light meter, accelerometer, gyroscope, proximity gauge, compass and barometer.

2.3 Connectedness

Not only do ever more objects contain computers and/or collect data, they are ever more connected with each other, physically or through some form of electromagnetic waves (satellite signal, mobile signal, radio, wifi, Bluetooth). The range of connections is widening as is the speed and reliability with which data can be transferred. Thus, when we talk of “vehicle to vehicle” communication, we are describing an extremely rapid conversation between objects, whose relative speed could be quite large. The current excitement about 5G reflects the considerable benefits that can be gained from improved speed and accuracy of communication.

2.4 Cognitive computing/artificial intelligence/machine learning

This combination of terms glosses over distinctions which would be important to a computer scientist but the general thrust here is that computers are becoming increasingly able to carry out tasks which had previously been thought the sole domain of humans – recognition, interpretation, judgement, learning. And it is for this reason that automated vehicles are now considered a much more realistic prospect than before.

2.5 Robotics & automation

We have had automation in various forms for many decades – people unthinkingly ride in lifts because this is a form of automation that works well. But the combined fields of robotics and automation have been advancing such that the range of tasks that can be automated has been rapidly expanding. The prospect that a drone might deliver a package relies on a vehicle flying by itself, adjusting its movement to reflect the mass of the package, navigating around obstacles and arriving at a defined destination to a required level of precision.

2.6 Advanced materials

Probably last to the party are materials, more invisible even than energy. They too are changing. A simple example is the use of carbon fibre. It is being preferred to steel in bicycle manufacture because it is lighter and stronger, and it is also being used in the manufacture of aircraft, where aluminium previously dominated, for similar reasons. As its price falls, we can expect it to be more extensively used in transport.

Potentially more exciting are carbon nanotubes which exhibit extremely high levels of strength given their light weight. Their application in “macroscopic” items is at a very early stage but this is set to change.

2.7 How fundamental changes combine

It is useful now to think about how certain of these fundamental changes are combining to produce the types of advance that are being widely discussed in the transport sector – automated vehicles, for example – and beyond – 3D printing etc.

This is illustrated by Figure 1 and Figure 2 which connect fundamental changes to UAVs – drones and teleservices, respectively.

- UAVs – drones are made possible mainly through automation – the vehicles are able to carry out the flying task based on code that determines how they should behave in a series of situations and they are able to act because their extensive sensors provide data concerning their surroundings. They can locate the right package and deliver it to the right destination thanks to connectedness, which enables a “conversation” between the drone, its cargo and the drop point.

