Deliverable D3.2 Potential Impact Assessment

STTRIDE

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Issue 4	26/02/2018	Jean Hopkin	Final version accepted by PEB.

CONTENTS

1 EXECUTIVE SUMMARY OF THE FORESIGHT ANALYSIS

This report looks at 10 technology groups in terms of their potential uptake and impact on modal shift in transport.

Overall, the development prospects can be described as fairly strong for all groups, with significant activity and investment already underway and barriers in the innovation system reasonably well understood. Impacts on modal shift are largely indirect, highly uncertain and in some cases mixed between the positive and negative. On balance, experts expect a net positive impact (i.e. a shift away from car use). For those technologies related to vehicle automation there remains some fundamental uncertainty in terms of implementation pathways (cellular vs. dedicated networks) and the long-term positive impacts, which depend on the diffusion of mobility-as-a-service (MaaS) business models.

Overall conclusions related to different types of modal shift are presented in section 4, below. Selected conclusions per technology include:

Advanced fare management and beacon-based ticketing systems have a ‘soft’ impact on modal shift by meeting the user needs ease of use and reduced costs. Barriers are not primarily technological but related to standardization.

Open data and information system integration providing data about both collective and individual transportation is an enabling technology for other services in this group, and thus has an indirect, ‘soft’ impact on modal shift by meeting the user need ease of use. Costs to open data providers are not high but economic benefits are uncertain and accrue in part to private developers and service providers. Organizational issues related to legacy data structures and API development can also be challenging.

Traffic management systems can have a ‘harder’ impact on modal shift by prioritizing road use by public and shared vehicles, and a ‘soft’ impact by meeting the user need of reduced travel time and increased safety. Technological development is still required for real-time adaptive systems, both in terms of data processing capabilities and vehicle-to-infrastructure communications.

Augmented reality technologies can have a ‘soft’ impact on modal shift by meeting the user need ease of use. Displays and interfaces for different environments still need to be developed.

Voice recognition technologies can have a ‘soft’ impact on modal shift by meeting the user need ease of use. The nature and scale of the impact is similar to Augmented Reality.

Vehicle-to-everything (V2X) technologies have a ‘soft’ impact on modal shift by meeting the user needs ease of use and safety. This impact is likely to be negative in the medium-term, as comfort and safety for drivers leads to additional car journeys, but potentially strongly positive in the longer-term, when MaaS scenarios featuring autonomous vehicle fleets could additionally deliver reduced costs and improved journey efficiency. The primary barriers to V2X adoption are first-mover disadvantages, since benefits are tied to network effects. A rapid transition to the positive modal shift scenario is likely dependent on strong policy action and public investment.

Electric vehicles can have a ‘soft’ impact on modal shift by meeting the user needs ease of use and reduced costs as a part of MaaS scenarios featuring autonomous vehicle fleets. In the absence of such a scenario EVs likely have no net impact on modal shift. Current barriers to adoption (upfront costs, range issues) are not expected to persist far into the next decade; roll-out of charging infrastructure will be essential.

High definition (HD) maps and road databases can have a ‘soft’ impact on modal shift, meeting the user need ease of use and reduced costs by accelerating the availability of safe, trusted, effective autonomous vehicle fleets. HD Maps are available today; their inclusion in future MaaS scenarios would require significantly increased investment in keeping information current; updating relating to roadworks may be particularly challenging.

Powering solutions for smart infrastructure are enablers for V2X solutions, and thus have an indirect impact on a MaaS scenario based on the ease of use and reduced costs. There remains great uncertainty about how the infrastructure will be powered in the future and via which business models those solutions will recoup their costs. Some of the most promising technological options (e.g. non-solar energy harvesting) are still in the very early phases of development.

Smart textiles and wearable technologies can help make walking and cycling easier, safer and more efficient. In addition, such devices can increase awareness and leverage growing consciousness of healthy choices, encouraging people to walk and bike more. Barriers today relate to a lack of interoperability between these devices and other systems. In the future connected wearables may create privacy concerns.

2 BACKGROUND AND INTRODUCTION

The strategic objectives of Work Package 3 (WP3) in the STTRIDE project are to:

Identify the enablers and barriers associated with the shortlisted technologies; and
Identify the likely and expected impacts on modal use by those technologies.

To reach these strategic objectives, WP3 has:

1. Conducted a PESTLE (Political, Economic, Societal, Technological, Legal, and Environmental) analysis of each of the shortlisted technologies;
2. Using Foresight Analysis, identified potential impacts based on existing evidence and stakeholder/expert insight and classified these based on scale and mode; and
3. Engaged with selected stakeholders to verify these findings.

In practice, all three objectives were purused simultaneously. As such stakeholder input and verification was an important input to the Foresight Analysis summarised in this document and the summary PESTLE analysis (D3.1). As the exogenous barriers and drivers influencing technology deployment in its wide scale environment identified in the PESTLE analysis were essential to an assessment of the future potential of the technologies, findings from the PESTLE analysis were included in this document where relevant. The Foresight analysis takes the PESTLE results into account in looking at how the drivers and barriers will affect the technology. The two deliverables are best treated as one analysis, with D3.1 serving as a set of summary tables focused on exogenous barriers and drivers. The diagram below summarises the scope of and differences between the PESTLE analysis and the Foresight analysis.

Stage 1 PESTLE Analysis

- What is influencing technology deployment in its wide scale environment?
- Determines exogenous drivers and barriers influencing development of each shortlisted technologies:
  - Political
  - Economic
  - Societal
  - Technological
  - Legal
  - Environmental

Stage 2 Foresight Analysis

- How do the drivers and barriers affect the technology?
- Focused on the prospects for and potential of the technologies
- in terms of deployment and impact on modal shift

2.1 About this document

The document that follows contains two main sections.

- ***Section 3 – Foresight by Technology Group*** examines each of the technology groups in (relative) isolation. This analysis is focused on the prospects for and potential of the technologies in terms of deployment and impact on modal shift. Readers can use this section as a reference on specific technologies, without a need to read it in its entirety.

- ***Section 4 – Conclusions and Implications for Further Research*** examines the technology groups in relation to each other. It summarizes some of the findings from section 3 and presents them in terms of the different types of modal shift to which they may contribute. This section also highlights some conclusions that were not specific to a single technology group. Readers interested in a system-level overview of how these technologies are relevant to modal shift may focus on this section.

Section 2 introduces the methodological approach taken in Section 3, and Sections 5 and 6 are appendices with lists of references and stakeholders consulted. Selected (anonymized) quotes from consulted stakeholders are included in Section 6.

2.2 Overall approach and methodology

2.2.1 Objectives and relation to other STTRIDE analyses

A foresight analysis was undertaken in conjunction with D3.1, a PESTLE analysis of (primarily exogenous) drivers and barriers to the adoption of these innovations. The two analyses are based on the same literature review and stakeholder consultations.

This analysis takes its starting point from the work done in STTRIDE WP2, which assessed user behaviours and needs, which are essential for evaluating the potential impact of the technologies on modal shift. WP2 also defined the technology groups analysed in depth here.

The foresight and PESTLE analyses were based on a literature review and stakeholder consultations (both one-on-one interviews and a workshop held in the UK).

The literature review was focused on ‘grey’ literature rather than scientific/academic publications, as these sources were judged to be more relevant for an assessment of uncertain long-term impacts and the political and social context for the innovations.

Stakeholders consulted included both technology experts and actors with a more ‘systemic’ view; individuals from research, industry, and the public sector were included.

A list of sources and stakeholders consulted can be found in the Appendices.

2.2.2 Components of the technology foresight

Logic maps

For each technology group, a high-level 'logic map' is included to provide a reader with an understanding of how interventions in support of the technologies can generate impacts related to modal shift. Other impacts from these interventions, such as improved safety or personal security, are addressed to the extent that these impact modal shift positively or negatively. Likewise unintended consequences of interventions are highlighted if they are expected to impact modal shift, particularly negatively.

The logic maps are based on the widely established elements of logic modelling for impact assessment and program evaluation. In accordance they attempt to illustrate

- the ***context*** for different stakeholders' interest in the technology;
- potentially relevant ***interventions and inputs*** by public and private sector actors that are needed to support innovation
- the relationship between the short-term ***outputs*** from these interventions and longer-term ***outcomes*** and ***impacts*** at the societal level.

The logic maps, like the text that follows them, are a synthesis of the findings of the literature review and stakeholder consultation. The relationships described are at a general level for an entire technology group and are should be treated as approximate for any specific technology or intervention.

Future market characteristics and potential

For each technology group, the nature of future markets (suppliers and customers, geographical scope, and volume) is described to the extent possible.

Innovation characteristics

For each technology group, the specific development challenges to be resolved and the functioning of the technological innovation system (TIS) are reviewed. The functional analysis of an innovation system is anchored in the literature[1] and involves an assessment of seven different functions related to the development potential of the innovation. These seven functions are:[2]

- ***Guidance of the search***: This function involves the signals and expectations of actors in the innovation system. A positive assessment indicates convergence of the signals (policies, statements, activities) and expectations towards the same direction.
- ***Knowledge development and dissemination***: Knowledge development involves learning activities (e.g. R&D activities, patent-taking) while knowledge dissemination involves the spread of learning through networks.

[1] See Bergek, A. et.al. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, 37(3), 407–429.
[2] See http://www.innovation-system.net/functions/ for a useful summary using slightly different definitions.

- ***Entrepreneurial experimentation***: Involves the translation of knowledge into business through experimentation in a commercial context.
- ***Resource mobilisation***: Involves the allocation of financial and human resources towards the development of the innovation.
- ***Market formation***: Involves actions to facilitate commerce around an innovation, including both incentives and trust-building and market-making activities
- ***Legitimation***: Entails the creation of support in society, and among decision-makers for the innovation. Often in the form of advocacy.
- ***Positive externalities***: Positive externalities may arise when the development of an innovation spills over or has enabling consequences for other desirable innovations or societal goals, thus reinforcing the innovation system in question.

Assessment of impacts (modal shift and secondary)

For each technology group a discussion of the impacts of the technology group is included. These impacts are often highly uncertain and the assessment included is qualitative.

2.2.3 Research questions

The foresight and PESTLE analyses used a set of shared research questions to guide both the literature review and the stakeholder consultations (interviews and workshop). These questions, and the associated search terms for the literature review, follow. (Note that the stakeholder consultations developed tailored interview and discussion questions based on these guiding questions but tailored to the stakeholders engaged.)

Innovation characteristics

- What are the **main challenges and enablers** related to realizing the technology, e.g. cost, performance, reliability, safety, integration, etc.)?
    - Are these challenges and enablers[3] widely understood and agreed by industry, users, regulators, politicians etc.? Is the direction of development well established?
    - What are priority areas for knowledge development (including basic research, patenting, etc.)?
    - What are the channels for knowledge diffusion? (E.g. networks, research fora, etc.)
    - Are there entrepreneurs who are currently developing and/or demonstrating new commercial concepts related to the technology? How robust is this activity?
    - Are their sufficient financial and human resources available to entrepreneurs and researchers working with this technology?

[3] Note that challengers and enablers are not to be confused with the drivers and barriers identified in the PESTLE analysis

- To what extent do markets for the technology already exist, or need to be created? Are there competing technologies?
- Are advocacy coalitions/civil society groups working in support of the technology? In opposition? In support of competing technologies?
- What is the financial investment required for eventual deployment of the mature technology?
- What is the expected timeline for successful development of the technology for transport-relevant use?

Search terms: [Tech-specific terms] + cost, performance, development, milestones, priorities, timelines, investment, patents, networks, entrepreneurs, start-ups, demonstration, prototype, capital, finance, human resources, expertise, markets, lead markets, advocacy, legitimacy

Market characteristics and size

- Who are the likely adopters/investors for the technology (e.g. companies, individuals, public authorities)?
- At what scale (e.g. local, national, international) is the adoption likely to take place?
- What is the market potential of the technology, in terms of share, at the scale above (e.g. winner-take all/dominant; competitive mass-market solution; niche solution)?
- What is the economic size of the market for the technology, given the market size of comparable technologies today and the potential above?

Search terms: [Tech-specific terms] + markets, market size, potential, market growth, users, consumers, investors, deployment, companies, public sector, urban, local, regional, national,

Impact on modal shift and other benefits

- What end user needs related to modal shift that the technology can help meet?
- Does the technology have a 'hard' or 'soft' impact on modal shift?
- Is the technology likely to create secondary environmental, social, or economic benefits (e.g. reduced emissions/pollution; reduced congestion/improved health and well-being; new jobs or productivity increases)? At what scale? Are there any studies/reports on this?

PESTLE Analysis of Enablers and Barriers

- What political positions and policy decisions are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years?
    - At the local/regional level
    - At the national level?
    - At the EU level?
    - Globally?

- What economic developments are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years (e.g. fast/slow growth; increasing/decreasing public sector budgets; profitability of automobile or IT sectors; growth of sharing economy; loss of jobs to automation; etc.)?
- What societal developments are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years (e.g. demographic changes; urbanisation/sprawl; changing values related to environment; changing personal mobility requirements; etc.)?
- What developments related to *other* technologies are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years (e.g. enabling technologies; competing technologies)?
- What legal frameworks and considerations are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years (e.g. related to safety, liability, privacy, intellectual property, etc.)?
- What environmental developments are likely to have an impact (positive or negative) on the technology's prospects in the coming 5-15 years (e.g. weather patterns including extreme weather events and natural disaster risks; environmental health hazards; land availability)?

Search terms: [Tech-specific terms] + politics, policy, policies, regulations, subsidies, incentives, economics, growth, finance, investment, budget, auto industry, sharing economy, automation, employment, unemployment, demographics, population, urbanisation, sprawl, values, green, environment, mobility, [tech-specific technology terms], legal, liability, safety, privacy, privacy, IP, intellectual property, climate change, weather, floods, natural disasters, pollution, hazards, land use.

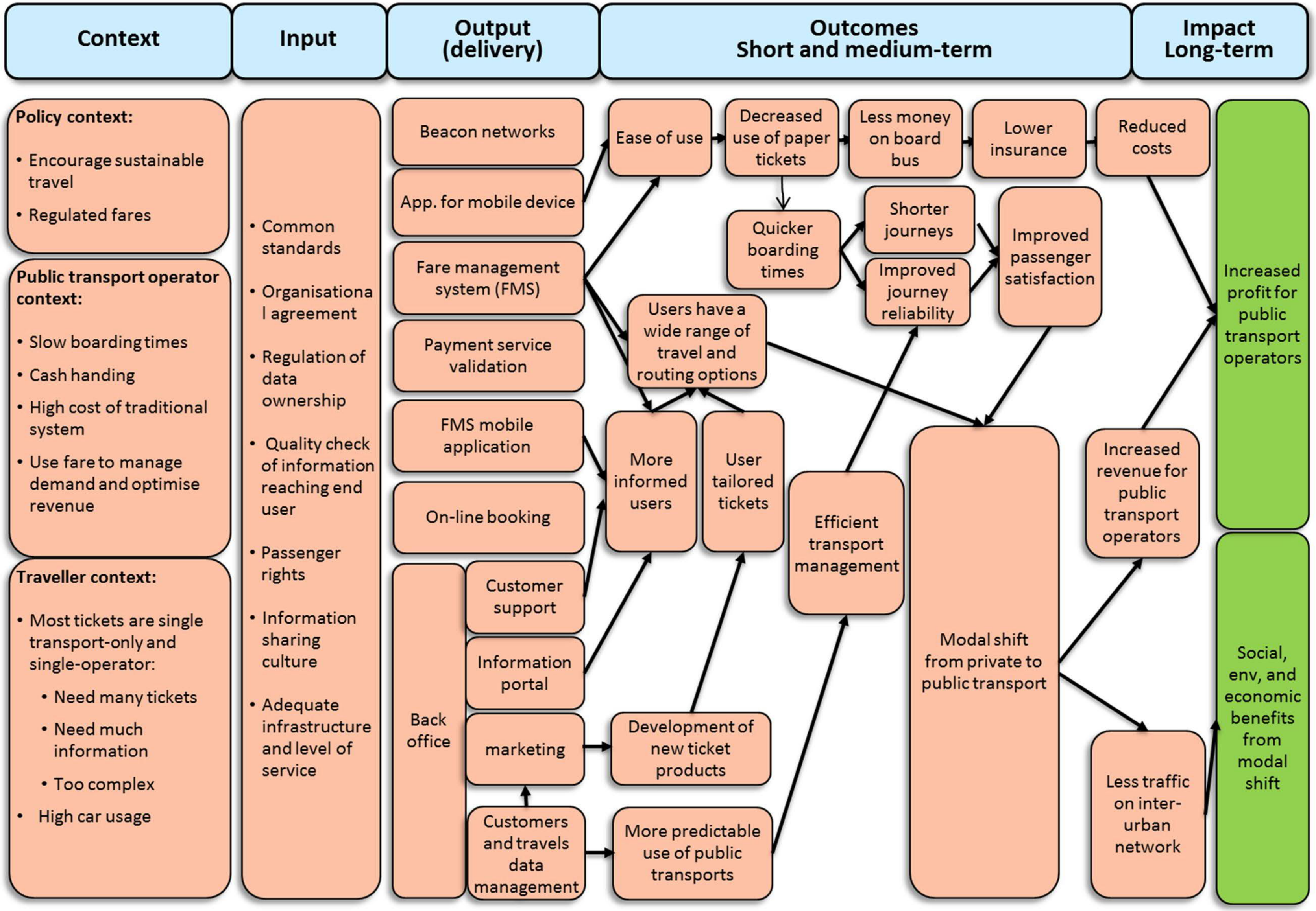
3 FORESIGHT BY TECHNOLOGY GROUP

The following sections present the findings of the foresight analysis on a technology-by-technology basis.

3.1 Advanced fare management and beacon-based ticketing

Advanced fare management systems (AFM) and beacon-based ticketing are likely to impact choice of transport mode by making the use of public transport easier for travellers. Travellers will have simplified access to a wide range of travel and routing options without needing to manage multiple payment options and sometimes without presenting a traditional 'ticket' at all. The efficiency of the service overall will likely be improved as utilisation is optimised and wait times for boarding passengers are reduced, making services even more attractive. The necessary interventions to promote these innovations will likely be taken by public transport operators and will involve data sharing (see also Open Data below) and validation and the development of new service (i.e. ticket) offerings. For inter-urban road networks the impacts will come through greater use of train and bus services whose fares and tickets are transparently integrated with other urban transport offerings.

Figure 1 Logic map for advanced fare management and beacon-based ticketing



3.1.1 Future market characteristics and potential

The ITS public transport market (which includes services such as fleet management systems for routing and scheduling optimisation, real-time information for passengers, intelligent traffic lights and priority schemes for buses and trams) reached €1.35 billion in Europe in 2015 and it is expected to grow to €1.91 billion by 2020.[4] Benefits are expected to outweigh the costs for its development, in particular, among all the services, the highest revenue share is predicted to be generated by ticketing management systems (Research Beam, 2017). Leading countries in the European market are Germany, France, United Kingdom and the Netherlands.

Beacon-based ticketing systems have received a lot of attention in the last couple of years, as demonstrated by the high number of trials performed and in progress. Examples include the bus route 662 between Keighley and Bradford, which was equipped with beacons at about 200 stops as well as on the vehicles, the ‘proof of concept’ project within the Transport for the North’s Integrated and Smart Travel (I&ST) programme, which is planned to function on a ‘Pay As You Go’ basis in West Yorkshire in 2017; and the ‘FutureRailway’ programme in the United Kingdom.