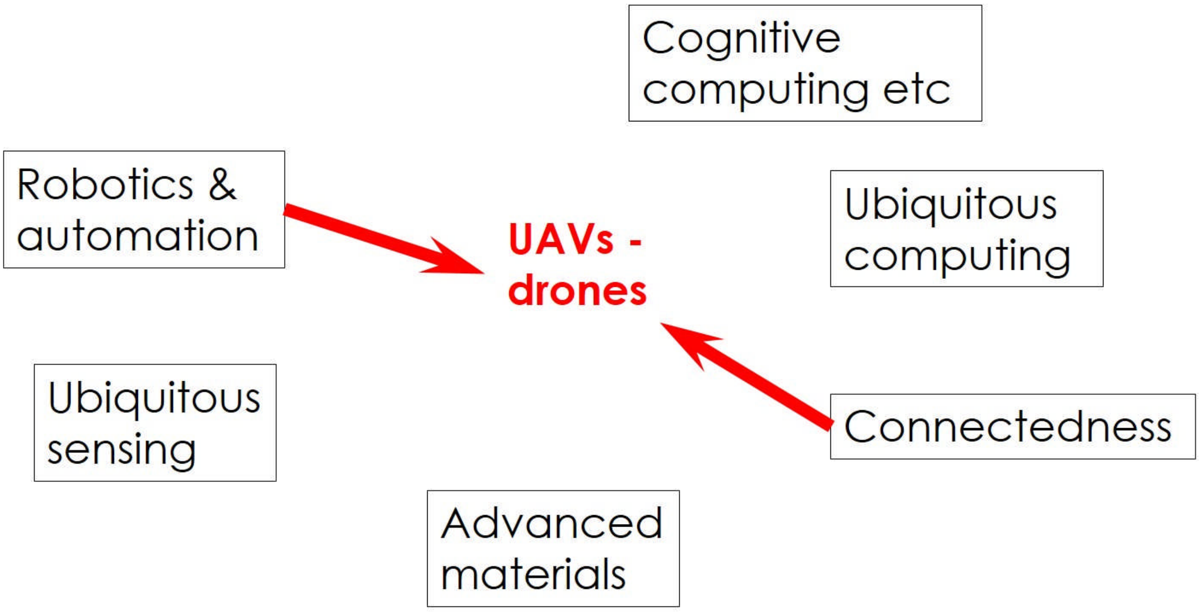

Figure 1: UAVs – drones

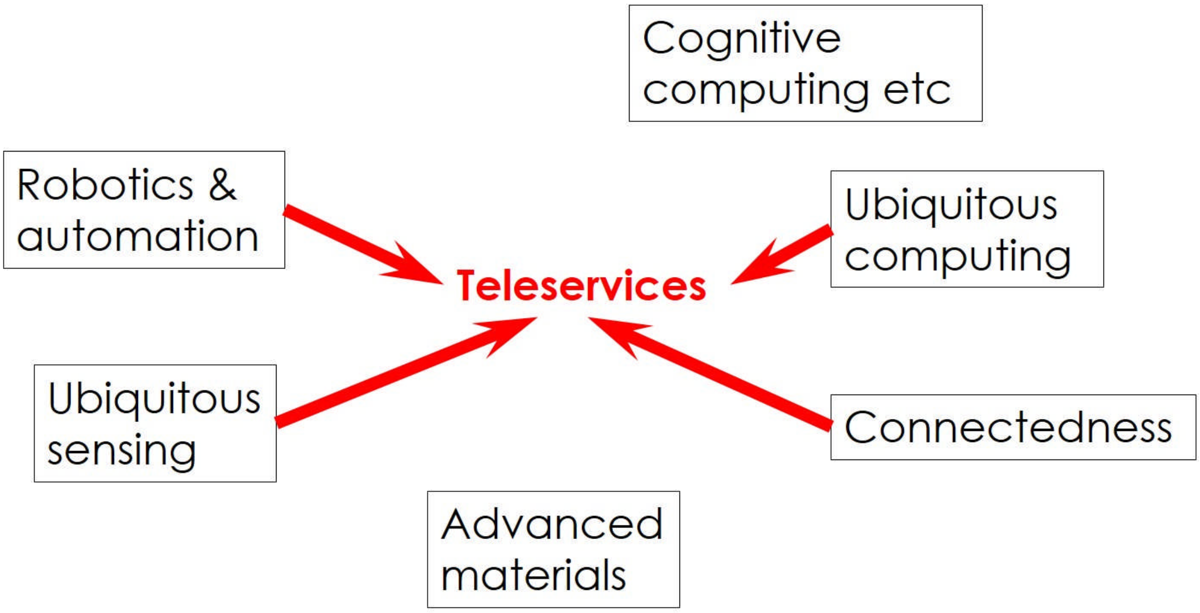

Figure 2: Teleservices

- Teleservices are enabled by the prevalence of computers that can capture and transmit images and sound, and by connectedness which supports the movement of data between correspondents in a speedy and reliable way. More advanced teleservices – telesurgery, for example – relies on the widespread presence of sensors (that provide the surgeon with a range of accurate information about the patient) and robotics (which enable the surgeon to carry out surgical procedures remotely).

These characterisations are not definitive – a claim could be made that UAVs rely cognitive computing, for example – but they help to demonstrate that a small number of fundamental shifts underpins the majority of the developments being discussed in the transport sector. In Sections 3 and 4, tables provide an equivalent set of linkages for each of the advances discussed.

3 Transport technological advances

3.1 Introduction

We begin by spending a short time discussing some of the ways in which a given technological advance may affect the "world" of the transport policy maker and/or city leader. This is set out in Figure 3.

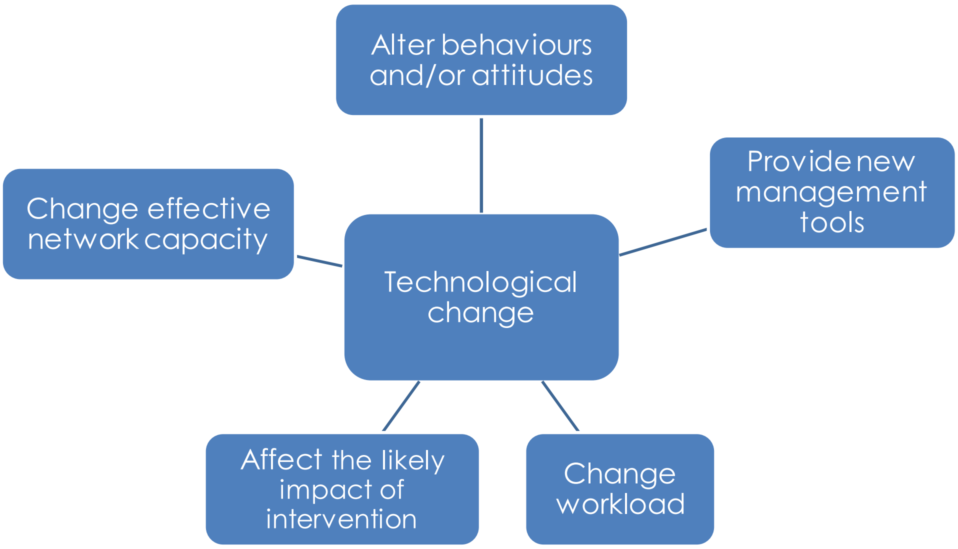

Figure 3: Transport impacts of technological change

One impact that naturally preoccupies policy makers is the possible change in behaviours or attitudes amongst users of the transport network: they may travel more or less or in different ways or at different times; and they may develop new expectations of the system. The complement of this impact area relates to the network: a technological advance may alter its effective capacity, by enabling vehicles to travel less far apart, say. The other impacts in the figure are closer to the policy maker's home: the technological change may provide new management tools. For example, increasing volumes of detailed traffic data (arising from ubiquitous sensing and connectedness) provide transport managers with an ever richer understanding of the network's performance. The change may affect the likely impact of intervention. For example, the effectiveness of messages asking drivers to follow a given route has diminished as they have increasingly relied on proprietary navigation aids (connectedness, ubiquitous computing) that plot an "optimal" route. And they may simply alter the transport manager's workload. For example, the rise of so-called ride-sharing companies such as Uber and Lyft (ubiquitous computing, connectedness) has led to increases in traffic in many major cities.

In this section, we discuss a set of transport technological advances that either already are or are predicted to start having an effect in the short- to medium-term. In each case, we address the following:

- Description
- Current state of development
- "Mature" state (and variants)
- Probability
- Timescale

- Potential benefits
- Potential harms
- Significance
- Governability
- Public acceptability
- Contingencies and interactions

Below, the table links the advances dealt with in this section with the fundamental advances introduced in Section 2.

Table 1: Transport technological advances

	Fundamental technological change					
Transport technological advance	Ubiquitous computing	Ubiquitous sensing	Connectedness	Cognitive computing etc	Robotics & automation	Advanced materials
Automated driving		X	X	X	X	
MaaS	X		X			
UAVs – drones		X	X		X	
Hyperloop						X
Cargo sous terrain						
Smart road pricing	X	X	X			
Dynamic road management		X	X			X

3.2 Automated driving

Title	Automation of the driving task (automated vehicles)
Description	Various connected technologies designed to enable vehicles to carry out the driving task with limited or zero human intervention
Current state of development	Numerous “controlled” trials taking place in various countries including the USA, UK, France, Netherlands, Sweden. These trials are controlled in terms of vehicle speed, driving environment, level of automation being tested, and extent of human involvement.

“Mature” state (and variants)	The “ultimate” form of automation is as described by SAE’s Level 5 – no requirement for human engagement. Level 4 (full automation within a limited spatial domain, e.g. motorway) is also a plausible final stage. It is currently envisaged that the technology would spread to all forms of motorised, land-based transport: private/collective, carrying persons/freight. Major questions remain concerning level of automation, and environments in which operation would be permitted.
Probability	Level 4: **extremely high** Level 5: **high** These estimates reflect both the pace of the technology’s development and the open enthusiasm for the technology expressed by a very wide range of powerful stakeholders.
Timescale	2020-2030 for an operational, useful Level-5 system; 2025-2060 for Level-5 automation to be commonplace
Potential benefits	Safety; accessibility; network capacity; reduced journey time; productive use of travel time
Potential harms	Deteriorating public health; intensifying mobility; sprawl; social fragmentation and/or polarisation; loss of employment
Significance	**Very large**
Governability	**High**: national and urban governments can control the types of technologies permitted, can limit their operation spatially and temporally and can stipulate that particular groups should benefit from automation. But this requires early engagement (because it would be very hard to impose constraints in retrospect) and courage (because the pressure to embrace the technology is fierce).
Public acceptability	Currently **unclear**. Evidence to date is inconclusive and appears unreliable. A better picture is likely to emerge in the next two years (approximately).
Contingencies and interactions	To be a useful technology in urban areas, it relies on segregation from other road users and/or social acceptance that collisions with other vehicle/road user types will occur.

	There is a presumption that such vehicles will be **electrically powered** (though this is not essential to the technology); hence widespread predictions of improved air quality. Various researchers advocate a **shared-ownership** model, arguing that this is essential if the technology's promised benefits are to be enjoyed. At the extreme, low-capacity instances of the technology may be constrained to operate as a first/last mile option, with collective mass transit catering for trunk sections of journeys.

3.3 MaaS

Title	Mobility as a service (MaaS)
Description	The move towards increasingly "seamless" multi-stage journeys through integrated planning, payment and delivery
Current state of development	Elementary MaaS is well established in the form of multi-modal journey planners such as Citymapper and cross-platform smartcards for payment. Recent developments include a blockchain protocol[1] to support ready exchange of service request amongst providers.
"Mature" state (and variants)	The idealised version of MaaS will involve travellers being offered a tailored, door-to-door journey that best matches their needs and preferences, with payment made to a single provider, any interchange taking place smoothly, and adjustments made automatically in response to any incident. MaaS may mature at a point between the status quo and this idealised version.
Probability	Idealised version: **High**
Timescale	2020-2025
Potential benefits	Sustainability (as collective transport is made more attractive and travel consumes less energy in aggregate)

[1] https://travelspirit.io/2018/02/01/tsio-protocol-better-integration-transport-blockchain/

Potential harms	Reducing physical activity (as MaaS provides attractive door-to-door, motorised options for certain trips that might otherwise have involved a walk stage)
Significance	**Medium**
Governability	**Medium**: city governments can lead the way by initiating MaaS and creating the structure into which third parties are invited. Otherwise, this is likely to be market-led; it is not clear that this will deliver outcomes that are as socially desirable.
Public acceptability	**High** – MaaS is perceived as optional and unthreatening. If a given provider became dominant and began to charge accordingly, this may change public attitudes.
Contingencies and interactions	MaaS is conceived as embracing formal and informal collective transport, shared transport (such as car clubs and bike-hire schemes and, in some formulations, private motorised transport. Its ultimate form in a given location will reflect the status of those various components and the willingness of the providers to collaborate.

3.4 UAVs – drones

Title	Unmanned aerial vehicles (UAVs) – "drones" – for transport[2]
Description	Transport of goods and individuals by automated aircraft
Current state of development	Extensive trials and some commitments to operation (e.g. Dubai)
"Mature" state (and variants)	Schemes such as Uber's Elevate present the service as being equivalent to a taxi running on the road but with the advantage of "leaping over" traffic. Amazon's Prime Air indicates it will deliver parcels to customers in nominated drop zones. There is at present considerable doubt what civil aviation authorities will allow in terms of flight paths.
Probability	**Very high**

[2] Drones are already being used extensively in civil applications (such as surveying) and for military purposes. Transport bodies may derive value from using drones to monitor the status of infrastructure that they manage.

Timescale	Next five years
Potential benefits	UAVs could offer safety benefits in enabling the urgent movement of individuals in peril who cannot be reached by more conventional means.
Potential harms	UAVs are possible targets for hacking and have already been involved in numerous near misses with larger aircraft. If extensively used without effective decarbonisation of the powertrain, they can be expected to have a negative environmental effect. There are also concerns about visual intrusion, noise and privacy. And if, as predicted, passenger travel by drone remains the preserve of wealthy elites, the benefits they enjoy in circumventing traffic congestion will exacerbate inequalities of accessibility.
Significance	Medium – likely to remain at most marginal compared with surface transport.
Governability	Medium – jurisdictions can stipulate in some detail what is and is not permitted but authorities are currently struggling with creating successful governance methods[3].
Public acceptability	Probably high at first as the potential personal benefits (of obtaining a parcel very quickly, for example) are perceived. This may change quickly if drones are found to be a nuisance and very quickly in the event of injury resulting from technical fault or crash.
Contingencies and interactions	Drones need to plan and execute their routes successfully, managing any conflicts en route. The technology required is not dissimilar to that of automated (road) vehicles but much less attention has so far been given to whether the aircraft can be relied upon to avoid collisions. "Drops" also require a suitable landing site (or the means to parachute) and this remains a matter of debate.

[3] Examples are the UK Civil Aviation Authority's "drone code" (http://dronesafe.uk/drone-code/) and the European Aviation Safety Agency (EASA)'s drone proposal https://www.easa.europa.eu/document-library/opinions/opinion-012018

3.5 Hyperloop

Title	Hyperloop
Description	High-speed transport of people and goods in capsules travelling through vacuum tubes, using magnetic levitation
Current state of development	Prototype is under construction in USA and various jurisdictions (e.g. Dubai) have formally contracted for its implementation
"Mature" state (and variants)	The top speed is predicted to be 670mph
Probability	The probability that the technology will achieve what is predicted is **high**; whether the model will prove economic is less clear (**medium**).
Timescale	Virgin Hyperloop One (the company leading development of the technology) states that its goal is to have operational systems by 2021. A more conservative estimate would suggest 2025-28 for the completion of a viable intercity service.
Potential benefits	Sustainability (diversion from air travel); economic growth (but also a source of potential harm)
Potential harms	Sustainability (environmental impact of construction and operation); economic loss arising from increased accessibility of rival centres
Significance	**Low** – not expected to affect urban travel to a great extent
Governability	**High** – construction will require planning permission and operation can be subject to regulation
Public acceptability	**Not known** – considerable media attention has prompted interest but the technology's true acceptability will only become clear when the consequences of its construction and operation in urban areas are understood by citizens and other stakeholders
Contingencies and interactions	If placed in tunnel, Hyperloop need not cause significant difficulty but the "stations" would still require land at ground level. Installations on columns would of course be a cause of at least visual intrusion. The impact of Hyperloop on the transport market is more complex: it could be expected to

	disrupt the conventional rail and aviation markets, subject to its cost and capacity. Its affordability to potential travellers is an open question.