3.1.2 Innovation characteristics

FMS (Fare Management Systems)

The challenges for stakeholders in the development of a national and international advanced fare management system are not mainly technological, but related to the need to reach agreements for cooperation. While may be an understanding at the policy level, at the operator level the technology is not seen to meet short-term goals cost-effectively, and many small transport operators are not yet involved or well-informed. Nonetheless, standards are under development, companies around the world are investing, and where implemented the service has high acceptance among users.

Integration of the various ticketing systems is one of the issues. Due to different utilizations of the shared services, or to different and complex tariff systems which need to be combined, the integration process can be complicated[5,6]. It is also necessary to have standards which cover the different aspects of the ticketing systems. The standards published so far concern data elements (EN 1545), a framework for interoperable ticketing (EN 15320), and a public transport interoperable fare management system architecture and business practices (ISO 24014-1, ISO 24014-2 and 24014-3, which contains complementary concepts to part 1 for multi-application media). Another key factor is to develop and put into practice measures which can guarantee that systems protect the data collected and the privacy of customers.[7]

Various industries in Europe and worldwide are investing in the FMS sector. In Europe, major groups are present in France, UK, Spain, Italy, Germany, Norway and Austria. Public sector organisations are supporting system development, promoting and funding several initiatives in recent years.

[4] (IoT Business News, 2016)
[5] (Beutel, 2016)
[6] (CIVITAS, 2016)
[7] (URBAN ITS EXPERT GROUP, 2013)

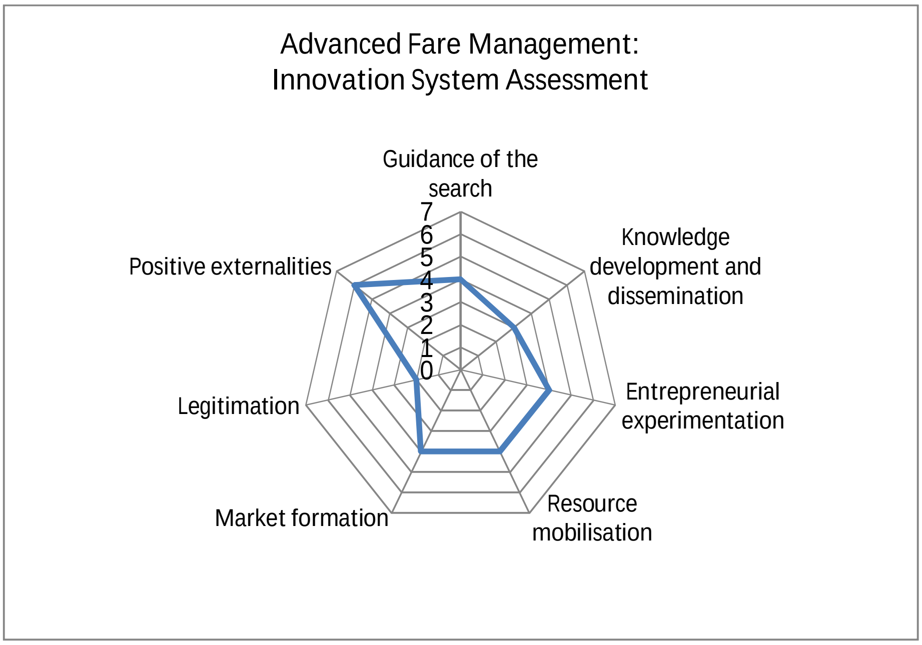
Beacon-based ticketing

Wireless beacons are a mature technology and the Bluetooth Low Energy (BLE) communication standard is currently the commonly technology employed. A number of beacon standards are available on the market; the leaders are Apple's iBeacon, Google's open-source Eddystone, and Radius Networks' AltBeacon open-source standard.

The majority of mobile devices support this technology; however, the software necessary for the use of the beacons is not widely supported by all the operating systems. Devices using Apple iOS, for example, are usually suitable for the use of the technology, but only about the 12% of Android systems and about the 50% of Windows devices support BLE (2016 data). However, the Bluetooth Special Interest Group (SIG; a not-for-profit corporation for the promotion of Bluetooth Technology) expects that more than 90% of Bluetooth-enabled smartphones will support the BLE communication technology by 2018.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (4 out of 7): There is understanding at policy level but at operator level the technology is not seen to meet short term goals cost-effectively
- *Knowledge development and dissemination* (3 out of 7): Fairly clear ideas on technology, necessary arrangements less clear
- *Entrepreneurial experimentation* (4 out of 7): Investment from industry and the public sector
- *Resource mobilisation* (4 out of 7): Standards are under development, companies around the world are investing
- *Market formation* (4 out of 7): PT ITS market growing rapidly
- *Legitimation* (2 out of 7): Challenges in cooperation and integration between companies, but high acceptance among users
- *Positive externalities* (6 out of 7): Reduce operating costs for transport operators and increase revenues; increase attractiveness and access to public transport with knock-on effects for emissions reduction



3.1.3 Assessment of impacts

As concluded in D2.1 (Section 5.1), convenience and ease of use are among the most important factors affecting people's choice of transport mode. Therefore, the availability of door-to-door seamless trips which integrate different modes may increase travel demand (D2.1 Section 3.2.1). In this context, an AFM system is expected to have a significant impact, since makes it easier to access and use public transport; it is expected to attract more customers, especially those who are not used to travelling by public transport.

Another key requirement for travellers is that the journey is cost effective; an AFM system which calculates the cheapest combination of fares could help users to save money and make it clear to them that public transport is more competitive in comparison to the cost of car use. Furthermore, this technology makes it possible to create tailored offers to suit traveller needs, travel patterns or specific user groups. Such a system can use the data collected through the ticketing system to provide information on customers' usage and habits, enabling operators to adapt their services accordingly. On the basis of ticketing data, yield management can be used to optimise transport occupancy and therefore it could potentially reduce overcrowding on public transport; a better service should, in turn, encourage utilisation. Thus, a strategy to invest in advanced fare management could increase revenues for the operators, who would then have further resources to invest in enhancing services.

Some of the major benefits in more people choosing to use public transport instead of private cars are an improvement in air quality and reduction in noise pollution as well.

In addition, AFM systems which integrate the fares and ticketing systems between different areas, regions and countries have the potential to facilitate travel between areas, regions and across borders, generating economic benefits for example by encouraging tourism in Europe.

Beacon-based ticketing

Wireless beacons enable hands-free payments and seamless access to public transport, thanks to the two way communication between the customer's smartphone and the infrastructure. Therefore, this system offers the passenger the advantage of quick boarding, eliminating at the same time one of the possible causes of delay in the journey. It also reduces the inconvenience of complicated tariffs and ticket machines, as well as removing the need to carry an additional document.

Similarly, bicycle sharing schemes can benefit from the technology, in a scenario where wireless beacons are installed on the bike and the customer has access to the bikes and pays for the services simply by being within the communication range of the bike.

Beacons could also provide additional services, such as navigation support around public transport systems for customers who are unfamiliar with the network or visually impaired. Trials have been conducted or are in progress worldwide; for example 500 BLE beacons have been implemented on two lines of buses and trolleybuses in Bucharest; the London Underground trialled a system at Euston in 2015; and the Metropolitan Transportation Authority has run a pilot programme in Los Angeles Union Station.

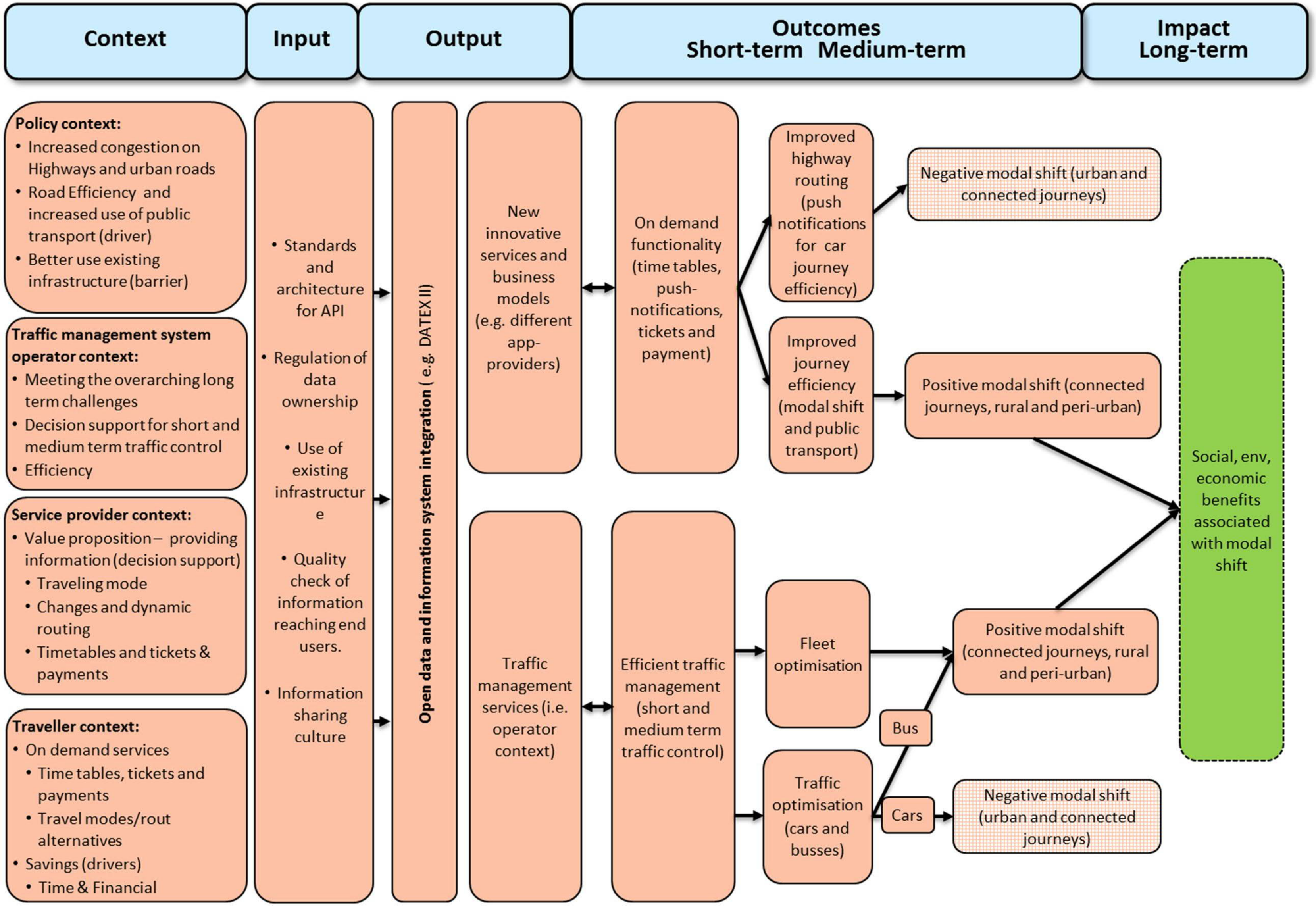
Nature of impact on modal shift (soft-hard 0 to 5 scale): 2

Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 2

3.2 Open data and information system integration

The opening up of transportation-related data sets and integration of data systems impact modal shift in a positive way by making public transportation easier to use in terms of planning, ticketing, and similar functions; by making public transportation journeys more efficient through prioritisation of bus traffic and fleet optimisation; and by enabling mobility-as-a-service (MaaS) models that lead to declining car ownership and increased ride sharing and multi-modal journeys. Slightly negative impacts on modal shift may result from improved highway routing and traffic optimisation, making driving more appealing, but this effect is likely to be smaller than the positive impact. These shifts will follow from the development of new services on both the consumer side and on the traffic management side, and authorities can facilitate them through the development of standards and architecture for APIs, appropriate regulation of data ownership, quality checks on information reaching travellers, and the promotion of an information sharing culture.

Figure 2 Logic map for open data and information system integration



3.2.1 Future market characteristics and potential

Opening data related to transport and mobility is expected to become a vital part of future transport systems: Open data will allow authorities and service providers to chart demand for mobility and enable smarter coordination of increasingly 'on-demand' services that meet these demands. Consequently the range of data that is open – public datasets free for re-use – is expanding, improving in quality, and becoming more dynamic through live feeds that are constantly updated. The increased range and scope of the datasets becoming available makes their coordination more challenging, and can even make it harder to discover and exploit high-value transport data feeds.

In terms of geographic scale, traffic management systems can be designed for local, regional and national use. Maximising the reuse of existing infrastructure will enable the effectuation of the different components of the system. This requires that all components use the same basic infrastructure standards, which is a property of open data systems.

In terms of deployment, the dominant channels through which open data will be exploited will be consumer apps and organisational decision support systems. Both are likely to be developed in large part by private actors.

Open data, or API (Application Programming Interfaces), are needed to realise the emerging Intelligent Mobility market, a sector of the wider transport industry, which is predicted to be worth around £900 billion a year by 2025. Open API enables use of outside calls for data sources by any actors and underlying new innovative services. One such example is the Tom-Tom, using information from the Swedish Trafikverket (e.g. road works, accidents, traffic intensity) in their own algorithm, in order to produces decision support for the driver.[8] Often outside calls for data do not include separate business models. End user usage is rather an asset for extending customer contact/ownership.

Open Data is expanding, improving in quality, and becoming more dynamic through live feeds that are constantly updated. Increased range and scope of datasets becoming available makes future coordination more challenging, and can even make it harder to discover and exploit high-value transport data feeds. The assessment of future demand is thus challenging to anticipate.

3.2.2 Innovation characteristics

Open Data and Information System Integration seeks to provide common and actionable information that helps the public transport and traffic management sectors support the mobility services of tomorrow. While there is no strict definition of open data, the term implies non-exclusivity and reusability in other services.

Open datasets likely to drive the emergence of intelligent mobility and enable modal shift away from cars include: map data; weather; personal location data; network disruptions; planned events; real-time network capacity for people, vehicles & goods; public transport schedules; vehicle location data; fare and pricing data; sentiment data from service users and non-users; third party service usage data; and payment/transaction data.

[8] Söderman, 2016

Traffic management utilising these kinds of data can be divided into three different levels of decision-making.

- Decisions concerning short-term traffic control (i.e. time-frame of a few minutes and with no human action required).
- Decisions on medium-term traffic control (i.e. time-frame of a few hours, implemented in the traffic management systems).
- Decisions made on long-term traffic control (i.e. time-frame of days to years, systems to integrate with human design and planning efforts).

Only short- (and perhaps medium-) term information is needed by travellers, while long-term information is needed by planners and policy makers. Short-term data thus needs to be highly accurate and up-to-date. Medium and long-term data needs primarily to be accurate and reliable. Core features of multi-modal traffic management systems are:

- Traffic signalling control systems
- Motorway management systems
- Incident management systems
- Toll collection systems
- Route guidance systems
- Road monitoring and data gathering systems.

In terms of the economics of implementation, an important requirement is contractual regulation that allows third parties to offer (and charge for) innovative mobility services. Economic viability is greatly increased by data sources reusing existing installations and infrastructure and existing investments can thus be protected by regarding the current infrastructure as a skeleton system in need of an upgrade. Social acceptability of investments is influenced by funding, largely public, and privacy issues.

Stakeholders note that the primary challenges to opening existing data sets are organisational, such as:

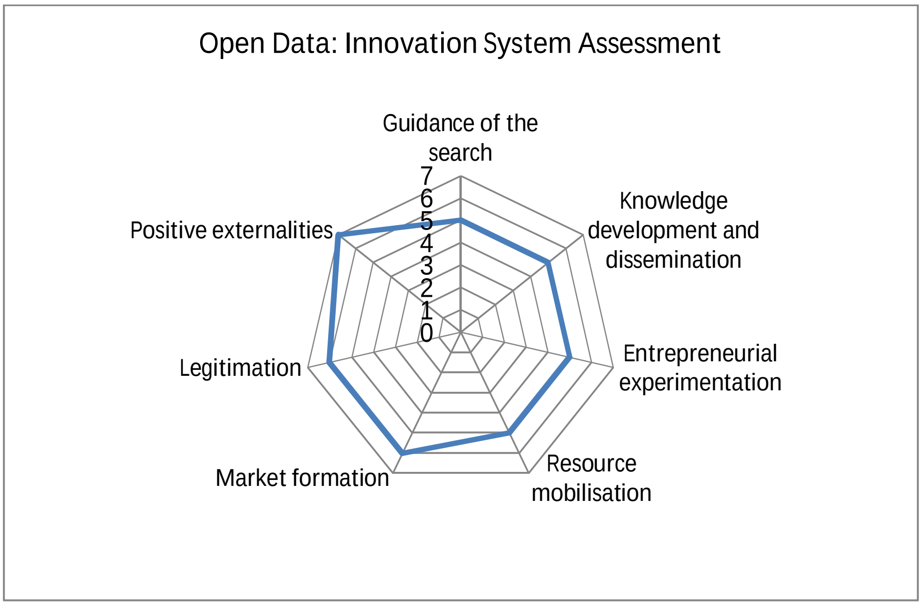
- Organisational anchoring of the decision to open the data source for unknown users
- Organisational silo-ing slowing access by integration and opening initiatives
- Uncertain and hard-to-measure gains to data owners
- Organisational reticence/fears related to quality of data delivered to end-users.

In the long-term, the market for mobility-as-a-service (MaaS) is expected to drive opening and sharing. Public transport firms are so far focused on the digitalization of public transport services and are unsure of the role they will have vis a vis other transport actors, but the interactions are beginning (e.g. discussions with taxi firms on data sharing).

Technological Innovation System: Functional Perspective

- *Guidance of the search* (5 out of 7): Understanding of the importance of and role for open data is growing. Challenges relate to handling distribution challenges (e.g. 4/5G network configurations), as well as organisational culture among data owners.

- *Knowledge development and dissemination* (5 out of 7): Knowledge about how to open data and make use of it is not a major barrier and is developing successfully, with platforms for knowledge and experience exchange playing a significant role.
- *Entrepreneurial experimentation* (5 out of 7): The number of app suppliers of open data for travel information is expanding. Limitations in the data structure (via APIs and API standards) affect the range of innovations that are currently possible.
- *Resource mobilisation* (5 out of 7): This is unlikely to be a barrier for private industry as app development does not require major investment. While the cost to public authorities to open and maintain databases is relatively low, they need to have processes for limiting/prioritizing calls on these databases.
- *Market formation* (6 out of 7): The potential market penetration for open data (for short term use) is well developed. However increased use of data in new and innovative ways requires, among other things, further work on standardisation and integration of data from private actors.
- *Legitimation* (6 out of 7): In general public transport suppliers in Europe work actively with open data for short, medium and long term use. Public transport actors see opening of data as important to meeting social, economic and environmental goals.
- *Positive externalities* (7 out of 7): Open data by its nature generates positive externalities as new ways to utilize the data are discovered.