3.6 Cargo sous terrain

Title	Underground cargo (Cargo sous terrain)
Description	A network of tunnels through which freight travels on automated vehicles which ascend to/descend from the surface on escalators
Current state of development	A Swiss consortium is raising money and seeking the necessary permissions
“Mature” state (and variants)	The scheme sponsors envisage a network of tunnels beneath and between cities, with freight on pallets/in containers travelling on conveyor belt-type tracks by electromagnetic induction at between 30 and 60 km/h.
Probability	**Medium** – scheme cost is high and the initiative will very likely need to be funded by the private sector which may not feel the potential return is secure or quick enough.
Timescale	The consortium hopes to begin construction in 2023 and complete its first tunnel by 2030
Potential benefits	Such a system could reduce the volume and size of freight vehicles on road with smaller vehicles fulfilling the access/egress trips. This could bring air-quality improvements, reduce carbon emissions, enhance road safety and release highway capacity.
Potential harms	The scheme (if implemented) would require a series of “stations” at surface level which would need to be in central locations in order for the benefits to come about. High levels of traffic could be expected in their vicinity.
Significance	**Low-medium** – a dense network of tunnels could promote a significant movement of freight away from road; a single tunnel might produce an effect at the corridor level.
Governability	**High** – most states have close restrictions on tunnelling.
Public acceptability	**High** (at first) – citizens are unlikely to perceive a problem if they are not negatively affected by construction, the “stations” or associated traffic.

Contingencies and interactions	The capacity to put tunnels under a city will depend on topography, soil and what is already present. As with all developments that may cause reductions in demand on the surface road network there is a risk of a rebound effect.

3.7 Smart road pricing

Title	“Smart” road pricing (SRP)
Description	A system of road pricing that is dynamic and allows authorities to levy charges that differ spatially, temporally and by vehicle type in order to achieve specific policy objectives
Current state of development	The technology to support SRP is generally agreed to exist and, in particular, GNSS-based pricing (where vehicles are charged for the distance driven) has been successfully trialled. But political difficulties have prevented its implementation. One obstacle is that it is almost inevitable that vehicles would need to be fitted with a tracking device in order for such a scheme to work.
“Mature” state (and variants)	The mature form of SRP has vehicles charged dynamically to reflect the presence of congestion and other undesirable transport impacts such as air pollution in such a way that a defined optimum is achieved. It is generally accepted that such a system would be “fiscally neutral”, in that government would not accumulate more revenue than under the pre-scheme arrangements; this would be achieved by scrapping flat taxes such as vehicle excise duty and its equivalents.
Probability	**Medium** – the advent of automated vehicles (AVs) provides a natural opportunity for governments to circumvent the public and political opposition to the installation of tracking devices because AVs are bound to carry such equipment as standard. At a certain point, their installation in manual vehicles could be made compulsory on equity grounds. But the history of road pricing is chequered and fully automated vehicles are not an immediate prospect.
Timescale	The technology is available now; meaningful implementation is probably a minimum of ten years away.

Potential benefits	SRP would, in principle, enable governments (city, state and other) to pursue a wide range of policy objectives relating to congestion, road safety, air pollution, accessibility and transport sustainability in general.
Potential harms	The principal objection to road pricing is that it is regressive (i.e. that is has a larger relative impact on poorer people) though SRP could conceivably be configured using means testing to avoid this. There is a small chance that cities implementing SRP would lose out economically to those that did not adopt such a system but this, again, could be actively managed through the scheme's design.
Significance	**High** – SRP could provide cities with a high level of control over the operation and impact of their transport systems.
Governability	**Low/high** – authorities could have control over any SRP scheme but the problem remains that, up to now, road pricing has proved consistently unpopular with citizens and other stakeholders.
Public acceptability	**Low** – market research suggests that citizens would tolerate a fiscally neutral scheme but all attempts to implement road pricing, however equitably structured, have excited strong opposition
Contingencies and interactions	See remarks above concerning the advent of automated vehicles. SRP could interact with a range of other transport policy measures and in fact is likeliest to be publicly acceptable if pricing income is recycled into other transport services.

3.8 Dynamic road management

Title	Dynamic road management (DRM)
Description	A suite of tools that exploit the prevalence of sensors, ubiquitous computing and increasingly flexible materials to enable transport managers to change dynamically the characteristics of the road and to communicate with users accordingly

Current state of development	Some types of DRM – the tidal-flow lane and speed-activated road signs, for example – have existed for decades. New options are arising on an ongoing basis – dynamic road markings are a relatively new possibility, allowing managers to turn parking "on and off", for example. The most recent technological advances have only been used to a limited extent.
"Mature" state (and variants)	In principle, DRM could evolve to the point where the only fixed items would be the area delimited as highway and immovable items such as tram tracks, lighting columns and power cables. In practice, kerb-lines will remain for the foreseeable future but, beyond this, the road-space could be effectively flexible. It is possible that the take-up of the technology will stop short of this maximal position, with road managers using it in a spatially specific way or to achieve particular goals.
Probability	**High**
Timescale	From now onwards
Potential benefits	Effective use of DRM has the potential to make use of the highway more efficient and to increase its effective capacity. It could contribute to the vitality of urban centres (by promoting a liveable atmosphere) and could help to manage bugbears such as illegal parking and urban congestion.
Potential harms	DRM needs to be implemented with sufficient care to ensure that road users are not confused by changes to configuration of the highway. The effect of DRM could be to reduce the effective cost of private motorised travel, thus prompting a rebound effect in the form of additional driving
Significance	**Low** – unless taken up very extensively, DRM can be expected to have a positive impact in targeted areas.
Governability	**High** – authorities tend to control most aspects of the public highway.
Public acceptability	**Medium** – citizens are likely to be comfortable with the idea of DRM (and they have accepted such forms of it as are already in use); their support is not guaranteed where it is

	used to address behaviours (such as illegal parking) in which they indulge.
Contingencies and interactions	The scope of DRM will widen as highway materials become increasingly capable of showing dynamic laning. The gradual renewal of road surfaces over time will allow the technology to be rolled out across authorities' networks. As vehicles are increasingly fitted with tracking devices, it will become possible to communicate with drivers, providing them with individualised advice (on obtaining a parking space, say).

4 Non-transport technological and other advances

In this section, we turn to advances (technological and other) that are taking place or expected to take place outside the transport sector but which are expected to have some impact on that sector. As with Section 3, we address the following:

- Description
- Current state of development
- "Mature" state (and variants)
- Probability
- Timescale
- Potential benefits
- Potential harms
- Significance
- Governability
- Public acceptability
- Contingencies and interactions

Below, the table links the advances dealt with in this section with the fundamental advances introduced in Section 2.

Table 2: Non-transport advances

	Fundamental technological change					
Advance	Ubiquitous computing	Ubiquitous sensing	Connectedness	Cognitive computing etc	Robotics & automation	Advanced materials
Virtual presence & teleservices	X	X	X		X	
3D printing					X	X
Blockchain	X	X	X			
New/evolving energy systems						X
The sharing economy	X		X			

4.1 Virtual presence & teleservices

Title	Virtual presence & teleservices
Description	A range of connected technologies making audio-visual communication increasingly authentic; the parallel distribution of services (e.g. health) via electronic information and telecommunication technologies
Current state of development	Skype and its equivalents are increasingly used but their deficiencies are well understood. Video-based health consultation is well established in some jurisdictions; more sophisticated interventions such as remote surgery, despite having passed "proof of concept", are less well advanced
"Mature" state (and variants)	In their mature state, the experience for the person interacting with others or receiving a service indistinguishable from that of being in the same location as the service provider. Variants are simply versions based on slightly less reliable communication or less convincing "presence".
Probability	Teleservices are already taking place widely, where the communications technology support them and there is a business case. The probability that they will gradually improve is high though whether they will ever be "as good as being there" is doubtful. An increasing range of remote activities will become possible as technology advances; whether the activities will be extensively practised will depend on savings that can made against in-person services.
Timescale	Now onwards
Potential benefits	In principle, virtual presence and teleservices enable the avoidance of travel. And, as the technology develops, the number of trips made unnecessary can be expected to rise. This may free up space on the network, and could also improve air quality and reduce carbon emissions. Teleservices also have the potential to address disparities of accessibility (resulting from mobility difficulties, remoteness or both) by preventing affected individuals from having to make difficult journeys.

Potential harms	There is a chance of social isolation as people obtain an increasing quantity of "what they want" remotely. Space freed on the transport network could lead to a rebound effect, with greater travel of other kinds expanding to fill the perceived gap. The "digital divide" could create an underclass of individuals who are either unable or unwilling to use this technology and who will receive an inferior service as a result.
Significance	**Low/medium** – the possibility that trips made unnecessary by virtual presence & teleservices will be replaced by other journeys suggests only a slight net decrease in use of the transport network. If teleservices are designed on principles of social equity, explicitly to assist those in greatest need, this will make the impact greater.
Governability	**Low** – the technology enabling virtual presence is not being led by government; most teleservices are planned/delivered outside the transport sector.
Public acceptability	**High** – the proportion of transactions that people are happy to conduct on-line and the extensive use of Skype and equivalents suggests that people are comfortable with the teleservice concept.
Contingencies and interactions	Teleservices depend for their feasibility on high-quality communications and the necessary equipment at both ends of the chain. They also depend for their viability on having a business case.

4.2 3D printing

Title	3D (additive) printing
Description	The creation of solid items through the deposit of successive layers of material, thereby circumventing traditional production processes and enabling small volumes to be produced at minimal notice
Current state of development	The technology is well advanced but its adoption is at an early stage – 3D printers are owned by a small number of

	specialist manufactures. A wide range of items can be manufactured – metal, resin, plastic[4]
"Mature" state (and variants)	One scenario has 3D printers extremely widely distributed – including in private homes – and printing becoming the standard way in which most items are created; a more modest model has 3D printing remaining in the business sector, used for manufacturing in circumstances where it offers a cost saving over conventional methods. In particular, spare parts would be printed to order as part of the repair process.
Probability	**High** (remaining in the business sector); **low** (full societal penetration)
Timescale	**Ten years** (business sector)
Potential benefits	The logistics market may be revolutionised by this development, with far less movement of goods and, instead, the transport of "feedstock" (raw materials used by the printers), meaning a considerable reduction in freight movements; the service sector may also see major change with the number of journeys reducing as spare parts can be printed to order.
Potential harms	The removal of many "trunk haul" trips may be counterbalanced somewhat by a growth in short trips with small loads; the aggregate effect on the transport network is hard to foresee. The transport sector may experience a significant adjustment in response to the above: logistics firms may need to downsize; personal travel may reduce or alter as fewer shopping trips are necessary.
Significance	**Medium**
Governability	**Low** – transport authorities have little leverage over the development or adoption of the technology.
Public acceptability	**High** – citizens will see benefits and few costs to themselves
Contingencies and interactions	The extent to which 3D printing affects transport and other sectors will depend on various factors including the supply

4 There is also the possibility that living tissue will be manipulated using 3D printing.

	of feedstock from which items are made. The variety of feedstock and the means by which it is transported will both help to determine the ultimate impact of this technology on transport systems.