3.2.3 Assessment of impacts

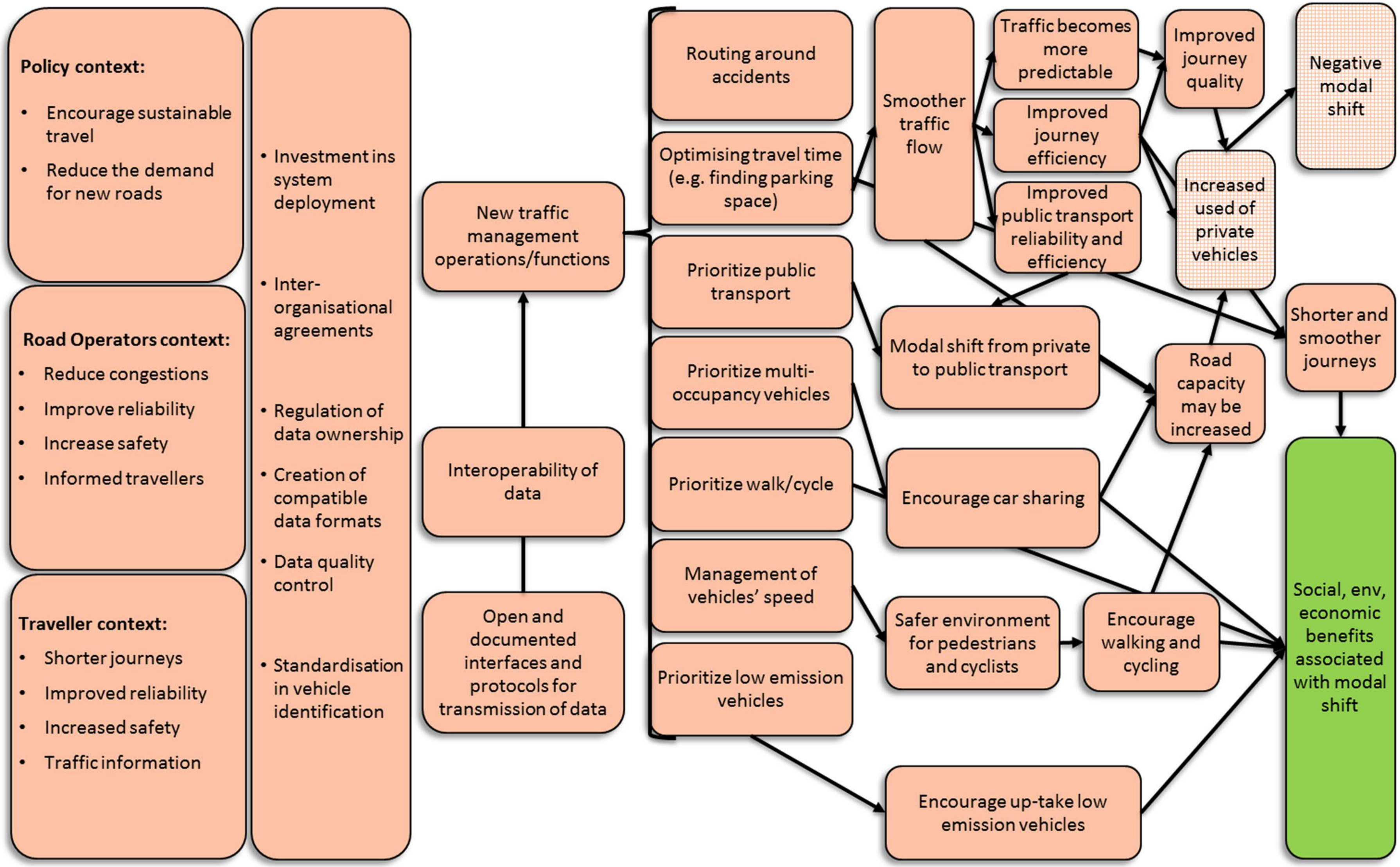
Nature of impact on modal shift (soft-hard 0 to 5 scale): 1. The impact of open data on modal shift is primarily soft. Potential harder impact relates to development of sensors providing data.

Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 1. Open data is likely to drive the emergence of intelligent mobility enabling modal shift from cars. Short (perhaps medium) term highly accurate and up-to-date information will be used by travellers and support short term decisions of modal shifts.

3.3 Traffic management systems

Traffic management systems are primarily tools for managing road utilisation, easing congestion, and optimising the flow of vehicles. Implementing them can create multiple benefits for travellers and the environment, regardless of mode, by smoothing traffic flow and making journeys shorter and more predictable. The impact on modal shift from such measures may be neutral or even negative if private car journeys benefit as much or more than other options. However, these systems also give authorities direct tools for prioritising public-transport, car-sharing, and low-emission vehicles, thus promoting positive modal shift.

Figure 3 Logic map for traffic management systems



3.3.1 Market characteristics and size

Among the ITS systems, advanced traffic management systems (ATMS) have been described as the most successful;[9] ATMS are estimated to have generated more revenue than other ITS road mobility applications in 2015, accounting for a 38% share of revenue.[10] Projections show that the ITS global market is expected to grow at a compound annual growth rate of 11.57% between 2015 and 2020, reaching about $34 billion by 2020, suggesting that the market for ATMS can also be expected to expand.

Although the rate of return on investment may not be clear,[11] a variety of actors are already involved in system development and implementation; the private sector (OEMs, system integrators, service providers, chipset vendors) is investing in R&D, and public authorities are increasingly interested in using these systems to pursue their commitments to improve road traffic efficiency and reduce pollutant emissions. Major players in the European market are located in France, Austria, the Netherlands and Norway.

3.3.2 Innovation characteristics

Strategic traffic management, balancing traffic and minimising congestion across regions, nationally or internationally, requires investment in ITS across the network that is being controlled, as well as integrated wide-area traffic management using real-time information and the exchange of data between traffic control centres. Technological advances have enabled strategic traffic management systems to be developed across regional networks on strategic roads. Going forward traffic monitoring, traffic information systems and traffic control will be increasingly integrated.

The most established traffic management systems disseminate information collected from fixed infrastructure to road users. At a European level, there have been developments to enable data sharing and common formats to enable road operators to harmonise traffic management on key international routes and at major bottlenecks.[12]

Integrated corridor management is a recent concept for traffic management across different organisations, optimising use of motorways and all-purpose arterial roads by managing them together from one operations centre, which in some cases may also carry out public transport management for the corridor.[13]

Recent developments have also taken place in collecting data from vehicles and communicating directly into vehicles and between vehicles to improve traffic management through C-ITS (cooperative ITS); C-ITS relies on communications between vehicles and between vehicles and the infrastructure (whether at the roadside or in the back offices of traffic management centres or other service providers). Despite the fact that standards for communications between vehicles and between vehicles and infrastructure are already available in Europe and that several service providers are present worldwide, various barriers still need to be overcome in order to have a service which can work effectively and available both locally and cross-border. The main challenges can be summarised as follows:

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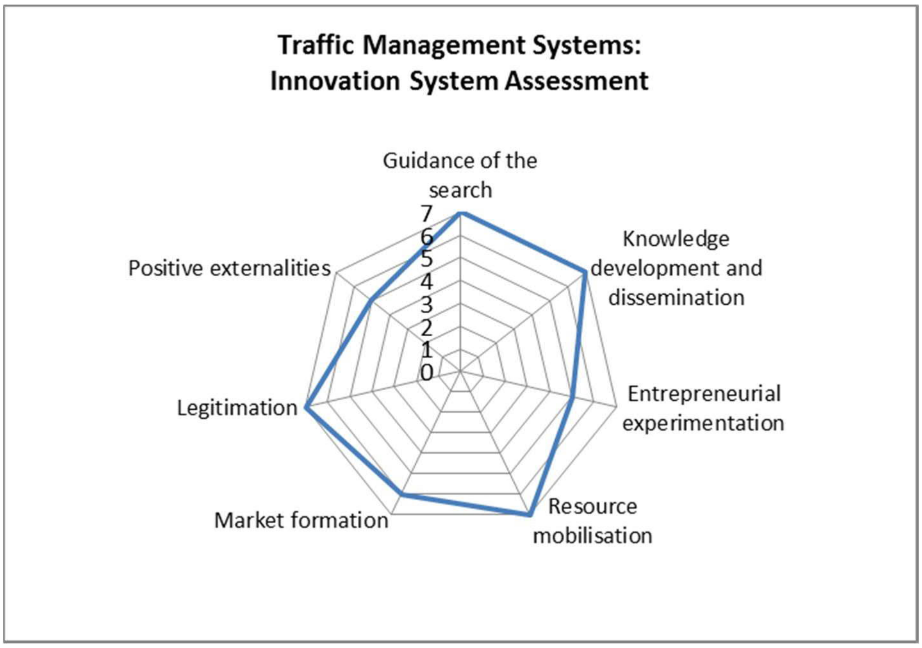
[9] (Market and Markets , 2015)
[10] (BIS Research, 2017)
[11] (Traffic Management 2.0, 2015)
[12] (European ITS Platform, 2015)
[13] (World Road Association, 2015)

- The need for a secure infrastructure for Cooperative Vehicle Data
- A wide mobile network coverage (for cellular data communications)
- Interoperability between systems
- Unique interface standardization for traffic management plan data between vehicles and service providers
- The need for open location data; agreement on how to facilitate data exchange between public-public, public-private and private-private actors
- Agreement on who controls the data and their quality
- Liability agreements
- Development of an international transport system, since ITS is not uniformly developed in all countries yet.[14]

Technological Innovation System: Functional Perspective

- *Guidance of the search* (7 out of 7): There is widely shared agreement on the purpose and role of traffic management systems
- *Knowledge development and dissemination* (7 out of 7): Systems are mature and already widely deployed. Innovation is focused on implementation
- *Entrepreneurial experimentation* (5 out of 7): A broad range of actors of different sizes are active
- *Resource mobilisation* (7 out of 7): There is significant investment (public and private) ongoing
- *Market formation* (6 out of 7): The market for these systems is well-understood and mature
- *Legitimation* (7 out of 7): Systems are widely accepted as necessary to improve services for freight and movement of people
- *Positive externalities* (5 out of 7): Improved road utilisation has multiple positive knock-on effects.

[14] (UNECE, 2012)



3.3.3 Assessment of impacts

Advanced traffic management systems can improve journey quality and experience, increasing road capacity, reducing congestion and improving safety.[15] Less congestion and optimised traffic signal times contribute to improving fuel economy and to reducing pollutant emissions.

Services may promote modal shift. Smoother traffic flow also has impacts on public transport, improving punctuality and reliability and, therefore, making it a more appealing alternative to use of private vehicles. An additional feature could be employing the system for prioritising public transport and shared vehicles.

Social and environmental impacts within the life of this study are likely to be strong given the value created for travellers, traffic management and potentially achieving policy goals: improved information for travellers; increased safety; and efficiency. Impact on the environment stems from modal shift away from cars and better and more efficient use of existing road infrastructure leading to less congestion, decreased noise and emissions.

Nature of impact on modal shift (soft-hard 0 to 5 scale): 4

Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 2

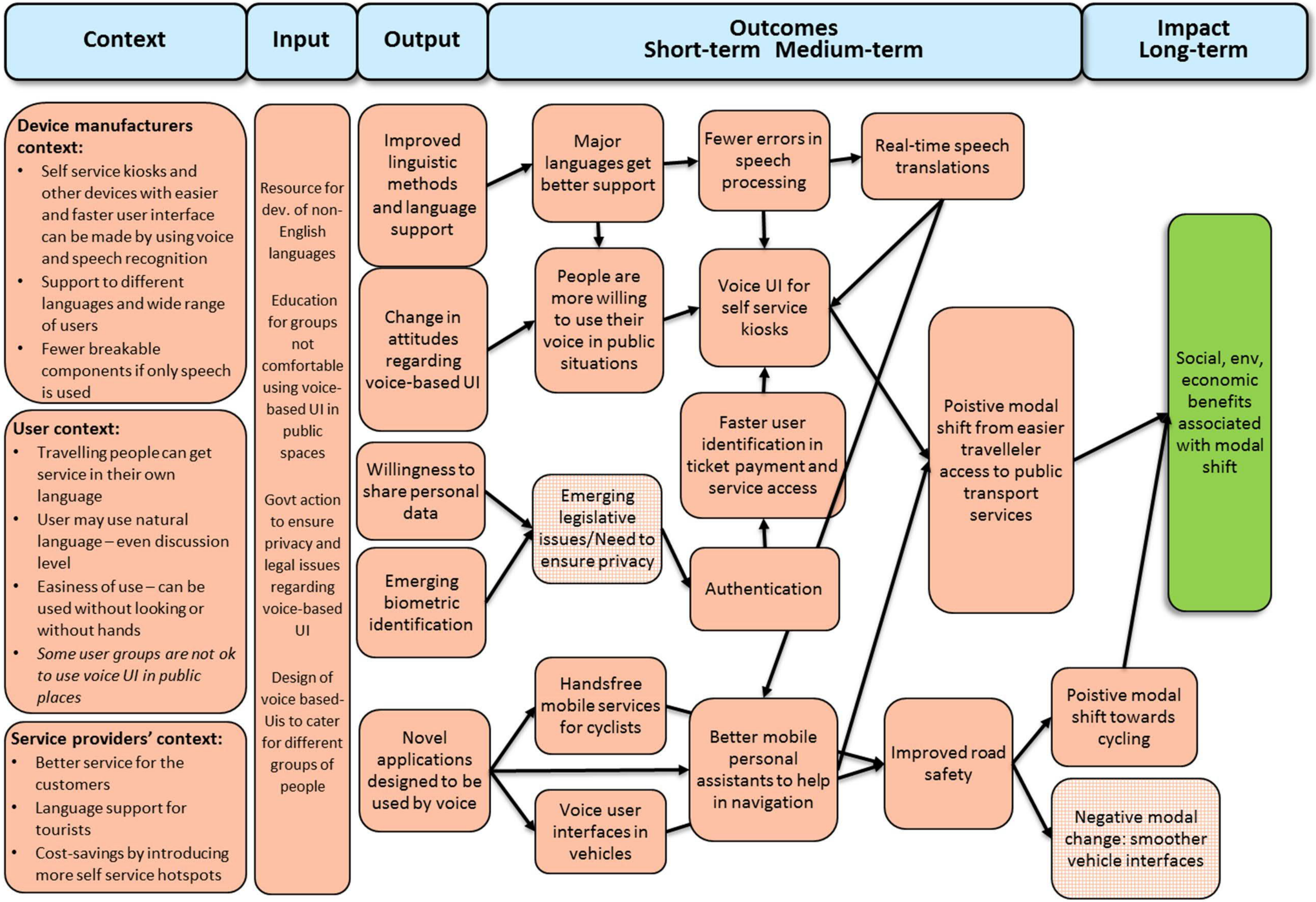
3.4 Voice recognition

Developments in voice recognition technology can have an impact on choice of transport modes via a few different causal chains. Improving linguistic methods, more trusted handling of personal data and integration in transport applications in cars, public transportation environments, and on handheld devices can contribute to travellers' journey efficiency, ease of use, and safety. Positive modal shift from car use to public transport can then follow as users find public transport more user-friendly. Shift from cars to walking and cycling may also be indirectly encouraged through increased road

[15] (TM 2.0, 2016)

safety. Some negative modal shift may be encouraged, however, as voice recognition makes personal car journeys more comfortable for drivers. The overall net contribution to modal shift is expected to be positive.

Figure 4 Logic map for voice recognition



3.4.1 Future market characteristics and potential

Voice recognition is a technology that has taken great strides in the last three years. After years of different approaches, the computing involved has advanced and language and speech can be digitally understood and processed more effectively. Big data, neural networks and statistical methods are able to handle previous weaknesses like language exceptions variations in expression for the same meaning.

Younger users are more likely to use speech-based user interface with their devices, though adoption is also happening (slowly) in the older demographic. At this point user interfaces (UI) tend to be simple, increasing the chance that user intent is misunderstood. Younger users appear more willing to invest in learning how to speak to their devices to get the best possible result.

Deployment will mainly occur via private companies selling know-how and products to other service providers, including public organisations. The voice recognition technology is a software product which must be hosted in a device with processing power, but devices relevant to transportation (dashboards, display screens, vending machines, and handheld devices) are plentiful, so global dissemination will not be a significant barrier.

According to a study on Speech and Voice recognition market by technology, the market for both is expected to grow from USD 4.1 Billion in 2015 to USD 12 Billion by 2022.

Market potential is global, but will occur incrementally across non-English languages. English is a frontrunner in speech recognition and other major languages are following. With smaller or more difficult languages (e.g. Icelandic), global companies may never develop an economic case. Thus public funding is probably needed to cover these situations.

The field will be divided into two different deployment cases. One is a ‘personal assistant’ which usually is used in mobile devices or in a vehicle. Personal assistants will learn the preferences for the user and can be used in different contexts. Another group of technologies is machines which have a speech interface instead of buttons, touchpads, etc., where speech makes interaction with the machine easier and faster. Here the machine sets the context where interaction happens around choices, and there is less need for conversation. In combination with the Internet of Things, speech recognition is projected to be used to control different consumer devices like ovens, thermostats, etc.

3.4.2 Innovation characteristics

The drivers of costs and the focus of technology development are in the development of neural networks, statistical methods and of course more computing power. The processing can be done in the back-end or in the front-end, with the former preferred if the use case allows it.

Technological progress in voice and speech recognition has advanced more rapidly than expected in recent years, a trend that now looks likely to continue as the fundamentals and approach are now established and can be exploited.

Already simple speech and commands can be understood with a low error rate Word error rate in English has dropped from 43 percent in 1995 to 8.5 percent in July 2016. By December 2016 it was already 6.1% and in May 2017, according to Google, it is 4.9%. Among other applications, automated subtitles on YouTube use this technology, with, given acceptable sound quality, almost flawless results. Applications that subtitle real-world conversations for hearing impaired people are currently under discussion.

Speech recognition is expensive to develop, but as software requiring only runtime resources it is very cheap to use.

From the point of view of users, five areas of innovation have been identified in voice recognition:

1. Intimacy
2. Dependability
3. Intelligence
4. Personality
5. Conversation.

Intimacy means that there is a barrier where people feel awkward using voice interaction in public and audible interaction with the device. Younger generations do not feel this as strongly than older generations, but it is slowly changing. This problem may be highly relevant to public transport applications but is more societal than technological and requires time for increased acceptance.

Dependability means that the speech recognition needs to work all the time, every time. Service outages and possible conditions where it could not be used will lower the credibility of the technology.

Intelligence means that the responses the service offer need to be meaningful. Deep down this is not a problem of speech recognition but the service itself. From the users' point of view the fault may still be put on speech recognition technology if the service does not work as intended.

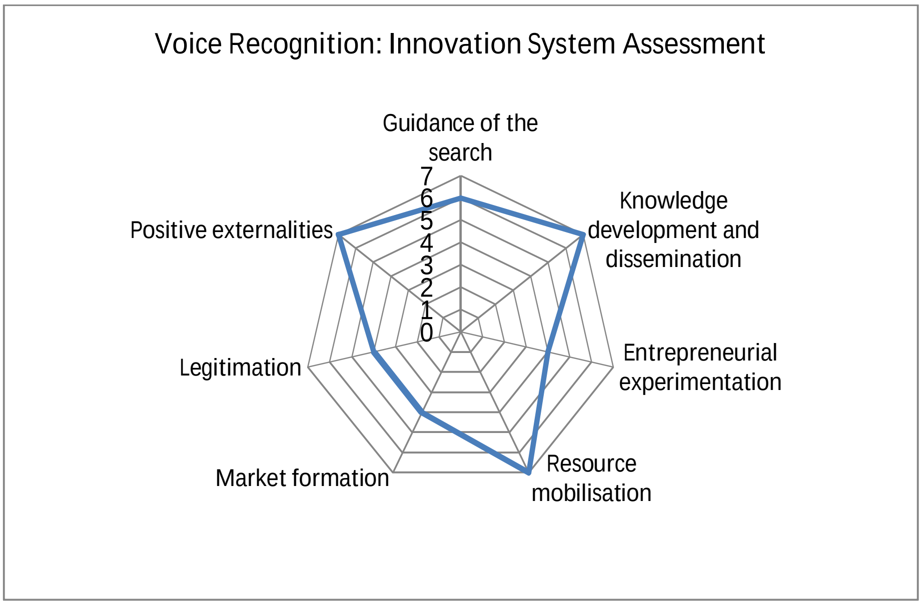
Personality makes interaction with devices and machines easier. Talking to a machine might feel silly to the user, but if the response can be masked behind a “personality” the conversation is more natural and the user feels that there is somebody who is listening. AI-based personal assistants have a name and may have different ways of “speaking” to create a personality.

Conversation means that there should be a possibility to have a conversation in natural language at a level of nuances, double meanings and possibly even sarcasm. This is a big research topic and the timeline for this development is long-term, but in the end this is a holy grail of speech recognition and artificial intelligence.

In the context of wearable devices, speech and voice recognition is envisioned to be one of the key interfaces to devices. The recognition needs to understand the context the user is in and there the wearable devices may help as well.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (6 out of 7): The field and use cases are widely understood, targets are set and private companies are competing. Challenges relate to the development of non-English languages and how they can be served with the same tools that are developed for analysis of English language.
- *Knowledge development and dissemination* (7 out of 7): Algorithm development is happening fast and knowledge is primarily developing in a competitive environment.
- *Entrepreneurial experimentation* (4 out of 7): The domain is dominated by large players and small start-up undergrowth is lacking
- *Resource mobilisation* (7 out of 7): Significant investment is being devoted to perfect English speech recognition. This will continue for some years
- *Market formation* (4 out of 7): Monetization approaches for speech and voice recognition are at an early stage. It is usually envisioned as integrated to different services as an additional feature.
- *Legitimation* (4 out of 7): Legal topics and societal problems related to privacy will likely arise when speech recognition is deployed in more applications.
- *Positive externalities* (7 out of 7): Many novel services can be designed when a speech recognition component is added.



3.4.3 Assessment of impacts

Speech and voice recognition will have both a positive and negative impact on modal shift. In private vehicles navigation is likely to be a strong use case, as navigators have used speech and thus the interface is widely accepted. The car is a private and socially easier place to use voice commands. Thus private car use may be promoted by voice recognition somewhat.

On the other hand, safety will be improved when both drivers and cyclists are able to use voice to handle their devices and touch is not needed. Focus can stay on traffic and ability to steer the vehicle is maintained. Improved road safety may encourage walking and cycling in more contexts.

Digital personal assistants like Siri help people in their need of information and can guide a traveller through a public transport system. Constant observation and quick responses from the personal assistant may help people to react correctly to situations they face during their trip, e.g. when a bus is late or advice when a new ticket is required. The user does not need to know where the information is found but needs to know how to formulate the question for the assistant (this may require practise).

The most positive effect on modal change will be via ease of access to services. Barriers to using machines may get lower as no understanding of different interfaces will be required, even for infrequent users such as tourists.

Nature of impact on modal shift (soft-hard 0 to 5 scale): 1

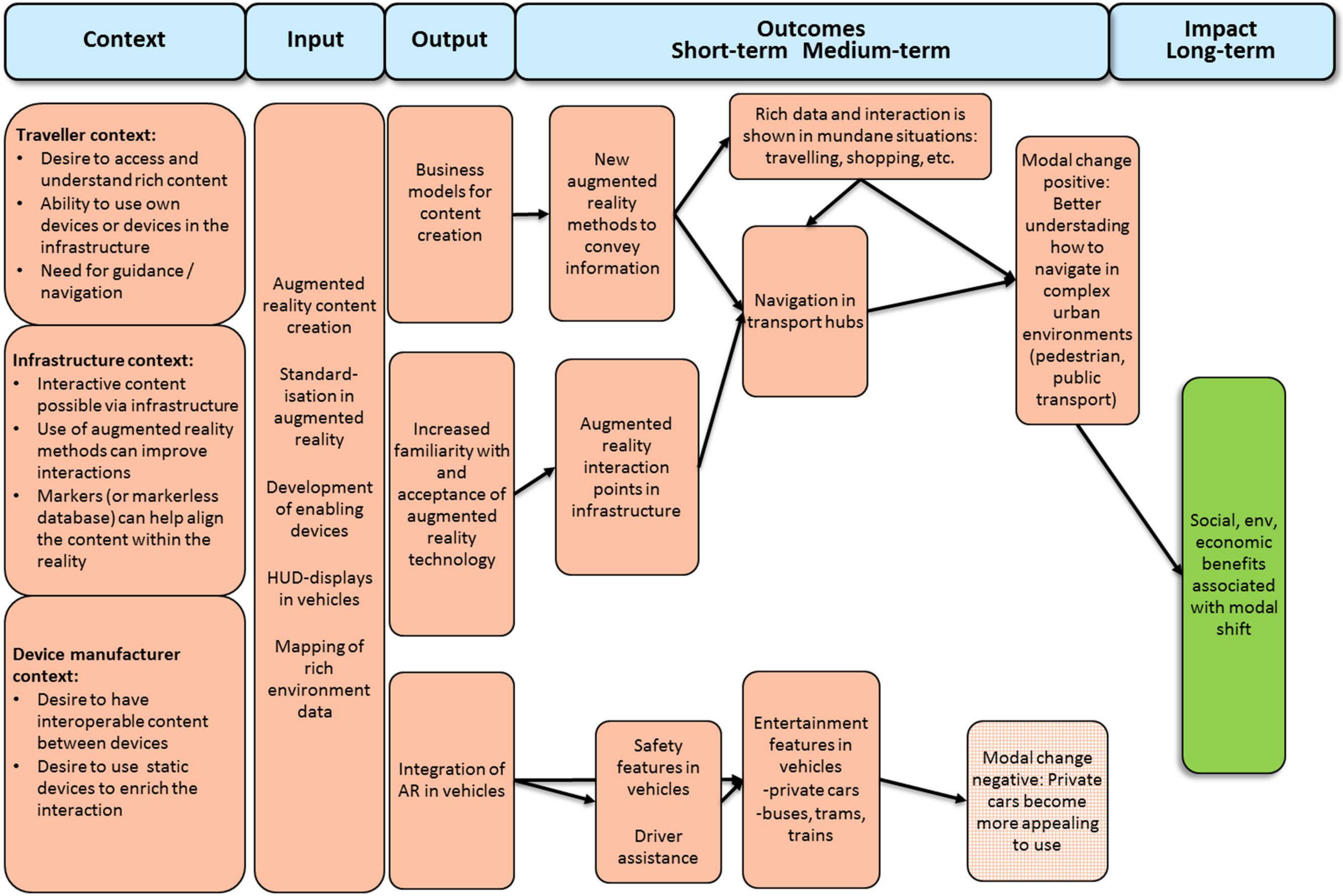
Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 1

3.5 Augmented reality

Developments in augmented reality technology can have a positive impact on choice of transport modes, primarily through the improvement of the user experience of transport hubs and complex urban environments. These technologies can both alleviate difficulties (including for irregular travellers such as tourists or travellers with special needs) as well as improve journey efficiency by communication of otherwise unavailable information about traveller options. These outcomes require increased acceptance of the technology among users and the creation of business models for distributing rich content. Interventions by public authorities and companies should be focused on providing content (i.e. through open data interfaces), standardisation, and integration with new devices.

Augmented reality technology is also likely to be integrated in vehicles, with applications for driver assistance and passenger/driver entertainment. In private cars these may promote 'negative' modal shift by making car journeys more appealing. Similarly, rich entertainment options may make bus and train journeys more attractive.

Figure 5 Logic map for augmented reality



3.5.1 Future market characteristics and potential

Augmented Reality and Virtual Reality are two different technologies, but usually they are considered as one technology group and are predicted to converge somewhat in the 2020s through similar use cases and technological advancement. In a nutshell, virtual reality will block the real world and fill the immersion with digital content. Augmented reality adds digital elements on top of the real world. The market for this technology group is currently led by virtual reality technology where relatively cheap VR-headsets and more expensive amusement park-grade devices are widely sold. In 2016 Augmented Reality took off when the Pokemon GO mobile game was introduced and took the world by storm. The general public is now aware that the technology exists and user acceptance has increased.

AR glasses such as Microsoft Hololens are a novel avenue for augmented reality content. It remains to be seen if a second generation of Google Glass-type devices can penetrate the customer base.

Large companies like Microsoft, Google, Facebook, etc. are spending billions to create augmented and virtual reality devices and services. Google's Magic Leap, Microsoft's Hololens and Facebook's OculusRift are well-known technologies that should feature in the near future of AR and VR. The big names are concentrating on hardware development to get the wow-effect and challenge our view of the world. For example the mobile app Google Tango and its novel 3D scanning of a room have been developed with AR in mind.

Mobile augmented reality is already here in its infancy. It has gained traction through the latest entertainment innovations (Pokemon Go, etc.). AR devices will likely remain focused on using the mobile device lens in the beginning of 2020s. By the mid-2020s AR devices and headsets should be light enough, stylish and able to provide easy and helpful content to users.

The market is developed and driven by private enterprises and it does not need much public sector support. The open data movement and opening of public data for AR use will help as augmented reality is in need of content. The content can be created by private companies, crowdsourced by the users or by accessing public authorities' databases.

The technology itself is a global one which can be replicated everywhere, but the content is always local, so different regions can be expected to advance at different speeds. Bigger, dynamic regions are likely to be pioneers.

In the transport domain, AR is predicted to be applied to driver assistance where the windscreen (for example) can augment information about a driver's surroundings. This might be the first 'futuristic' use in the near future as cars offer a stable environment to develop functionality: cars have the ability to carry more weight and the orientation of the user is fixed.

Via mobile devices, pedestrians and public transport users can utilise augmented reality for navigation: the most important use case in public transportation. Also, user guides for different machines and devices (e.g. ticketing machines) can be augmented to make the interaction easier.

Augmented Reality is forecast to show high growth: by year 2020 the global market is predicted to reach 90 billion USD. Virtual reality sports could be an additional 30 billion market in 2020. The largest share of the market will be for AR hardware, followed by augmented commerce, data, voice, enterprise, theme park, advertising, apps and games.

3.5.2 Innovation characteristics

One of the challenges for AR is to resolve how content will be shown in different situations. Augmented information can be too rich or too poor or it can be shown in a way which is hard to understand. There is ongoing research in this area, but suitability in different cultures and with different user groups may only be apparent at full-scale deployment.

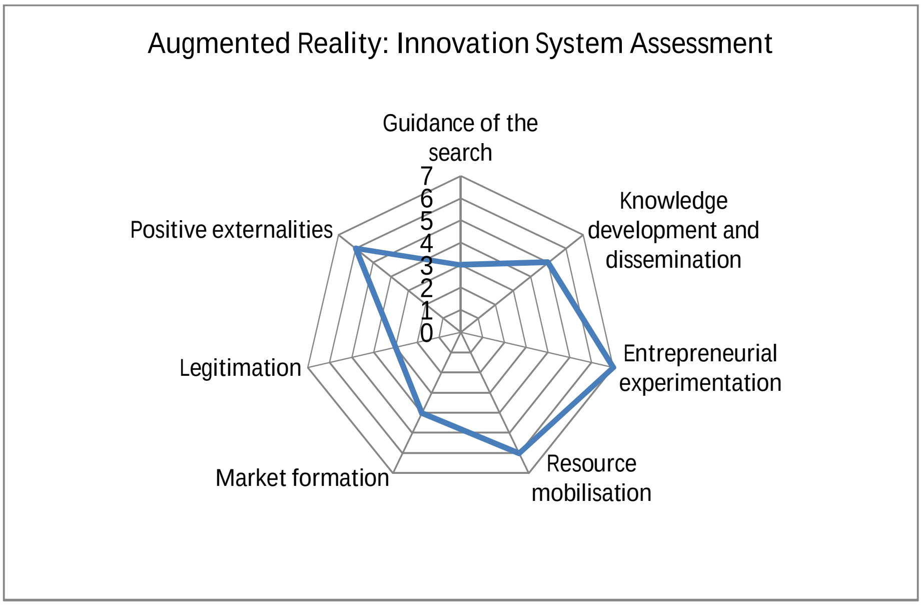
AR technology is cheap to deploy. Markers in infrastructure can be used to improve the accuracy and orientation of AR elements, especially in closed spaces like buildings or transport hubs, though markerless augmented reality is already in use.

Novel AR user interfaces may be important for specific AR devices. For example hand tracking may provide a solution to different real world human-computer interface problems.

The technology will be paid for mostly by the users, who will need (at first) expensive and high-performance devices to execute and display the augmented reality content. The technology is market-driven and emergence will depend on successful use cases. For vehicles, the first-generation upfront costs will be paid for by the car manufacturers, with the expectation that the technology could become a selling point for vehicles in the future.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (3 out of 7): Augmented reality use cases are a mix of speculation and hopes. Real piloted use cases in non-gaming contexts are rare
- *Knowledge development and dissemination* (5 out of 7): Augmented reality as a technology and part of services is an understood concept. The level of technology and processing power behind it is lacking
- *Entrepreneurial experimentation* (7 out of 7): Augmented reality is researched and developed by big companies and small companies and innovation in the field is high
- *Resource mobilisation* (6 out of 7): Investment in development is robust and bolstered by virtual reality development.
- *Market formation* (4 out of 7): Monetization of services which are using augmented reality has not yet had a breakthrough so the market is still forming.
- *Legitimation* (3 out of 7): Society needs to have rules on how augmented reality is used in real world situations and how (especially moving) people are kept safe when their attention might be in the augmented reality service
- *Positive externalities* (6 out of 7): Novel services can be designed when an augmented reality component is added.



3.5.3 Assessment of impacts (modal shift and secondary)

AR can be expected to produce new public transportation users as it addresses one of the biggest user problems – navigation through confusing public transport systems (and indoor navigation).

Big urban areas and especially tourist destinations will be contexts where AR helps users better understand how the system works and avoid intimidation, uncertainty and guessing.

While it may not generate additional car drivers, it may make car travel more comfortable and thus increase car journeys.

When more advanced applications such as high-performing AR glasses with rich information are more widely adopted, human errors in travel may be reduced as systems can track vehicles and paths according to travel plans. Such AR devices will work in situations when the user has both hands occupied. Thus AR devices may encourage cycling.

Nature of impact on modal shift (soft-hard 0 to 5 scale): 1.

Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 1.

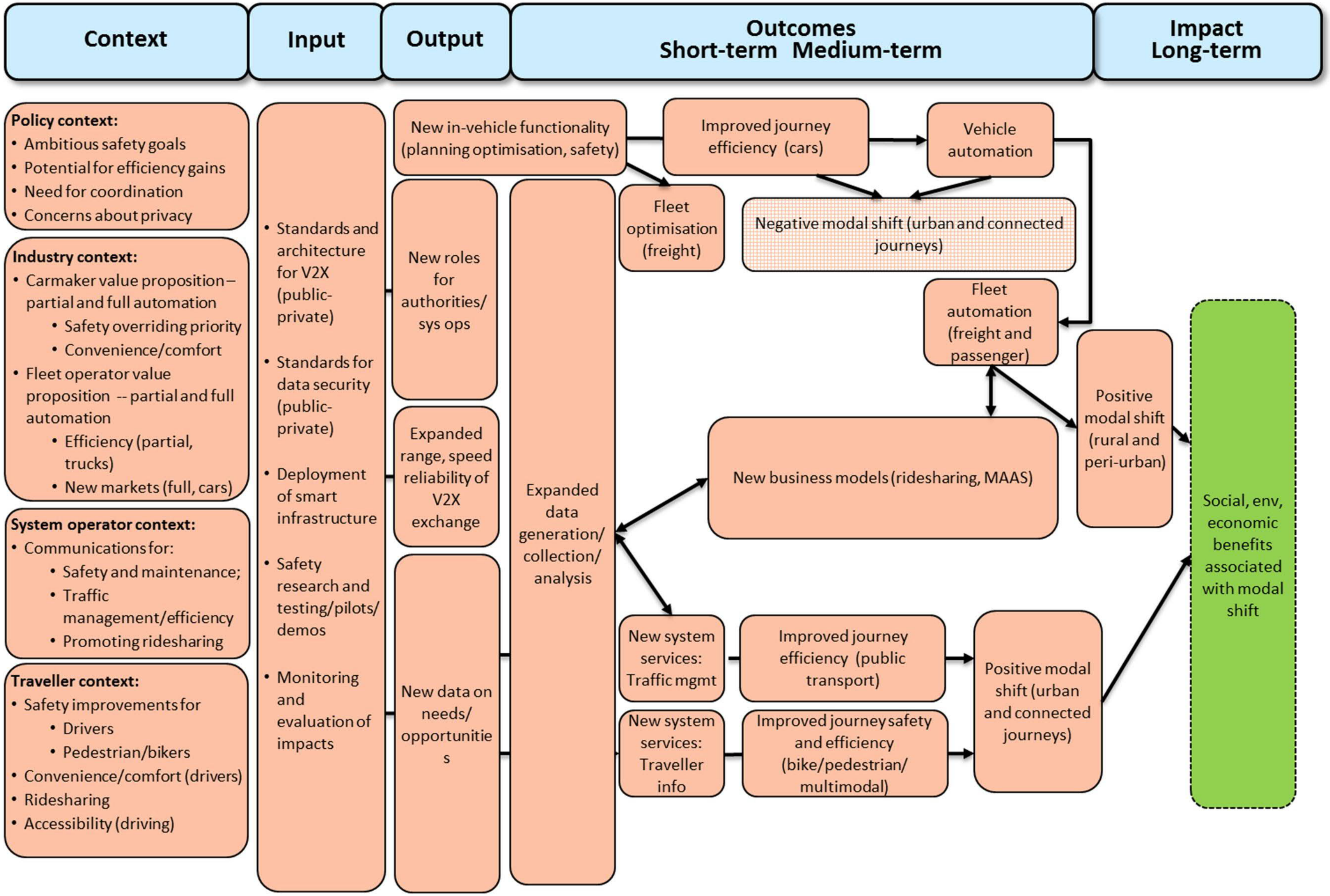
3.6 Vehicle-to-everything (V2X)

Vehicle-to-everything (V2X) communications can impact traveller choice of mode through several channels. First, urban and connected urban/peri-urban/rural journeys can be provided with information about traffic, accidents, and most efficient options in real time, allowing traffic management systems to provide advantages to public and shared options, and potentially encouraging drivers to pursue multi-modal journeys (e.g. via park-and-ride). Second, V2X may be an important part of vehicle automation, both partial and full.

The largest impacts on modal shift will come if automation of passenger vehicles leads to increased ridesharing and mobility-as-a-service (MaaS) models of transportation, whereby fewer persons own their own cars and/or fewer total passenger-miles are required to achieve the same outcomes. Stakeholders consider these developments highly uncertain. A smaller but important impact on modal choice could come through automation of freight vehicles, increasing the amount of efficient door-to-door deliveries and reducing the need for single car occupancy journeys. Finally, on the negative side, vehicle automation may encourage some travellers to use their cars more, as convenience, efficiency and safety are improved. The net impacts from automation are unclear.