4.3 Blockchain

Title	Blockchain
Description	An anonymised ledger ("distributed database") system which enables multiple actors to collaborate in the provision of a service
Current state of development	Early – various protocols have been created but the current narrative speaks of the potential of blockchain once it has become established
"Mature" state (and variants)	Its mature form will have providers contributing to a collective activity (transporting goods or an individual, say) with minimal negotiation or oversight.
Probability	**Medium/high** – there is confidence that the technology is feasible and that it could prove valuable; at this stage, it is not clear whether it will be taken up with enthusiasm by the transport-delivery sector.
Timescale	Next five years to become a viable tool; a further ten years to realise its potential
Potential benefits	Advocates of blockchain claim that it will make transport transactions quicker, cheaper and more efficient. The user will, it is argued, benefit from a more seamless process of arranging travel and from adjustments being made automatically in real time to overcome hitches (such as one provider not fulfilling its promise). This is claimed also to be true of the logistics sector, which may see savings in cost and efficiency. Blockchain may, in addition, widen the range of components for a journey, by bringing, for example, unused private cars into the choice set.
Potential harms	Concerns have been raised about the possible abuse of blockchain through collusion to keep prices high. Despite

	confidence on the part of blockchain advocates, some are concerned about data security.
Significance	**Low/medium** – if taken up on a large scale by the transport sector, blockchain could have a considerable impact on the nature and cost of transport services and the means by which they are organised.
Governability	**High** – authorities can use regulation to control the development of blockchain and its nature.
Public acceptability	**Unknown** – the technology is as yet unproven. But recent experience of citizens' willingness to share data suggest that blockchain would be accepted if it was seen to offer personal benefits.
Contingencies and interactions	To achieve its potential, blockchain will depend on the transport sector using it consistently. If multiple protocols coexist, this is not likely to prove efficient, which suggests a role for governments in fostering a unified approach. The technology also relies on acceptance of crypto-currency as a payment mechanism.

4.4 New/evolving energy systems

Title	New/evolving energy systems
Description	A set of developments that enable transport to be increasingly powered without use of fossil fuels or with reduced local air pollution
Current state of development	Electric vehicles are commonplace and the batteries are becoming lighter, developing higher capacities and can be charged more quickly; the cost of electric vehicles is gradually falling (though they remain substantially more expensive than ICE vehicles for now). Hydrogen is gaining ground as a viable energy source (either combusted or within a fuel cell) though hydrogen-using vehicles remain expensive.
"Mature" state (and variants)	The "ideal" scenario involves the disappearance of vehicles running on fossil fuels, replaced by battery-electric, mains electric and/or hydrogen, all achieved on a low-carbon basis. A role would also be played by wind and solar power.

	Over the coming fifty years, it is likelier that the proportion of the fleet will continue to run on hydrocarbons, though this proportion will gradually diminish.
Probability	**High** – the technology is developing well and *current* government anti-diesel policy will provide additional impetus.
Timescale	2050 ("ideal" scenario, if it transpires)
Potential benefits	The removal of locally-burnt fossil fuels from the transport sector (or their very significant reduction) promises improved local air quality and (to a lesser extent) reduced transport noise. If the powertrain is *genuinely* decarbonised (see contingencies and interactions), an additional benefit is reduced carbon emissions. Knock-on benefits could include growth in walking and cycling in response to improved local environments (all else being equal).
Potential harms	If it becomes cheaper to drive a non-fossil fuelled vehicle, an increase in mobility can be expected with consequent congestion impacts (assuming mode choice and vehicle occupancy remain similar to current levels).
Significance	**High**
Governability	**High** – authorities can do much to guide this process through regulation and pricing
Public acceptability	**Medium/high** – cars such as the Tesla Model X and Renault Twizy have helped to make electric cars palatable to those who might otherwise see them as a pale shadow of ICE vehicles. Improving local air quality, meanwhile, is *presently* a topic of great societal concern.
Contingencies and interactions	Road freight will be the last part of the transport sector to convert to electricity because of the high power that it demands, though vehicles are emerging in this category. The major question relating to changes in the transport powertrain is how much they actually reduce carbon emissions. The bulk of electricity is still generated from fossil fuels, for example, and the cheapest way of generating hydrogen is from natural gas.

	These concerns are compounded by the fact that batteries are made using rare earths, some of them extracted in controversial conditions. Alongside the moral concerns that this excites are questions of energy security: what if a crucial battery component becomes unavailable because of geo-political changes? An additional factor is the oil and gas lobby which remains powerful and is counteracting government pressure to decarbonise.

4.5 The sharing economy

Title	The sharing economy
Description	An umbrella term for a range of practices: 1. The paid non-overlapping use by qualifying consumers of facilities owned by a third party (e.g. a car club) 2. The paid overlapping use by qualifying consumers of facilities owned by a third party (e.g. a proprietary minibus) 3. Payment to the owner of facilities for sharing their use whilst the owner also uses them (e.g. car-sharing/pooling) 4. Payment to the owner of facilities for sharing their use whilst the owner is *not* using them (e.g. parking space rental) Thus the term "sharing economy" actually describes a variety of economic and social phenomena, some of which are more novel than others (Definition 2 being little more than a "club" version of collective transport). We note that these definitions all imply payment for services rendered; true sharing suggests the absence of a financial transaction (e.g. Streetbank) though this is not being seriously discussed in transport circles.
Current state of development	All of the above mechanisms are well developed in technological terms; their uptake varies significantly though, reflecting levels of understanding, issues of trust and convenience, and social norms.

"Mature" state (and variants)	A widely discussed scenario relating to automated vehicles has us renting "pods" on a per-trip basis, at least in urban centres. This is equivalent to Definition 1 above. It assumes a profound change in societal attitudes to ownership, given that the overwhelming majority of private car use currently takes place in vehicles to which the user has exclusive access. A more realistic, medium-term scenario involves a considerable increase in sharing compared with today but with the owner-user model remaining dominant.
Probability	**High** (realistic, medium-term scenario)
Timescale	2030
Potential benefits	Non overlapping sharing of cars, for example, could free up road space occupied by unused vehicles and may accelerate the renewal of the fleet (as a result of more intensive use), which would bring through manufacturing advances more quickly; it does not offer any definite benefits in terms of congestion or environmental impacts and in fact could exacerbate matters if people transfer from collective transport to a car club or equivalent. Sharing that results in increased simultaneous, collective use of the transport system (e.g. car-sharing or -pooling) achieves efficiency savings on the network, in terms of use of both network capacity and energy.
Potential harms	Though transport authorities may not consider this a cause for concern, sharing that results in high-occupancy, intensive use of vehicles is likely to affect manufacturers negatively.
Significance	**Medium** – the significance depends on the balance across models of sharing. High-occupancy, high-intensity use of vehicles could make a very significant impact on cities.
Governability	**Medium** – authorities can use pricing and regulation to make the various forms of sharing more or less attractive. For example, by giving preferential parking rights to car-club cars, they immediately increase the appeal of this form of transport.
Public acceptability	**Medium/high** – provided they are able to choose whether or not they share, citizens seem increasingly happy to do

	so, though there is a pronounced preference for asynchronous sharing (with some evidence that younger people remain relaxed about synchronous sharing).
Contingencies and interactions	As indicated above, the types and extents of sharing will be a function of the offer – whether the shared option is preferable to one consumed conventionally.