In order to promote the necessary innovations, public authorities will contribute to standards development and communications architecture and data security; deploy the smart infrastructure; and participate in testing, piloting, monitoring and evaluation of different technical and data solutions that underpin new business models.

Figure 6 Logic map for vehicle-to-everything (V2X)



3.6.1 Future market characteristics and potential

Future markets for V2X technologies (including those based on Dedicated Short Range Communication (DSRC) and applications using cellular networks) are: light duty vehicles, where the primary drivers are safety, comfort; heavy duty vehicles, where fleet management and efficiency are also important, and road operators, who will deliver the infrastructure-side communications. The initial roll-out of technologies in terms of geography may be quite policy-dependent, especially if technological mandates vary from country to country. Given the global nature of the auto industry, however the relevant scale for these technologies is likely to be global eventually. Implementers on the infrastructure side are likely to be national/regional road authorities, and initial implementation will probably occur in sub-national pilots. For vehicle-side communication and apps, deployment will be dominated by commercial actors, especially automobile companies and their suppliers. For infrastructure-side communications and apps, public financing, procurement and roll-out will be required.

As previously discussed, views on the potential of V2X technologies are somewhat binary, depending on the strength of the policy mandate requiring V2X capabilities in new vehicles. Analysts from the U.S. predict 100% penetration for all vehicles within 15 years if such a mandate is put in place, based on network effects and the likely strength of aftermarket installations. This would be approximately at $5B market. If no such mandate is implemented, industry experts expect a much smaller market (perhaps 10% of all cars) within that time frame, and with the emergence of alternative technologies (e.g. 5G mobile), potentially low or declining growth in DSRC-based systems.

3.6.2 Innovation characteristics

The development timeline for V2X is highly policy-dependent. While car companies are moving rapidly ahead with automation technologies based on sensors and radar, true ‘V2X’ approaches are so far less certain. Part of this relates to questions of technological pathways, as there are potentially multiple ways to send information (DSRC, WiFi, cellular/‘cloud’ solutions) each with its own advantages. In the absence of a strong policy signal there is scepticism from some as to whether V2X will be broadly rolled out at all, as the auto industry can achieve many of its safety and automation objectives through alternatives that it controls. However studies suggest that, given a strong policy mandate, rapid timelines for deployment of DSRC can expected – 1-3 years to market; 3-5 years for critical mass and aftermarket development; and 10 years to saturation. For eventual 5G-based technologies the timelines are not as clear as development and testing is at an earlier stage.

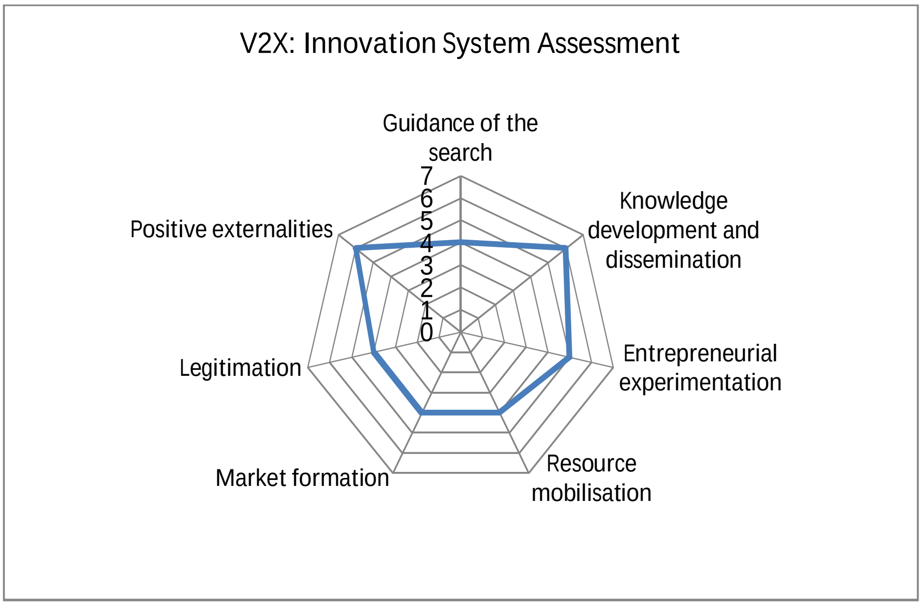
The United States appears to be moving towards a mandate for DSRC technologies in new vehicles, and the relevant EU working groups have been favouring a combination of DSRC and cellular-based technologies to deliver so-called ‘Day 1’ and ‘Day 2’ services. The existing ITS directive 2010/40/EU will allow the Commission to ensure that technology specification is coordinated throughout the EU.

Costs for adoption in vehicles should not present a major hurdle. Initial costs of DSRC technology in new cars estimated at $194 (for the OEM)/$369 (end consumer), but in a rapid adoption scenario, scale should bring manufacturer costs down by 70% within a decade. Costs on the infrastructure side can be large (in the US 300,000 roadside units;

cost to upgrade signal controllers roughly $2000 per unit). Open source development and bundling of apps in a standardized interface can lower pure technology costs.

Technological Innovation System: Functional Perspective

- *Guidance of the search*: 4 out of 7. Standards and mandates are essential. Competing technological pathways can create uncertainty. Carmakers are hesitant to create dependency on infrastructure or the cloud. Standards and coordination can help but mandated deployment may be necessary to get DSRC technologies to market.
- *Knowledge development and dissemination*: 6 out of 7. The necessary know-how exists to roll out DSRC technologies. The potential to use 5G cellular networks is being broadly investigated. Standards are developing; more work is needed to handle the risks of potential obsolescence.
- *Entrepreneurial experimentation*: 5 out of 7. Some relevant technology is already in place on the OEM side.
- *Resource mobilisation*. 4 out of 7. Given the right incentives/market, resources from private industry will be available; for road authorities resources to invest in smart infrastructure will be more difficult.
- *Market formation*. 4 out of 7. Standards will help with market formation but threshold issues can be a challenge – V2X technologies are significantly more valuable when they are broadly deployed than in their initial adoption phase.
- *Legitimation*. 4 out of 7. Acceptance among carmakers is mixed at best, as development based on proprietary technologies is a natural preference. There is also a need to build public acceptance for new safety functions.
- *Positive externalities*. 6 out of 7. There are likely strong synergies between V2X and other onboard technologies.



3.6.3 Assessment of impacts

Nature of impact on modal shift (soft-hard 0 to 5 scale): In the time horizon of this study (15 years), the impact is likely to be primarily soft (**1**), with V2X technologies making driving safer and more convenient. A slightly harder impact (**3**) may come from links to traffic management and prioritisation systems.

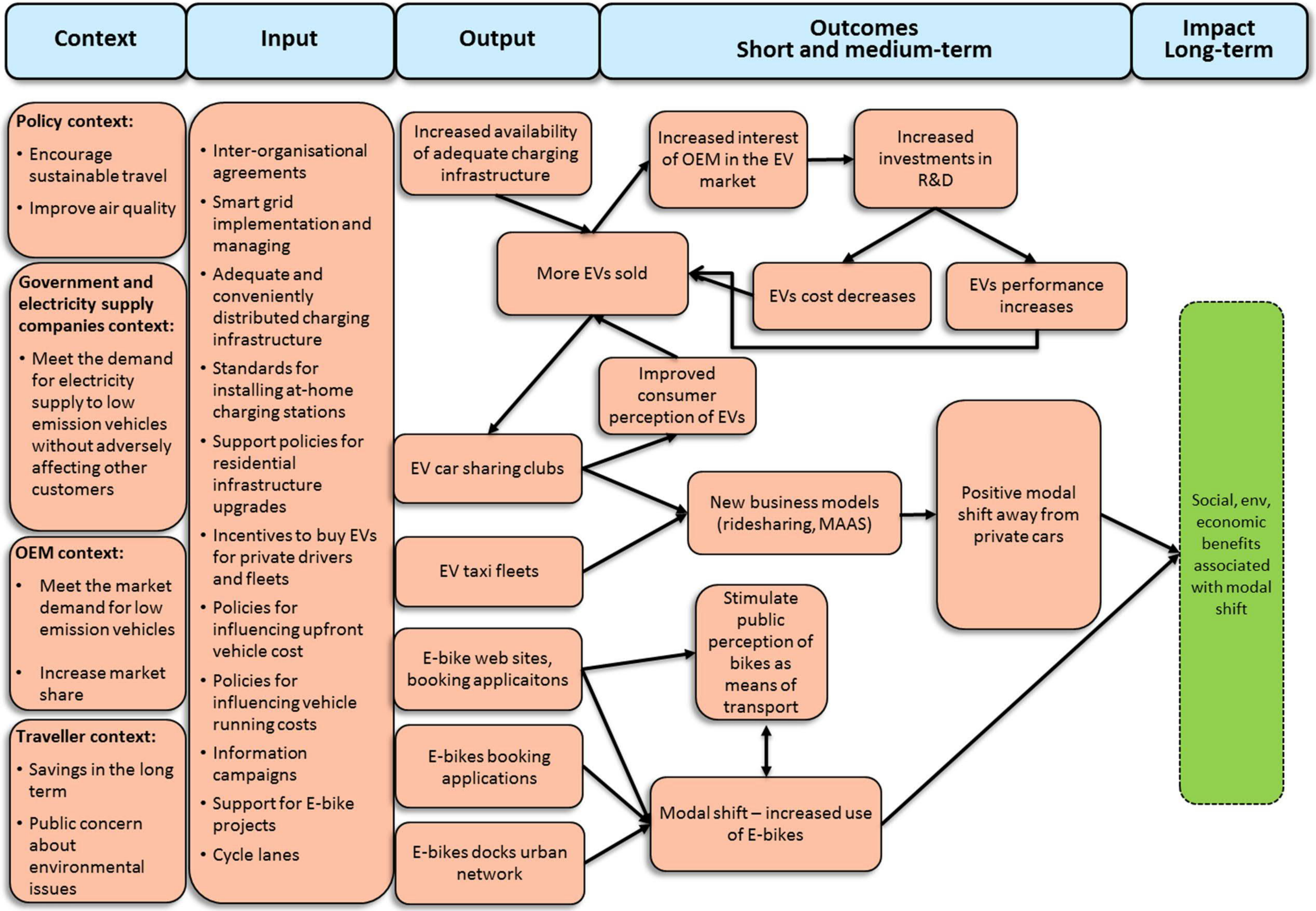
Strength of impact on modal shift (qualitative assessment 0 to 5 scale): The net impact within the timeframe of this study (15 years) is difficult to assess. Some industry analysts believe that the primary effect will be to make driving more safe and comfortable and increase road utilisation. At higher levels of automation the ability to undertake other activities while 'driving' may compound the road utilisation effects as drivers accept longer journey times. While V2X will also support prioritisation of shared/public vehicles, the positive impact of this on modal shift is likely to be smaller. Thus within this timeframe the net positive impact on modal shift is likely to be low (**0**) or even negative. Once full automation is in place, however, self-driving fleets of cars and mobility-as-a-service (MaaS) business models may contribute to a decline in car ownership and fewer cars on the road (**3**). Likewise in the transport of goods large efficiency gains from fleet management may decrease miles travelled, while autonomous delivery systems may decrease the need for private car journeys. Some experts believe that for full automation of this kind to be underway within the timeframe of this study that DSRC systems may be required, as alternative technologies cannot be counted on to deliver the low latency required.

Secondary impact (social, environmental, economic impacts of modal shift). Economic impacts within the life of the study are likely to be strongly positive, given the value created for drivers (through safety and convenience) and road authorities (decreased accidents and improved traffic management). The European Commission has estimated that the overall economic value of vehicle automation in Europe to be in the 'dozens of billions' of Euros per year. Societal and environmental impacts are less certain. Societally V2X may encourage dominance of personal automobile transport and allow for greater population 'sprawl'. Environmentally the effects of increased car travel, especially on national road networks, may be offset by efficiency gains and significantly mitigated by other technologies (EVs, etc.). However an influential scenario analysis by the Institute for Transportation and Development notes that while economic benefits can be captured in a variety of automation scenarios, only those where mobility-as-a-service (MaaS) models become dominant in urban settings can deliver the steep reductions in energy and carbon emissions reductions needed by 2050.

3.7 Electric vehicles

Electric vehicles can promote modal shift away from private car use in two ways: First, the deployment of electric car fleets can go hand-in-hand with the development of car sharing services. Users of these services will typically not need to worry about charging and range issues, as journeys tend to be shorter and charging occurs between uses. For operators of the services the (currently) higher upfront costs of battery-powered cars can be spread over many users, while running and maintenance costs for electric vehicles tend to be lower than for cars with combustion engines. This symbiosis means that broader availability of electric vehicles – promoted by public authorities via procurement, incentives, and the deployment of charging infrastructure – should have an indirect but meaningful impact on the shift from private car ownership to mobility-as-a-service (Maas). Secondly, electric bicycles, which can similarly be promoted via incentives, information, and infrastructure such as cycle lanes and docks, can encourage travellers to increase the use of the bicycles in urban contexts, perhaps increasing demand for multi-modal journeys that use public transport or shared vehicles for inter-urban legs.

Figure 7 Logic map for electric vehicles



3.7.1 Future market characteristics and potential

Stakeholders have clear ideas on the technology and its potential for improving air quality in urban areas and reducing vehicle operating costs; however, EVs are currently hindered by high upfront costs, range anxiety and lack of awareness and understanding on the part of users. There is considerable investment in R&D by the private sector; new operators are entering the field and incumbent companies are expanding their sphere of operations. Governments are also contributing with funding and policy mandates in order to stimulate development.

The market share of new sales in Europe for e-cars was 1.2 % in 2015, representing about 0.15 % of all passenger cars,[16] but prospects for growth are strong. According to a recent study' the potential market size for newly licenced e-cars could reach the 20% in 2030. Electric vehicles are increasingly present in car clubs and sharing fleets, businesses which are arousing an increased commercial interest with new operators entering the field. A secondary impact of these business activities is that they facilitate familiarisation of drivers with electric vehicles; making e-cars easily accessible helps drivers to gain a better understanding of the characteristics and potential of EV technology, making EVs more desirable to a wider audience.

The role of the OEMs in this market scenario is not restricted to the development of the technology; they are also encouraging the uptake of EVs by investing in charging infrastructure. For example, carmakers BMW, Daimler, Porsche, Audi and Ford are collaborating for the deployment of an ultra-fast electric charging station network across Europe.[17] Oil companies are playing a part in supporting the technology adoption as well. For instance, Shell, Eni and Total[18] are installing charging points at some petrol stations in Europe.[19]

Another type of electric vehicle that is attracting attention is the e-bike; interest is growing in the youngest part of the population, among whom e-Mountain Bikes are gaining popularity. In Europe, the sales of electric power-assisted cycles have grown from just under 100,000 in 2006 to 1.36 million in 2015[20]. The value of sales was more than $15.7 billion in 2016 and they have been forecast to grow to $24.4 billion by 2025.[21] The e-bikes market share predicted by Bosch is expected to reach 28% in the first years of the new decade.

It is important to note that European statistics show a correlation between cycling conditions and the size of the market; countries which invested more in facilities for regular cycling have by far the most successful cycling economy. This is the case for example in the Netherlands and Germany, where the e-bikes market recorded 24% and 11.5% growth in 2015, respectively.[22]

[16] (EEA, 2016)
[17] (Wilson, 2016)
[18] (RGN, 2017)
[19] (Ward, 2017)
[20] (CONEBI, 2016)
[21] (Navigant Research , 2016)
[22] (Oortwijn, 2016)

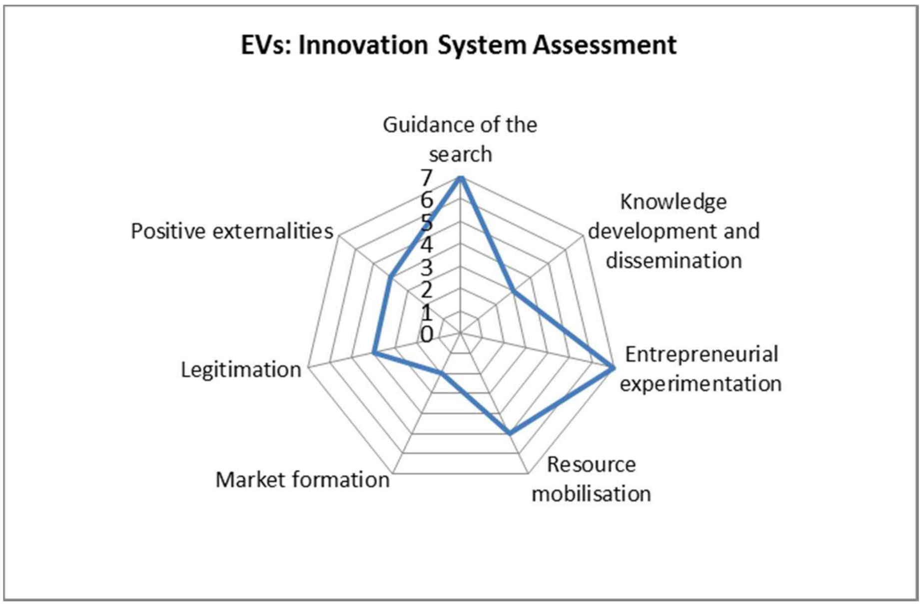
3.7.2 Innovation characteristics

From the point of view of the technology, EVs still present some drawbacks which make them unappealing to most drivers. Though costs are falling, batteries are still quite expensive, contributing to the high upfront cost of cars. The battery range is usually not considered sufficient for all drivers and the charging times are perceived to be too long.

Yet the technology performance is rapidly improving. For example in the last year a few car models with a range of 500 km have appeared on the market. At the Detroit Auto Show in January 2017, Samsung SDI presented its next generation of battery cell, with a range of 600 km. Series production is planned for 2021. Cost-competitiveness between PHEV/BEVs and cars with conventional engines is expected to be achieved during the first years of the next decade.[23]

Technological Innovation System: Functional Perspective

- *Guidance of the search* (4 out of 7): Priorities for innovation are clear. Some debate about the environmental benefits and role in the transport system.
- *Knowledge development and dissemination* (6 out of 7): Strong in technology research, but drivers are less well informed
- *Entrepreneurial experimentation* (5 out of 7): New operators are entering the field and existing companies expanding their sphere of operations
- *Resource mobilisation* (4 out of 7): Some government funding has been marshalled to stimulate development; private industry is investing significantly in R&D
- *Market formation* (4 out of 7): Demand remains relatively low due to customer concerns about costs and range; subsidies/procurement has had a minor impact so far.
- *Legitimation* (4 out of 7): Some debate among policy makers regarding full potential benefits; formerly weak legitimacy within industry is now increasing
- *Positive externalities* (6 out of 7): Improving battery technologies for transport are likely to impact the broader economy (power sector, electronics, etc.)



[23] (IEA, 2016)

The total investment in research and development projects in Europe for e-cars is estimated to be about €196 million, of which about 83% is funded by the EU.[24]

The target market penetration for electric cars in EVI Countries[25] is 1.7% of the market share by 2020, corresponding to 20 million electric cars. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action set a target of 100 million e-cars on the roads by 2030.

To support this expansion of the market, the EU issued a directive on the deployment of alternative fuels infrastructure (2014/94/EU) according to which member countries had to define electric charging point deployment targets for 2020. The plan is to deploy 8 million charging station across Europe by 2020, with at least 10% of them accessible for public use. Globally 300 million charging stations are expected to be required in the 488 cities with populations of more than one million by 2030; this figure implies a €3.7 trillion investment, of which €30 billion would be in four major European cities (London, Paris, Frankfurt and Milan).[26]

Despite the fact that e-bicycle technology is well developed[27] and various industries from different sectors, such as motorcycle companies and appliances components manufacturers have started to produce engines and components,[28] widespread use has been held back because of the relatively high cost compared with conventional vehicles.

Encouraging the uptake of e-bicycles through public financial support has proven to be a cost-effective way to reduce road transport carbon emissions; however not many countries have used financial incentives.[29] Sharing systems are effective for promoting the adoption of e-bicycles, to such an extent that bike manufacturers are investing in hire schemes, such as Movelo in Austria/Germany/Italy.

3.7.3 Assessment of impacts

E-car clubs and e-car sharing schemes offer a new model of urban mobility and an alternative to private car ownership; they are also an effective way of promoting the widespread use of e-cars. They not only reduce the burden of the costs of owning a car, but they also help to reduce overall car dependency, and, consequently, making more parking spaces available and freeing up road capacity. Electric car fleets for hire or for sharing contribute to better air quality in busy environments.

A Norwegian study showed that e-bikes are a promising tool for promoting the use of the bike.[30] In particular, shared e-bikes can attract new riders as demonstrated by the Shared Electric Bike Programme in England;[31] thanks to this experience, 15% of users bought an e-bike, and up to 80% said that they would consider it. Another example comes from Berlin, where 324 commuters were lent e-bikes for eight weeks and, after

[24] (ICCT, 2016)
[25] The EVI is a multi-government policy forum established in 2009 under the Clean Energy Ministerial (Canada, China, France, Germany, India, Italy, Japan, Korea, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, the United Kingdom and the United States)
[26] (Alix Partner, 2016)
[27] (ECF, 2016)
[28] (CONEBI, 2016)
[29] (ECF, 2017)
[30] (Fyhri, 2017)
[31] (Bikeplus, 2016)

the trial, about 50% of the participants changed habits and prioritised e-bike trips over car journeys.[32]

The change of attitude facilitated by share schemes is due to the easy opportunity they offer for trying a vehicle without commitment, thus giving people the chance to consider the e-bike as a regular means of transport. This also applies to people who are not fit enough to cycle or ride a standard bike. They also encourage cycling for longer distances and in hilly areas.

In addition to reducing ICE vehicles and therefore tail pipe emissions, e-bikes support a healthy lifestyle and improve well-being. E-bikes also help the ageing population to stay active, improving both physical and mental health. This is, for example, the conclusion of the cycle BOOM study which ran in the UK from 2013 to 2016.[33]

Nature of impact on modal shift (soft-hard 0 to 5 scale): 1

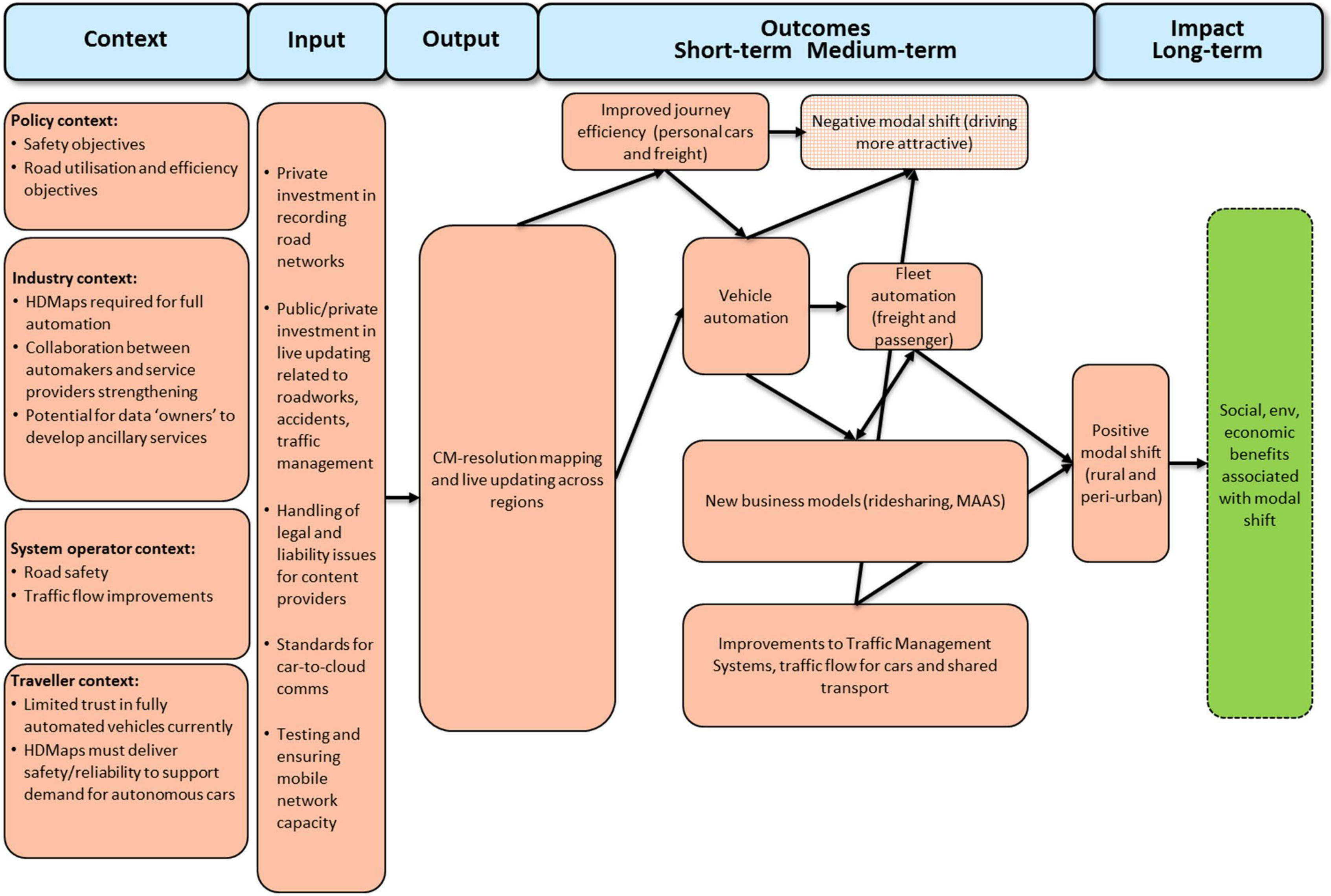
Strength of impact on modal shift (qualitative assessment 0 to 5 scale): 2

3.8 HD-maps and road databases

High definition maps and road databases can have an impact on choice of transport mode primarily through their contribution to vehicle automation, and thereby, through the potential to develop automated ride-sharing and mobility-as-a-service (MaaS) solutions. Once full automation is in place, self-driving fleets of cars and mobility-as-a-service (MaaS) business models may contribute to a decline in car ownership and fewer cars on the road. Likewise in the transport of goods large efficiency gains from fleet management may decrease miles travelled, while autonomous delivery systems may decrease the need for private car journeys.

[32] (Carplus, 2015)
[33] (cycleBOOM, 2016)

Figure 8 Logic map for HD-maps and road databases



3.8.1 Future market characteristics and potential

HD-maps are currently utilised in applications for improved decision making and planning and support services for traffic and public transport management. However, the future development of high-definition maps and road databases will be to a large extent shaped by the needs of increasingly autonomous vehicles. Self-driving vehicles require maps that differ in several important ways from the maps we use today for our turn-by-turn directions. Single-meter resolution maps may be good enough for GPS-based navigation, but autonomous vehicles will need maps that can tell them where the curb is to the nearest few centimetres.

Autonomous vehicles are already on in the streets, but only in test and demo settings in Europe, US and China, among others. When driverless vehicles will be a common feature of traffic is uncertain, but current cars in general are already becoming more and more autonomous, with e.g. adaptive cruise control, assisted parallel parking and active object identification support. However, none of current features for autonomous vehicles rely on live updated HD-maps or road information.

HD-maps and road databases are created locally. However developers see these maps as linked in a global system; seamless use between regions is essential for supporting autonomous vehicles. TomTom, Baidu, HERE and Google are some examples of HD-map developers offering some measure of global coverage. Today HD-maps are being rolled out in strategic geographies including the US, China and parts of urbanised Europe.

Expected deployment channels for navigation and apps are dominated by the private market. HD-maps for autonomous vehicles are highly integrated with the automotive industry. For the development of autonomous public transport services, public financing, policy development, procurement and roll-out will be required.

Autonomous vehicles are likely to spread in niche markets before they become popular in the broader consumer market. The initial cost of automated cars will be high, due to the addition of cameras, sensors, lasers, and artificial intelligence systems, therefore precluding adoption by the typical consumer. Rather, businesses and niche areas are positioned to be the early adopters. The most likely adopters include ride-sharing cars, buses, taxis, trucks, delivery vehicles, industrial applications, and transport for senior citizens and the disabled.

The market for semi- and fully autonomous vehicles is expected to be quite large in the coming decades. Boston Consulting Group anticipates that it will take 15 to 20 years for autonomous vehicles “to reach a global market-penetration rate of 25 percent”. Since autonomous vehicles are expected to hit the market by 2021, that would mean autonomous vehicles will comprise 25 percent of the global market between 2035 and 2040. Autonomous vehicles are likely to become a prominent option in mass transit systems.

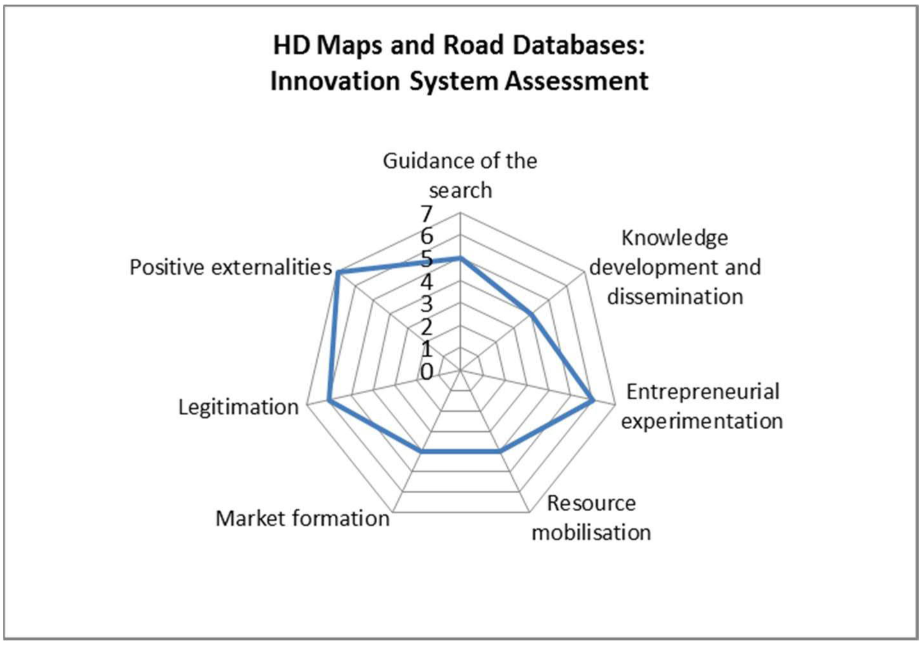
3.8.2 Innovation characteristics

HD-maps and road databases offer detailed information on the real world and will tell an autonomous vehicle what to expect along its route, with map resolution that can be as low as a few centimetres and include e.g. 3-D lane geometry, curb height or road sign information. The technology is considered vital for the development of self-driving vehicles as a priori information is used in combination with sensors to support the vehicle's detection of its surroundings in real time.

Modern cars are in general able to take increasingly more responsibility for driving manoeuvres, such as adaptive cruise control, assisted parallel parking and active object identification support. However, it is anticipated that there is a need for additional sequential steps towards full automation. The development timeline for HD-maps and road databases is thus rapidly moving forwards, mainly driven by partnerships between map developers and automotive suppliers. Costs for the technology are mainly related to recording the road network and delivering live updates, with information about accidents, traffic backups, and lane closures.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (5 out of 7): The role of HD maps and road databases in vehicle automation is well understood. Remaining questions around development pathways relate to data distribution (4/5G) and the role of high-performance live updates.
- *Knowledge development and dissemination* (4 out of 7): Necessary know-how for mapping exists. Handling live updates and distribution to and from cars in traffic quickly enough to avoid accidents needs to be developed. Future development of a car-to-cloud standard is needed. Artificial intelligence, deep learning, and big data analytics are vital to future automotive development.
- *Entrepreneurial experimentation* (6 out of 7): Private sector activity from both large and smaller firms is fairly robust. Tests of autonomous cars in a city environment are on-going in Europe, US and China.
- *Resource mobilisation* (4 out of 7): This is unlikely to be a barrier for private industry, but is likely to be problematic for public transport owners: It is uncertain who will pay for live updates about e.g. road works. Sunk costs relating to public transport hinders large investments in new autonomous flexible urban transport vehicles.
- *Market formation* (4 out of 7): The market is already established for current 'assisted' driving models, but for other uses and more advanced levels of automation uncertainty remains.
- *Legitimation* (4 out of 7): There is a need to build trust among passengers and acceptance among surrounding traffic. Legal issues relating to responsibility, traffic, and other policies needs to be established.
- *Positive externalities* (7 out of 7): Strong synergies exist with other on-board technologies.



3.8.3 Assessment of impacts

Autonomous vehicles potentially enable modal shifts from private cars to self-driving public transport solutions. Self-driving vehicles also support senior citizens and the disabled as these groups value mobility and the independence without the reliance on friends and relatives. HD-maps and road databases are also utilized by public transportation authorities, using traffic situation information as decision support. The information can also provide up-to-date rich context information for special groups lacking sensory abilities, simultaneously with on-board sensors, to get a more reliable view of the surroundings.

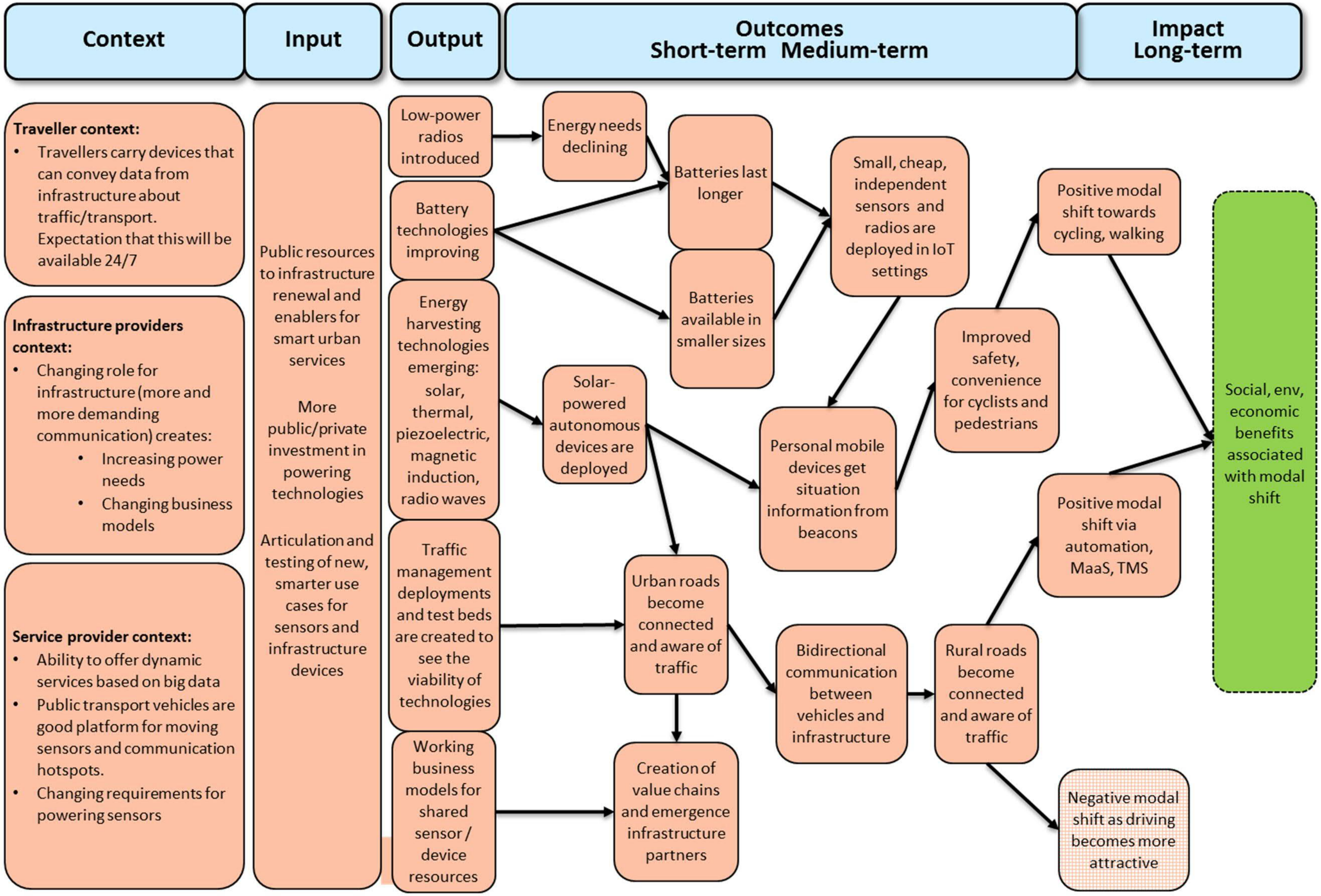
Nature of impact on modal shift: (soft-hard 0 to 5 scale): 0. HD-maps and road databases only indirectly impact modal shift by enabling and improving autonomous flexible urban transport and mobility-as-a-service (MaaS) offerings that compete with the use of private cars.

Strength of impact on modal shift: (qualitative assessment 0 to 5 scale): 1. The net impact of HD Maps on modal shift is related to the net impact of fully autonomous vehicles. This impact is likely to be outside the time frame of this analysis (beyond 15 years). Once full automation is in place, however, self-driving fleets of cars and mobility-as-a-service (MaaS) business models may contribute to a decline in car ownership and fewer cars on the road. Likewise in the transport of goods large efficiency gains from fleet management may decrease miles travelled, while autonomous delivery systems may decrease the need for private car journeys.

3.9 Powering the smart infrastructure

Technologies that supply power to tomorrow's smart infrastructure will have an important if indirect impact on passengers' choice of transport mode. Smart infrastructure will support cycling and walking with information that improves safety and journey efficiency. Vehicle-to infrastructure communications (v2i) can also play a part in traffic management systems that favour public/shared transport and thus discourage private car journeys. On the negative side to the extent that v2i/v2x make private cars more attractive to drive, some negative modal shift will result. For each of these impacts, sensors that can monitor the environment and maintain communications without power outages will be essential. Technologies that deliver this capability will include improved and longer-lasting batteries; lower power-radios that decrease energy requirements; and energy harvesting technologies. Transportation authorities will have a limited role in the development of these technologies, but will need to be proactive in developing use cases and deploying smart infrastructure in a way that takes advantage of new powering solutions.