5 Responding to technological change

A perennial part of the narrative in transport has been the imminent arrival of new forms of transport, be that the personal jetpack or a teleportation system. What is different now is the seriousness with which prospects such as drone-based personal transport and automated vehicles are being taken. There is a broad belief that these technologies are really coming rather than the stuff of science fiction.

And this alters the discussion about transport strategy, which used to be developed with the assumption that the available modes of transport would stay broadly the same. Nor is the change limited to the transport sector: developments such as 3D (additive) printing and virtual presence appear likely to change trip patterns too.

All of this adds to the existing anxiety about the future discussed above. When developing strategy is concerned, these technological changes can induce a feeling of powerlessness in cities: "we can't stop the arrival of automated vehicles so we had better simply prepare for them" (as discussed in the glossary). And this is made more complicated by the enthusiasm often expressed for new technology, as neatly described by the term "hype cycle" (see Figure 4, from Gartner (2016), which places "autonomous cars" very close to the peak of the hype cycle for emerging technologies, as of 2016).

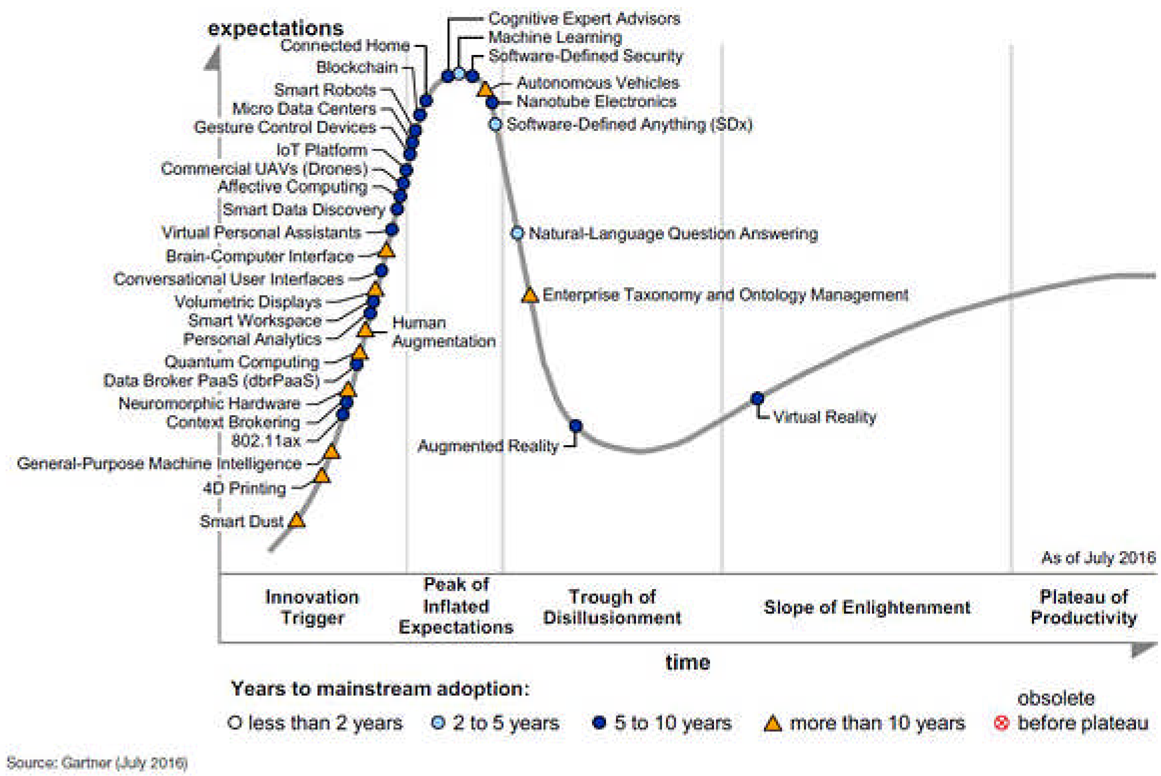

Figure 4: Hype cycle (from Gartner 2016)

Associated with the hype cycle is the role of policy entrepreneurs (Kingdon, 2013): just as technology is not neutral, nor are those discussing it. And many of those involved in the debate concerning technological development have a vested interest in its going a particular way. Policy makers will do well if they manage to find advisers who do not have their own agendas.

The general point to make is that most technological changes will pose some challenges and offer some opportunities. And the message of CREATE with respect to technological change is simple:

- Remain calm and think clearly

- Ask how a given technological advance may assist or obstruct you in achieving your vision
- Consider which policies can help you to get the best out of this technology

We now explore this with two practical examples: automated vehicles and virtual presence.

5.1 The automated vehicle: enjoying the benefits and avoiding the costs

Big claims are made for automated vehicles (AVs): they will dramatically reduce road traffic collisions; they will increase the effective capacity of the highway; they will liberate time currently spent unproductively at the wheel; they will enable people who currently cannot travel to enjoy fuller lives; and so on.

All of these things may be true. But equally negative predictions are also made: AVs will worsen our public health by providing door-to-door motorised transport; they will lead to sprawl as people choose to live further from the centre because journey time is no longer seen as wasted; they will cause a return to a car-dominated world as the demand for speed is met by surrounding roads with guard-railing; they will lead to social isolation and the death of the city as we all spend our time secluded in moving capsules; and so on.

Of course, we cannot know at present which of these caricatures is more accurate. But we can and do know that uncritically welcoming automated vehicles onto our roads would largely remove our control over which future emerges. And, as the development of the car ("horseless carriage") shows us, it is far from straightforward to turn back time once a technology has become embedded.

So we remain calm and we think clearly. And we note that, if we wish to enjoy some of the promised benefits of AVs, we need first to prevent their excessive use and second to guarantee their availability to those who would have most to gain from them, such as people with disabilities who are unable to drive.