Figure 9 Logic map for powering the smart infrastructure



3.9.1 Future market characteristics and potential

Powering devices and sensors embedded in infrastructure is an important part of the building of the smart urban environment. One long-standing question is how devices will be powered. For example, Bluetooth beacons have a lifetime of a few years before they need to be replaced. Changing batteries and finding devices that are no longer working takes lots of time and resources.

The market for solutions to this problem will start small via local installations that are more like pilots than full deployment, since the business cases for smart infrastructure are not clear yet. Today solar as a powering technology is dominant, and should continue to be so where the conditions support it.

Innovation in powering solutions will be driven by private companies, but deployment will involve public authorities responsible for the important locations that are ideal for smart infrastructure.

Predicting the market size for smart sensor and device infrastructure is difficult as different analyses use different assumptions about, for example, what is considered to be the infrastructure and how much the of the intelligence is embedded there versus elsewhere, for example in vehicles. Market emergence is forecast to be slow as there are still several core questions that need to be solved. Economic issues will become clearer as the business models for sensor installation and usage emerge. The use of cryptocurrencies (e.g. Bitcoin, etc.) is promising.

Smart infrastructure with cables, disposable batteries or use of solar power will characterise the first wave of installations.

3.9.2 Innovation characteristics

While the use cases relevant to transport are underdeveloped, technological innovation in the field is very active. Battery technologies are shrinking in size while growing in capacity. Low-power radio technologies have improved significantly over the past 10 years, and energy harvesting promises to extend operating times for devices.

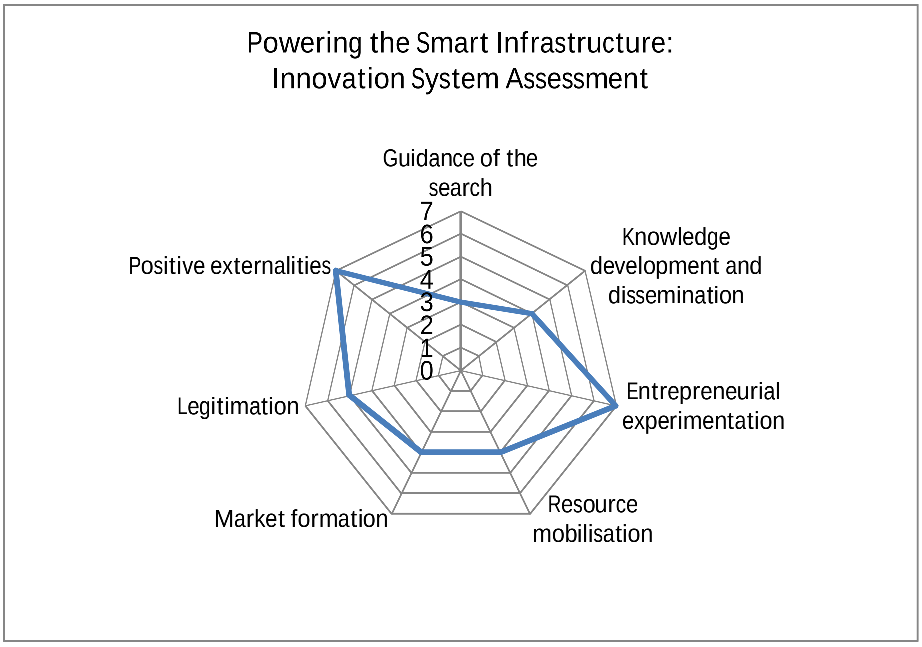
There are four main methods to harvest energy from the environment. The cheapest, most advanced and easiest to use is solar energy, which has taken great strides in recent years and is expected to continue to do so through the 2020s. Vibration-based energy is already utilized for measurement technologies in situations where there is constant movement around and something needs to be measured. For example, measurement of bridge durability and metal fatigue can be powered by the vibration the vehicles provide. Thermal gradient technology excels in situations where the temperature is changing and small amounts of power are required. Utilization of radio waves for power is promising as these transmissions can be produced on demand; however at the moment the harvesting takes more energy than it provides. At the moment solar is the only energy harvesting method that is economically feasible in a range of use cases; the other energy harvesting options are likely to be available for larger-scale deployment by the mid/late 2020s.

Business models for smart infrastructure centre around providing information from sensors at a cost. Power technologies will thus compete primarily on the basis of cost, though costs of different approaches will vary by use case and environmental conditions.

For battery technologies Li-ion is dominant and will continue to do so into the 2030s. There can be optimization innovations, but the basic battery technology will remain the same.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (3 out of 7): How the infrastructure will get its power and which kind of technologies will used are still in a fuzzy phase. The principles are known but pilots and implementations are scarce.
- *Knowledge development and dissemination* (4 out of 7): Principles for the energy harvesting etc. are known in physics but the technology is not there yet.
- *Entrepreneurial experimentation* (7 out of 7): The field is active in terms of research and experimentation. There are only a few legacy systems to keep in mind and new systems can usually be designed without those in mind.
- *Resource mobilisation* (4 out of 7): The world is not yet in a phase of independent powering of infrastructure, thus companies do not yet funnel lots of money into the field. A few technological breakthroughs are needed before resource mobilization becomes more important.
- *Market formation* (4 out of 7): The market for power technologies exists in the electricity system. The service market is not yet formed as local and more independent solutions are coming
- *Legitimation* (5 out of 7): Issues related to both privacy and liability will need to be resolved as data from sensors are collected and shared more widely.
- *Positive externalities* (7 out of 7): Many different infrastructure- related services will benefit from powering solutions.



3.9.3 Assessment of impacts

In terms of journey efficiency, smart infrastructure benefits vehicles most. Pedestrians and cyclists will get the same information as vehicles but will not have the automated processing and route management available to motorized traffic.

Thus the net impact on modal shift depends in large part on whether v2i/v2x communications are part of a move towards mobility-as-a-service or simply towards more automated private cars (see section on V2X). Another important issue is the extent to which these communications are used in traffic management systems that give advantage to shared options.

However in terms of safety, walking and cycling may reap more benefits. Smart infrastructure may enable travellers in urban areas to “see” around corners and avoid accidents. A rising societal question is the tracking of everything in urban context – sensors in urban environments may end up being much more pervasive than the CCTVs of today, and safety and efficiency may require tradeoffs around privacy.

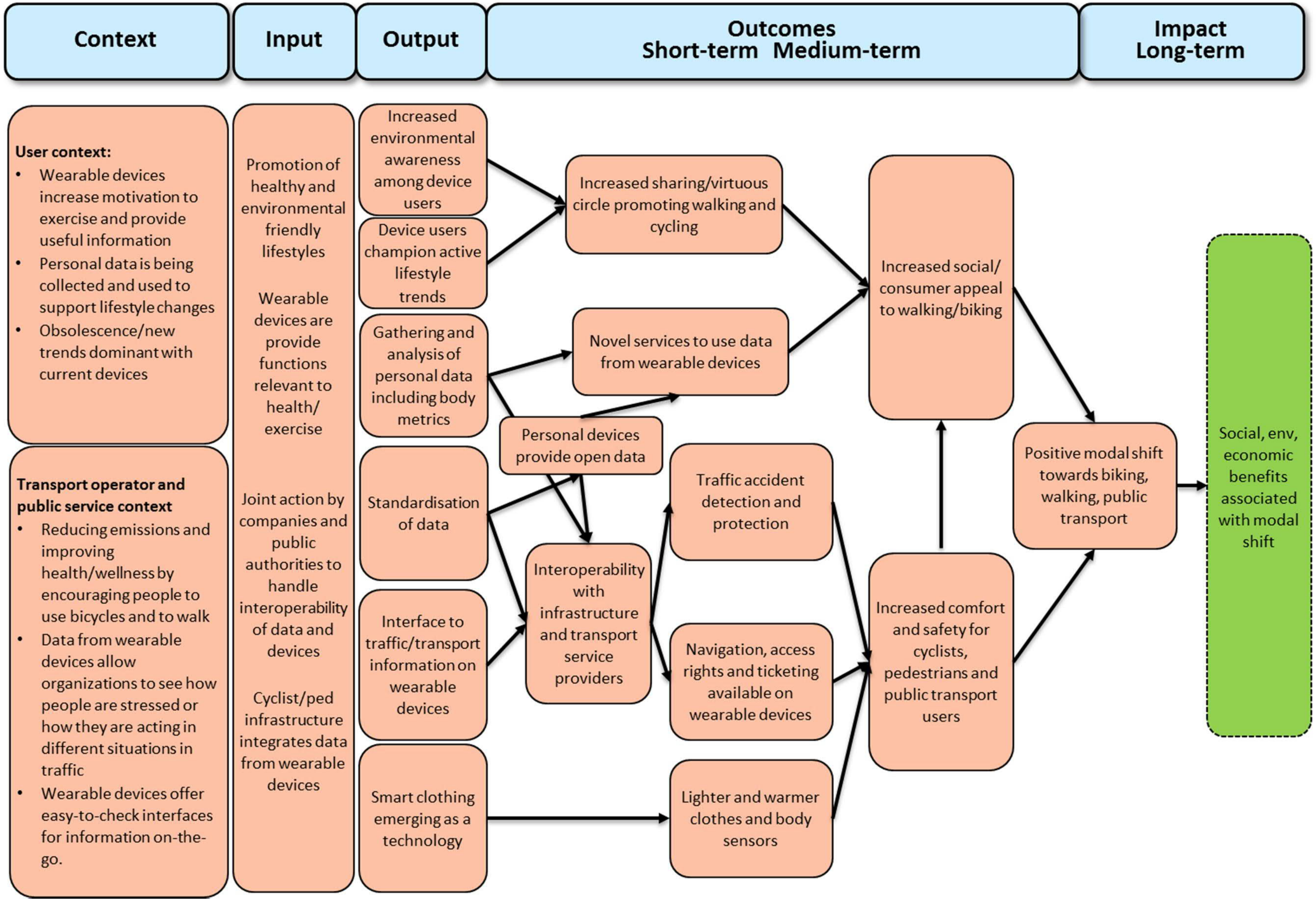
Nature of impact on modal shift: (soft-hard 0 to 5 scale): 1.

Strength of impact on modal shift: (qualitative assessment 0 to 5 scale): 1.

3.10 Smart textiles and wearable technologies

Wearable technologies can impact shift away from personal car transport by encouraging walking and cycling. One way in which they do this is by direct encouragement of active lifestyles and healthy choices, providing data about the users’ choices and behaviours and encouraging healthy options through goal-setting, competitions, and other personal incentives. Wearable technologies can also improve a traveller’s direct (on-person) access to transport-related information, making cycling and walking safer and more informed activities. Finally smart textiles can increase safety and comfort through monitoring of user’s physical states and environmental values and making adjustments so that travelling outside the protection of a vehicle is more attractive. Interventions to encourage these developments will relate to sharing of data between devices and infrastructure, testing and optimizing such devices for pedestrian and cyclist needs, and developing business models for devices that do not currently interact with each other.

Figure 10 Logic map for smart textiles and wearable technologies



3.10.1 Future market characteristics

Wearable technologies and smart textiles are divided into several product categories, and even within the categories there is specialized equipment to meet the different needs, of, for example, cyclists and runners. For the general populace such specialization will be less important. More generic wearable technologies like activity bands are blooming in the market because of their simplicity, light weight and a decent ability to track the activity of the user. In the future the market is likely to maintain this split between specialized and general-use technologies.

Smart textiles are now more in proof-of-concept phase than product phase. Different concepts are being tested but none has suggested clear commercial prospects yet. Nonetheless smart textiles are expected to reach the mass market in about five years. In the immediate future smart textiles will be more like wearable technologies than smart clothing as wearable devices are those which are integrated into the apparel. Material technology innovation is progressing slowly and somewhere in 2020s we can expect the first mass market adaptive clothing.

Integration with the environment and infrastructure is happening slowly and most likely avenues are Bluetooth beacon technology and room scanning which allows devices to be aware of their surroundings.

Target users for wearables and smart textiles come from all age groups and social segments. Interest in well-being and self-improvement is on the increase globally.

The technologies should be easily produced, sold and marketed globally. The miniaturization of computing technology has created new possibilities for devices and this miniaturization is not expected to slow in the near- to medium-term. This has led the devices themselves to follow a quick cycle of obsolescence and renewal.

The forecast wearable technology market is $34 billion in 2020 with smart textiles adding another $5 billion. Smart watches should be the leading device group with eyewear gaining ground from the beginning of 2020s.

3.10.2 Innovation characteristics

Recent years have seen significant innovation in wearable technologies and frequent introduction of new devices. Market performance has been related to perceived usefulness and aesthetics.

Wearable devices are considered to be very personal, especially if they are worn near ‘emotional’ zones like the face. This limits design options: for example some device categories such as jewellery are not acceptable in certain cultures.

Artificial intelligence is likely to be a key for wearable technologies’ breakthrough, with analysis of data from sensors maximizing the usefulness of devices.

Devices today suffer from non-interoperability. The fast pace of product development and market introduction has meant that interoperability has not been prioritized – this is an area for improvement in the future.

Smart phones will continue to work as a hub for different body area devices and provide the user interface and access to the cloud. This basic architecture is likely to continue to dominate in the future. The smart watch device category is trying to bring the smart phone functionality to the watch.

The focus for wearable technologies in recent years has been measuring the person's activity by tracking steps, heart rate, etc. On another front, smart glasses were introduced by Google in 2012, and a new generation will be introduced that proposes to learn from the first generation's failure.

Smart textiles, like wearable technologies, employ sensors, and the distinction between them might soon be outdated as clothes themselves get more intelligent. One development priority for smart textiles has been fabric that adapts to the environment automatically with the focus on protection of the wearer (e.g. helmets that emerge during collisions like airbags in cars). However the textile industry is not very fond of incorporating technology into its products: the value is hard to show and existing design and logistic chains are profitable.

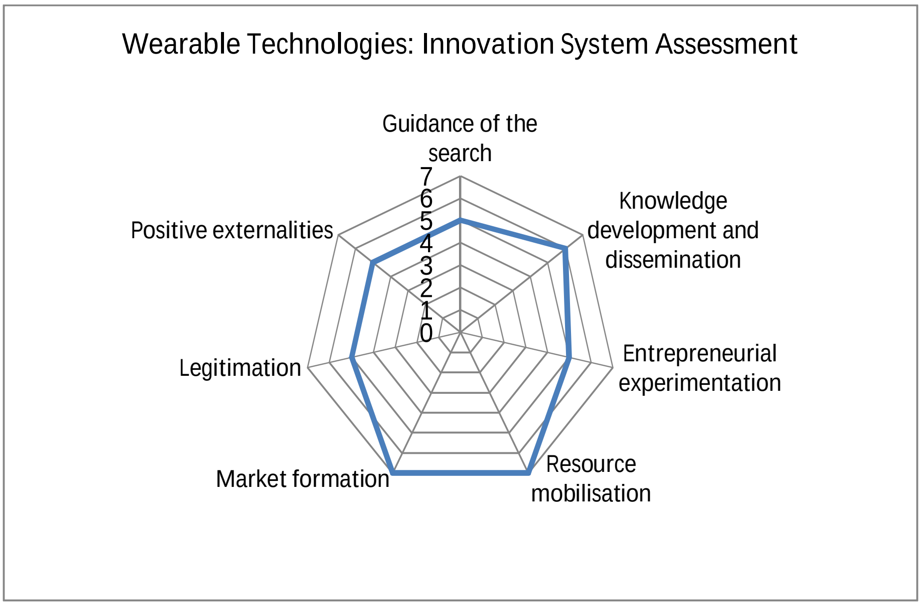
Costs of the technology are covered by the user, and costs do not appear to be an obstacle to mass-market penetration. The market is really open and new entrants should be common.

Technology development should follow three timelines. Activity tracking has gained traction and is already popular (Fitbit, etc.). The common use cases are now covered and innovation is oriented towards optimization of products rather than new functionality. Smart glasses represent the second line of innovation and the second generation is probably arriving in 2018 and developing new use cases over the following years. The third timeline is for smart textiles, and has more to do with material technologies than information technology, though IT-related use cases will pioneer the field.

Technological Innovation System: Functional Perspective

- *Guidance of the search* (5 out of 7): There is reasonably strong consensus about the role of wearable technologies and their expected development path. Smart textiles are a bit less certain with products today in a proof-of-concept phase.
- *Knowledge development and dissemination* (6 out of 7): Mainstream wearable technologies are in an optimization phase. Knowledge is developing quickly with the medical field especially generating many publications.
- *Entrepreneurial experimentation* (5 out of 7): Some wearable technology categories have stagnated as big players have taken their share. Most interesting innovation is happening in novel categories like glasses or in smart textiles.
- *Resource mobilisation* (7 out of 7): Wearable technologies have been mainstream for a number of years and companies have put significant resources into carving out market share.
- *Market formation* (7 out of 7): Monetization of wearable technologies is mature and based mostly on device sales.
- *Legitimation* (5 out of 7): Acceptance is broad if not yet universal. Privacy concerns may become material as devices begin to interoperate with each other and with infrastructure.

- *Positive externalities* (5 out of 7): Wearable technologies can contribute to socially desirable objectives such as healthy lifestyles and reduced CO2 emissions as people will walk or cycle more. They can also be used as an information channel for new services in the future.



3.10.3 Assessment of impacts (modal shift and secondary)

Wearable technologies and smart clothing are predominantly relevant for pedestrians, cyclists and users of public transport as these devices can help compensate for the shelter a vehicle provides. Some devices excel in showing information quickly to users; smart watches are trying to find their place in the device ecosystem as a continuation of the smart phone. They are easy to read and interact with for simple activities, and public transport guidance and real-time information is usually (though not always) simple enough to be provided through a smart watch. Wearable devices are ideal for notifying users about something when they are otherwise occupied (i.e. cycling).

Fitness trackers and smart watches have increased awareness of users' daily activities, and they should support active lifestyles where the use of private cars is frowned upon. By setting daily goals for steps, etc. wearable technologies are promoting modal shift from private cars to other ways of travelling. Connections to social media and the ability to share one's achievements reinforce these incentives.

There is possibility for governmental intervention to dictate that some devices must be used in certain situations. For example helmets are mandatory in some countries when cycling. Devices which will inform ambulances etc. when an accident happens might also be legally required in the future.

Today the data from wearable technology is owned and used by the user alone. In the future data mined from millions of devices will create a base for different services for cyclists and pedestrians in both urban and rural areas. Lots of data is gathered when people are on the move, and this data provides insights into behaviour and even moods of users. Devices can provide information about when users are stressed or hurried and likely to get lost or take risks in traffic. This knowledge can be utilized to optimize traffic flow and perhaps guide people towards better travel experiences.

Nature of impact on modal shift: (soft-hard 0 to 5 scale): 1.

Strength of impact on modal shift: (qualitative assessment 0 to 5 scale): 2.

4 CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

- The technology groups analyzed in STTRIDE Work Package 3 were selected for the range of user segments covered, the diversity in their dissemination channels and types of impact, and the ***opportunities they may create for transport authorities***.

- ***The technologies present new challenges and new opportunities*** in terms of evaluation:

    - ***The influence of most of these technologies on modal shift is 'soft' or indirect, and thus very difficult to attribute*** even in a controlled evaluation
    - Some impacts of technologies lie beyond the time horizon of the study (10-15 years) and even in a controlled evaluation are unlikely to materialize within a typical time frame (i.e. 1-2 years)
    - However ***all of these technologies will eventually generate data streams relevant to assessing modal shift***. Leveraging this data in evaluations will require thoughtful handling of issues of comparability, baselining, etc.

- ***The prospective development trajectories for these technologies are generally well understood***, and ***most are likely to see widespread rollout*** within the time frame (15 years) considered.

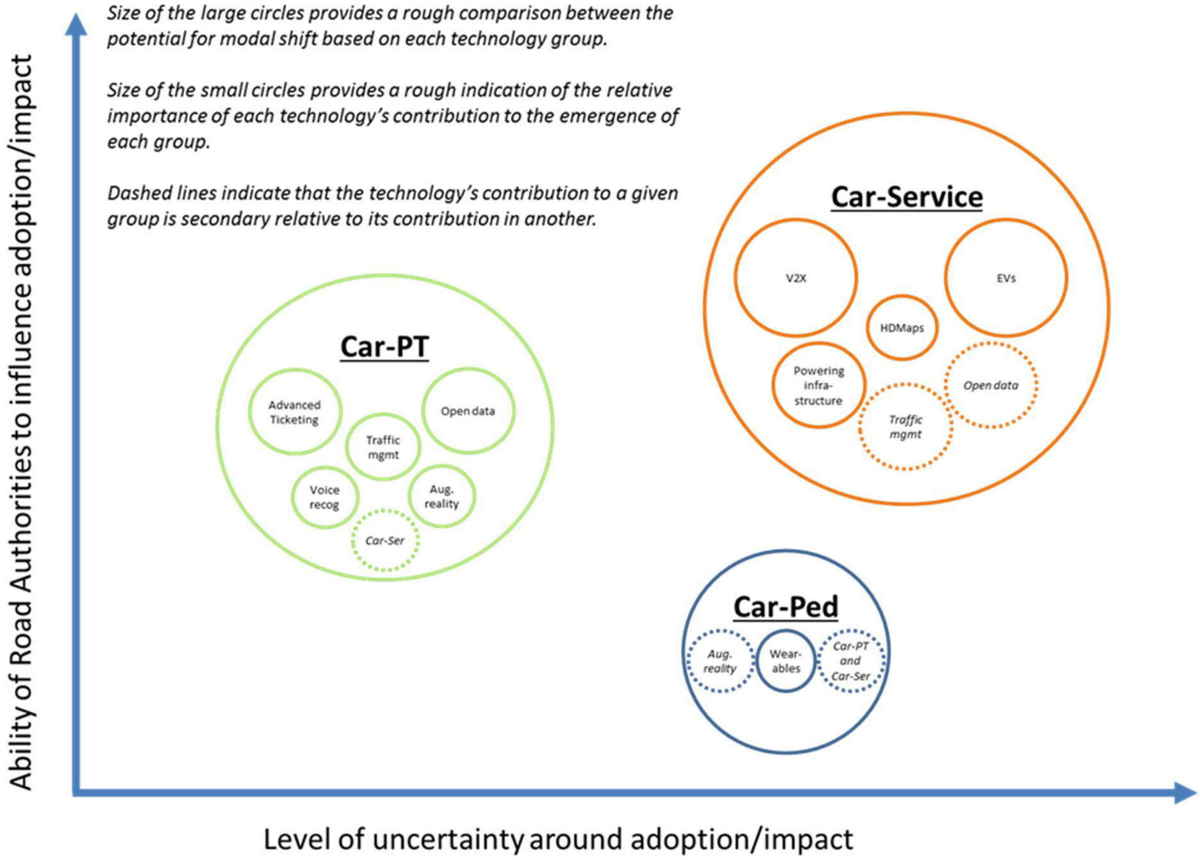
- ***The impact of these technologies in terms of modal shift is considered highly uncertain***. Only a few studies have modelled impacts at even a highly aggregated level, and the stakeholders consulted in large part treated this question as an ***almost fundamental uncertainty***, with one describing the question as "something for behavioural scientists to look at."

- There was an especially ***high uncertainty regarding how vehicle automation might impact car ownership and usage***. Recognition of the need to actively promote mobility-as-a-service (MaaS) as a complement to vehicle automation is fairly recent. ***Many stakeholders (especially in industry) are agnostic to modal shift impact***s and see automation as the dominant pathway regardless of whether it leads to more or fewer car journeys.

- The domain of ***multi-modal, connected journeys that cross urban/peri-urban/rural divides, and can involve both multiple transports and walking/cycling, adds another layer of uncertainty***, since little data or understanding of traveller behaviour exists today.

4.1 10 technologies, 3 types of modal shift

The analysis considered 10 technology groups, which together stand to influence three categories of modal shift. The three types of modal shift, and the technologies likely to contribute to each, are described below (note that 'Car-Ped' denotes a shift from car to walking or cycling).



A fourth type of modal shift, from travelling to not travelling (i.e. tele-commuting) or shifting travel in time, was not addressed in this analysis.

4.2 Impact on modal shift: summary table

The summary table below summarizes the impact on each category of modal shift by each technology. This is the project team's own assessment based on conversations with stakeholders and experts along with desktop research. The scoring is qualitative across three categories: level of impact, nature of impact ('hard' or 'soft'), and the size of the role to be played by road authorities. At the head of each section the impact of all the technologies on modal shift are scored 'overall' – this should be considered as a rough weighted average of the constituent technologies' impacts. In terms of scaling, the relative impacts of the technologies are in part based on the relationship to the shift in question, e.g. the impact on walking and cycling was judged to be greater for those technologies providing direct value to pedestrians and cyclists than those whose benefit was indirect via other transport services; the net impact of technologies explicitly targeting automation (e.g. V2X) was judged to be greater than more 'incidental' technologies (EVs).

	Level of impact (0=No positive impact 5=Major positive impact)	Nature of impact (0='soft'/indirect 5='hard'/direct)	Road Authority's role (0=none 5=leading)
Car-PT	***2*** ***Moderate*** potential to increase public transport ridership via services that improve rider experience. Services are ***likely*** to emerge. **Little/no potential for negative impacts** or rebound effects.	***2*** Modal shift primarily through ***'soft'*** influence on demand for public transport. Effect on the road system is primarily ***indirect*** via decreased urban car use and increased use of trains in connected journeys.	***2*** Road authorities will have a ***secondary/reactive*** role to play, mostly through open data and collaboration with other transport systems (rail, urban).
Advanced ticketing systems	2 (important tech, moderate impact)	2	1
Open data	1 (important enabler)	1	3
Traffic management systems	2	4	3
Voice recognition	1 (uncertain but positive impact)	1	0
Augmented reality	1 (uncertain but positive impact)	1	0
Car-Service	***4**** ***Large*** but ****uncertain*** potential impact by changing fundamental logic of car use. Positive modal shift to come ***after 2035 if at all.**	***2*** The modal shift occurs through ***'soft'*** influence as car ownership becomes less necessary/attractive. Effect on road system is ***direct***. **Large scope for negative impacts/rebound** effects.	***4*** Road authorities will have a ***primary/active*** role to play through investing and maintaining infrastructure, ICT, and data systems.
V2X	3 (net, post-2035)	1	4
EVs	2	1	3
HDMaps	1 (net, post-2035)	0	4
Powering sustainable infrastructure	1 (net, post-2035)	1	4
Open Data	*1*	*1*	*3*
Traffic management	*1*	*4*	*3*
Car-Ped	***1*** ***Small*** potential to increase walking and cycling by increasing convenience and safety. Walking/cycling in cities may reduce car usage on connected/multi-modal journeys. Technologies are mostly ***likely*** to emerge but timelines are uncertain.	***1*** The modal shift occurs through **'soft'** influence as walking and cycling become more attractive. Effect on road system is ***indirect*** via decreased urban car use and increase in connected journeys. Increased safety benefits both cars and bicycles/pedestrians, leaving **some scope for negative impacts.**	***1*** Road authorities may have a ***small*** but ***direct*** role to play via traffic management and safety measures supporting extended cycling journey; otherwise an indirect role in data sharing.
Wearable technology	2	1	1
Augmented reality	*2*	*0*	*1*
Traffic management	*1*	*1*	*3*
Car-Service technologies	*1*	*0*	*4*

4.3 Category 1: Car journeys exchanged for current public transport options (*Car-PT*)

4.3.1 The impact in brief

A suite of information technologies enable 1) Ease and convenience of passenger actions (ticket purchasing, public space navigation); 2) Effectiveness of service (prioritization on roads; timeliness; increased connections between modes). Thanks to these improvements, the number of public transport journeys can be expected to increase. The overall potential of this impact is likely to be moderate in the short-term as marginal improvements in ease of use and journey times do not overturn the perceived advantages of private car use, which may also improve on these dimensions. In the longer term, with the shift towards Mobility-as-a-service including car-based services, the impact could be larger.

4.3.2 The contributing technologies

Advanced ticketing systems have a ***'soft' impact*** on modal shift by meeting the user needs ***ease of use*** and ***reduced costs***. Such systems are important in the context of promoting demand for public transport, though the overall impact is expected to be moderate, especially in relation to reduction of car journeys on national road systems as opposed to within urban areas. In addition to the obvious convenience of integrated and automated (beacon-based) ticketing systems across multiple journey stages, such systems can also provide users with suggestions for cost-effective options, and transport providers with data about usage that allows optimization of services. ***Barriers are not primarily technological but related to standardization***.

Open data about both collective and individual transportation is an enabling technology for other services in this group, and thus has an ***indirect, 'soft' impact*** on modal shift by meeting the user need ***ease of use***. Open data is important in the context of promoting demand for public transport and prioritizing public options in traffic, and in delivering information through apps that promote mobility-as-a-service (MaaS). Relevant data sets include map data; weather; personal location data; network disruptions; planned events; real-time network capacity for people, vehicles & goods; public transport schedules; vehicle location data; fare and pricing data; sentiment data from service users and non-users; third party service usage data; and payment/transaction data. ***Costs to open data providers are not high but economic benefits are uncertain*** and accrue in part to private developers and service providers. ***Organizational issues related to legacy data structures and API development can also be challenging***.

Traffic management systems can have a 'harder' impact on modal shift by prioritizing road use by public and shared vehicles, and a 'soft' impact by meeting the user need of ***reduced travel time*** and increased ***safety***. Today's traffic management systems are expected to evolve towards real-time adaptive systems that react to evolving traffic conditions and intervene more directly. The technologies are expected to be important to public authorities, though the net impact on modal shift may be moderated by improved efficiency of car travel making car traffic more attractive. ***Technological development is still required for real-time adaptive systems***, both in terms of data processing capabilities and vehicle-to-infrastructure communications.

Augmented reality technologies can have a ***'soft' impact*** on modal shift by meeting the user need ***ease of use***. These devices can help passengers navigate access to public transport (finding and orienting themselves in stations) as well as improve interactions with devices for ticketing, etc. The impact of such devices may be moderate, though they may be more significant for groups with functional or cognitive issues, should they be developed to support these users. The net impact will also depend on whether advances in these technologies are successfully deployed in cars for driver assistance. ***In terms of technical challenges, displays and interfaces for different environments still need to be developed***. The technology will be developed within the private market and will likely bear its own development costs.

Voice recognition technologies can have a ***'soft' impact*** on modal shift by meeting the user need ***ease of use***. The nature and scale of the impact is similar to *Augmented Reality*.

Other technologies are addressed below as drivers of a shift from private to shared car services technologies can also have a ***'soft' impact*** on modal shift towards public transportation. The technologies for vehicle automation may be adopted early on by bus services, particularly in less dense areas where staffing routes can be expensive. Likewise autonomous vehicles such as light 'pods' or shuttles can provide dedicated connections to train and bus stations.

4.4 Category 2: Private car journeys exchanged for use of shared car services (Car-Service)

4.4.1 The impact in brief

A suite of technologies makes fully autonomous, electric vehicles widely available. Over time these are expected to be deployed in fleets providing transportation services (both mobility and delivery). These services will significantly weaken the incentives for private car ownership, and the number of private car journeys declines. ***In the short-term, the component technologies will likely make driving more attractive and thus have a negative impact on modal shift. If they become part of a transition to MaaS, the impact could be strongly positive***.

4.4.2 The contributing technologies

V2X technologies have a ***'soft' impact*** on modal shift by meeting the user needs ***ease of use*** and ***safety***. This impact is likely to be negative in the medium-term, as comfort and safety for drivers leads to additional car journeys, but potentially strongly positive in the longer-term, when MaaS scenarios featuring autonomous vehicle fleets could additionally deliver ***reduced costs*** and ***improved journey efficiency***. The primary ***barriers*** to V2X adoption are ***first-mover disadvantages***, since benefits are tied to network effects; the incentives for car companies to deliver automation using services that they can directly control; and uncertainty regarding policy (standards and mandates). A rapid transition to the positive modal shift scenario is likely ***dependent on strong policy action and public investment***.

Electric vehicles can have a ***'soft' impact*** on modal shift by meeting the user needs ***ease of use and reduced costs*** as a part of MaaS scenarios featuring autonomous vehicle fleets. In the absence of such a scenario EVs likely have no net impact on modal shift. Current barriers to adoption (upfront costs, range issues) are not expected to persist far into the next decade; roll-out of charging infrastructure will be essential.

High definition maps can have a ***'soft' impact*** on modal shift, meeting the user need ***ease of use and reduced costs*** by accelerating the availability of safe, trusted, effective autonomous vehicle fleets. HD Maps are available today; their inclusion in future MaaS scenarios would require significantly ***increased investment in keeping information current***; updating relating to roadworks may be particularly challenging.

Powering solutions for smart/sustainable infrastructure are enablers for V2X solutions, and thus have an indirect impact on a MaaS scenario based on the ease of use and reduced costs. There remains great uncertainty about how the infrastructure will be powered in the future and via which business models those solutions will recoup their costs. ***Some of the most promising technological options (e.g. non-solar energy harvesting) are still in the very early phases of development***.

Open Data and **Traffic management systems**, while primarily of interest to the Car-PT shift, are also relevant contributors to the Car-Service shift.

4.5 Category 3: Car journeys exchanged for walking/cycling (Car-Ped)

4.5.1 The impact in brief

Technologies carried on-person improve pedestrians' and cyclists' ability to navigate traffic ***safely*** and ***easily***; simultaneously improved traffic management and vehicle automation makes car traffic less hazardous to pedestrians and cyclists. Through these mechanisms the number pedestrian and cycle journeys could be expected to increase. The overall potential of this impact is likely to be small as the fundamental ease of use advantages of other transport forms are not overturned.

4.5.2 The contributing technologies

Wearable technology and smart textiles can help compensate for the shelter and travel information a vehicle provides, making walking and cycling ***easier***, ***safer*** and ***more efficient***. These devices can provide ***information and guidance***, even for users (e.g. cyclists) whose hands are occupied. In addition, such devices can increase awareness and ***leverage growing consciousness of healthy choices***, encouraging people to walk and bike more. Barriers today relate to a lack of interoperability between these devices and other systems. In the future connected wearables may create ***privacy concerns***.

Augmented reality technologies can have a similar impact on modal shift from cars to walking and cycling as they do on the shift towards public transportation (described above).

Traffic management and all **Category 2 technologies** can encourage modal shift from cars by ***improving traffic safety to the benefit of walking and cycling***.

Electric bicycles are increasing in popularity and could greatly improve ***ease of use*** for cyclists. Here again ***upfront costs are higher than for unpowered bikes*** and will continue to be so, but ***financial incentive programs*** can work as a driver.

5 APPENDIX 1: SOURCES INCLUDED IN THE LITERATURE REVIEW (BOTH D3.1 AND D3.2)

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6 APPENDIX 2: STAKEHOLDER CONSULTATION

Göran	Almkvist	Inventor, Innovation and Strategy	Volvo Cars
Anon	Anon	Data and Analytics Lead	Wearables company
Anon	Anon	Head of UX & Design	Wearables company
Elias	Arnestrand	Project Manager	Trafiklab
Robin	Blokopoel	Lead Researcher	Dynnig
Martin	Boehm	Head of Deployment, Business Unit Mobility	Austriatech
Martin	Borgkvist	Project Manager	RISE
Mike	Burden	Independent Consultant	Independent Consultant
Nic	Cary	Head of Data Policy	DfT
Venn	Chesterton	ULEVs and Energy Lead	TRL
Christofer	Englund	Research Manager	RISE Viktoria
Mark	Fell	Urban Account Manager	Mouchel
Suzanne	Hoadley	ITS & C-ITS Lead	Polis
Olof	Johansson	Acting Head of Accessibility	Trafikverket
Emmi	Joustlehto	CEO	RobustNorth
Mikko	Karimo	Assistant Professor	Aalto University
Chris	Kettell	Head of Transportation Software & Networks	TRL
Matthew	Lewis	Head of Smart Ticketing	Transport for West Midlands
Jonathan	Murray	Policy and Operations Director	Low Carbon Vehicle Partnership
Maria	Rautavirta	Senior Engineer	Ministry of Transport and Communications, Finland
Daniel	Rudmark	Senior Researcher	RISE Viktoria
Sami	Sahala	Smart Mobility Project Manager	ForumViriumHelsinki
Raja	Santhanaraj	Transport Modelling Expert	Qatar Railways
Alan	Stevens	Chief Scientist	TRL
Esko	Strömmer	Senior Scientist	VTT
Tom	Voege	Policy Analyst	International Transport Forum

Gert Jan	Wijihuizen	ISAAC project	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV
Charles	Woodward	Principal Scientist	VTT
Ian	Wright	Head of Insight	Transport Focus

Select quotations from the stakeholder consultation

“Public and individual transport are converging. The big systems will survive but will gradually be incorporated into Mobility-as-a-service.”

- *Representative from national public transit authority*

“The Uber effect should drive innovation in public transport, not hinder it. Their fare management is very simple for the user, and bus operators are starting to take notice.”

- *Manager of regional smart ticketing system*

“Ticketing technologies need to be easy and mitigation options have to be there for people who can’t access the technology.”

- *Consultant in Intelligent Transport Systems*

“Much of the necessary data could be available in three years. Some of the services exist already. But who should play which role?”

- *Specialist in open transport data*

“Open data is only open when it is reaching an audience.”

“Standardization is a long journey and regional differences still require a lot of customization for a service to be usable in multiple places. Niche services are difficult to develop in a fragmented market.”

- *Manager of open data initiative*

“The future of traffic management is in Machine Learning, which will reduce the analysis time to the order of seconds and will provide better results as well.”

- *Consultant and researcher in Transportation Software and Networks*

“Procurement rules leave authorities locked in to vendors, discouraging innovation.”

“Will the connection be in the infrastructure or cellular? Cellular has big advantages where population is spread out.”

“It is important to make the car as independent as possible. If we are fully dependent on the infrastructure, the car will not be fully autonomous.”

- *Representative from national public transit authority*

“Autonomous driving technology might not do much for safety if there is no legislation. Most of what is available in the car today is not used, or not used properly.”

- *Auto industry representative*

“Autonomous vehicles will help modal shift for the first mile from home, taking you to the high-frequency train or bus.”

“EV drivetrains are less complex and they could change the face of the car industry. Car companies will become brand owners, pulling together components from suppliers.”

Expert in low-emission vehicles and energy