We consider a range of policy measures:

- Procuring a fleet of AVs to be run under the city's jurisdiction, providing transport to a defined group who cannot either drive or use conventional public transport
- Stipulating that AVs should operate on a first/last mile basis in conjunction with high-capacity collective transport
- Preventing private ownership of AVs
- Prohibiting empty running of AVs beyond a threshold minimal distance
- Using road pricing to regulate the use of AVs (and, perhaps, other motorised private transport)
- Tightening land-use planning regulations to promote the maintenance of minimum densities, transit-oriented development etc

These alternatives vary in their likely impacts and their technical/political feasibility; they also would be used at different stages in the development and spread of the technology. But the point to emphasise is that it is possible even at this early stage in the AV story to conceive of government interventions that might be expected to influence this technological advance in a positive way. It is also possible to identify those which seem relevant to multiple future AV scenarios. This practice of planning public interventions in advance of the challenges they may be needed to manage would be a case of anticipatory governance (see glossary).

5.2 Virtual presence: possible effects on the transport sector

Over time, humans have gradually increased the extent to which they have been able to interact remotely with their environments and each other. A major leap forward came with the telephone which enabled synchronous, voice-based communication in real time. The arrival of various types of video-conferencing has introduced a visual aspect to this form of communication, thus broadening its application. And the next step, we are told, is virtual presence, with various immersive technologies vying to create the compelling sense that we really are somewhere else. Seeing from afar has already brought significant safety benefits, with drones now being used to investigate and inspect facilities in locations that would pose a threat to human operators. But what has been and will be the more general impact on travel?

We note that this is a different challenge from automated vehicles discussed above. First, we do not expect virtual presence to pose any direct challenges to the operation of the transport network. Second, because it is not a transport technology, per se, those in charge of transport may feel (and may be) removed from any governance required. But transport policy makers are well used to having to deal with the transport consequences of non-transport developments – urbanisation, industrial reform, growing personal wealth, etc. So the need here is to think through the possible behavioural consequences of virtual presence and, from there, the specific transport impacts.

Might virtual presence increase movement? It might, by fostering new connections between people that are then reinforced by face-to-face meetings. But the more common prediction is that it can reduce travel as it makes a variety of journeys less necessary by providing an acceptable alternative to face-to-face contact. As with automated vehicles, we cannot know. But we do know that virtual presence could alter the volume of travel and we could make some educated conjectures concerning the types of travel most likely to be affected (e.g. business trips). We discuss in Deliverable 6.4 the idea of developing multiple future scenarios as an aid to planning; we could make the overall volume of travel a variable taking different values across the scenarios we develop. Then, when considering whether to build the major new heavy rail system in our city, say, we could ask whether it remains viable against our various scenarios relating to volumes of travel.

6 Discussion and recommendations

The examples discussed above help to show that a city's scope to influence/govern potentially important developments will vary greatly – some are far more susceptible to regulation and other forms of government intervention than others. Some of the developments (3D printing, for example) will, in effect, happen to cities. And these are, in general, developments that may alter the overall volume of travel more than its nature. But others are much more governable and offer both opportunities and challenges. The task, then, is to take the opportunities and manage the challenges. In the terms introduced in the glossary, this calls for anticipatory governance. Cities that display either technological determinism or technological fatalism can expect to arrive at a less desirable outcome that those that engage *positively* with emerging technologies. For the avoidance of doubt, this is not the same as attempting to resist the technology. This course of action should only be taken if cities have satisfied themselves that it is preferable to any scenario in which the technology is allowed to operate. Nor is it *precautionary* governance which is based on minimising risk. A city's chosen path may well contain an element of risk; provided this risk has been estimated and the possible benefits considered to merit the risk, this is a justifiable path.

A fuller set of recommendations is provided in D6.4, embracing Work Package 6 as a whole. In this section, we limit ourselves to recommendations flowing directly from the discussion in this deliverable of technological and other changes.

Recommendation 1: Set a well-defined transport/mobility vision for the city

A vision is a picture of the city as its stakeholders wish it to be. This vision can relate exclusively to transport/mobility or have a wider scope. The latter will be better because it will enable transport interventions to be justified in broad terms (e.g. quality of life, welfare) whereas a "transport vision" is likely to frame issues quite narrowly and limit one to interventions that can be expected to address "transport" problems such as congestion. It is essential that any vision is articulated specifically enough to allow one to judge whether progress is being made towards its achievement. This is where many such statements fall down, meriting the description "motherhood and apple pie", meaning that they espouse positive concepts in terms so general as to ensure that no one would disagree. The reality is that transport inevitably involves trade-offs and the vision statement needs to be clear enough to make such trade-offs explicit. Having a pedestrian-friendly town centre is not compatible with an average door-to-door speed of 40kmh (unless there is a comprehensive network of vehicular tunnels!) A vision that claims both will obtain is therefore unrealistic and, more important, unhelpful.

Recommendation 2: Review the interventions available to your city for managing transport/mobility

Cities typically use only a fraction of the interventions available to them. This is partly because of path dependence. And they do not often give much thought in advance to the possible impacts of employing interventions. A "light touch" examination of the full range of measures that cities can employ will remind officers and members of what is possible and may encourage them to expand their horizons.

Recommendation 3: Beware hype and policy entrepreneurs

As we have discussed above, technological advances may offer considerable benefits but they may also pose real threats. The narrative surrounding them, in their early stages, will tend not to reflect this balance; instead, there will be more talk about the benefits than the costs, because of hype (a natural tendency to be excited by novelty) on the one hand, and the role of policy entrepreneurs (people with a vested interest in the adoption of the new technology) on the other. The wise policy maker is alive to both.

Recommendation 4: Investigate methodically what a given technological advance could contribute to the achievement of your vision

This is a keystone of anticipatory governance and will help to ensure that new technologies do not simply "happen to" your city. This task can helpfully be done in the context of future scenarios, dealt with in more detail in D6.4. Either way, the key word is "methodically" and here cities can benefit from work being done at a European level on many relevant technologies[5].

Recommendation 5: Consider experimental measures

The much-admired case of the Stockholm congestion charge started out as a trial. Only after citizens had seen the results of the charge being in place did they vote in a referendum on its permanent adoption. Experimental measures have the advantages that they can be implemented more quickly than "permanent" measures and that they can be reversed. This latter point makes them less controversial.

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[5] European Parliamenary Technology Assessment (http://www.eptanetwork.org/); European Parliament Science and Technology Options Assessment (http://www.europarl.europa.eu/stoa/cms/home/about/panel).

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