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DRAGON
Driving automated vehicle growth on national roads

D4.1 Final Report

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Glossary of Terms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
BaU	Business as Usual
B/C	Benefit/Cost ratio
CACC	Cooperative Adaptive Cruise Control
CBA	Cost Benefit Analysis
ENPV	Expected Net Present Value
ERTRAC	European Road Transport Research Advisory Council
NRA	National Road Authority
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PDO	Property Damage Only accidents
STEEPLE	Social, Technology, Economic, Environmental, Political, Legal, Ethical analysis
V2V, V2I	Vehicle-to-Vehicle, Vehicle-to-Infrastructure communications
VMS	Variable Message Sign

1 Introduction

Vehicle automation technology is developing rapidly with demand for automation systems across passenger cars and goods vehicles, based on existing benefits with current systems and greater anticipated benefits from higher levels of automation in future. The road networks which NRAs manage (mainly motorways and other strategic routes) are likely to be amongst the most suitable networks for automated vehicles, in that they are usually consistent, well-ordered environments in terms of layout, lane markings and signage, with comparatively few interfaces with other transport modes. It is important for NRAs to understand what potential benefits and costs automated vehicles may bring to their network, how they can best support their introduction, and to understand their potential role in influencing implementation, in order to maximise benefits and mitigate potentially negative side-effects.

The success of automated vehicles ultimately hinges on how well they meet their users' needs and this will be influenced by the support of the NRAs. As such the NRAs have the ability to influence directly the impacts of these vehicles on their network.

The DRAGON project focuses on the role of NRAs in supporting the movement towards high and full automation and realising the benefits and savings that come with it. It considers both the general case for NRAs in Europe as a whole, as well as focussing on the particular needs of individual NRAs through three selected case studies.

The overall aims of the project are to:

- Set out how vehicle automation will change road transport over the next 20 years
- Identify the constraints and enablers which will respectively hinder and facilitate progress, with a focus on the impacts on National Road Authorities (NRAs) and how automated vehicles will affect NRA operations
- Facilitate NRAs in taking decisions on when and how to provide support for automated vehicles

The approach has been to understand the potential costs, benefits and implications of vehicle automation to support European NRAs in making decisions that will help to achieve the best outcomes. The project covers all the steps from situations of no vehicle automation through to high and full vehicle automation, and from no NRA support to the deployment of vehicle automation through to NRAs providing support with policy, regulatory and infrastructure changes where relevant.

As a guide to achieving the aims of the project, we have tried to answer the following research questions:

A. What are the likely timescales for the introduction of vehicles with different levels of automation on NRA roads? How will developments differ for passenger cars vs. goods vehicles? Will the development be gradual or disruptive? What does this depend on and what role can NRAs play in these developments?

B. Do automated vehicles need to be segregated from non-automated vehicles to achieve maximum benefits? Will automation reduce congestion and smooth traffic flows and improve efficiency. What will be the impact on accident risk and safety? Would this segregation be enforced?

C. Does the physical infrastructure need to be adapted? This could mean either the reduction of infrastructure required (fewer and / or narrower lanes needed because of more efficient traffic flow) or adapting the infrastructure to accommodate demanding situations, e.g. by making acceleration lanes or changes to entry and exit ramps.

D. Is there a need to change traffic monitoring, traffic management and incident management strategies? For instance, is there a need to better distribute vehicles over various routes (taking into account their suitability for automated driving), to open lanes for automated vehicles only, or to deal with a malfunction of automated vehicles?

E. Would regulation or financial incentives initiated by NRAs be enablers to accelerate the deployment of automated vehicles? What other enablers could be envisaged? What constraints are there currently in how NRAs operate? What is needed to ensure interoperability across Europe?

F. What changes in legislation are needed to allow tests with automated vehicles on public roads, and what additional changes would be needed at a later stage to allow automated driving of any level (e.g. the Vienna Convention)? Which countries can serve as examples, having already implemented legislation allowing automated vehicles on the road under certain conditions (e.g. Sweden, Germany, the Netherlands)?

G. Is the traffic demand expected to increase or decrease as a result of automation, and what are the differences between passenger and freight transport forecasts?

H. What traffic situations are very demanding for automated vehicles and non-automated vehicles alike (especially at peak loading), and will automated vehicles of different levels perform more efficiently and safely in those situations (in regular situations such as entering and exiting a motorway, weaving sections, traffic close to breakdown, but also in irregular situations such as incidents, road works, or adverse weather)?

I. What kind of map data (static and dynamic) or data about the road network would be used by automated vehicles to support on-board sensors, and will NRAs need to play a role in providing this information (e.g. data about road works and lane closures)?

J. What can connectivity / cooperation contribute to the functioning of automated vehicles and road trains (and their interaction with non-automated vehicles)? In what situations is cooperation required in order to avoid negative side effects?

K. At present, automated vehicles driving autonomously, must keep longer headways than most human drivers would do in busy traffic, causing loss of network capacity and non-automated vehicles to cut in in front of automated vehicles. Is short range communication needed and does this require the installation of road side units?

The detailed answers to these questions are given in Appendix 1, and these answers are used in the conclusions and recommendations in this report.

2 NRA-focussed Roadmap for Automation

2.1 Approach

The initial starting point for the NRA-focussed roadmap for automation is a systematic and comprehensive review of existing road maps and deployment forecasts (for current day, 3-5 years in the future, 10 years in the future and beyond). This forecast is based on known research results and information from consortium members, working groups, networks, use of the TRL knowledge base database of transport research as well as Internet based investigations.

Synergies are drawn with concurrent projects that the consortium are undertaking in the area, which ensure the most up-to-date information is included. General conclusions about the content of existing road maps and deployment forecasts are drawn, with summaries of findings from the sources studied (including a check of which aspects are covered in each document studied). This leads to a deployment forecast, which is derived including all uncertainties as no level 3 (or higher) vehicles are yet on the market for commercial or private usage.

2.2 Findings

Different roadmaps have been elaborated by different stakeholders in the recent past. Currently the most consolidated roadmaps for Europe are provided by ERTRAC and serve the basis for the research activities on European level in the field of automated driving (see Fig. 2-2, Fig. 2-3 and Fig. 2-4 which are based on the 2015 roadmap and under revision at the time of writing)..

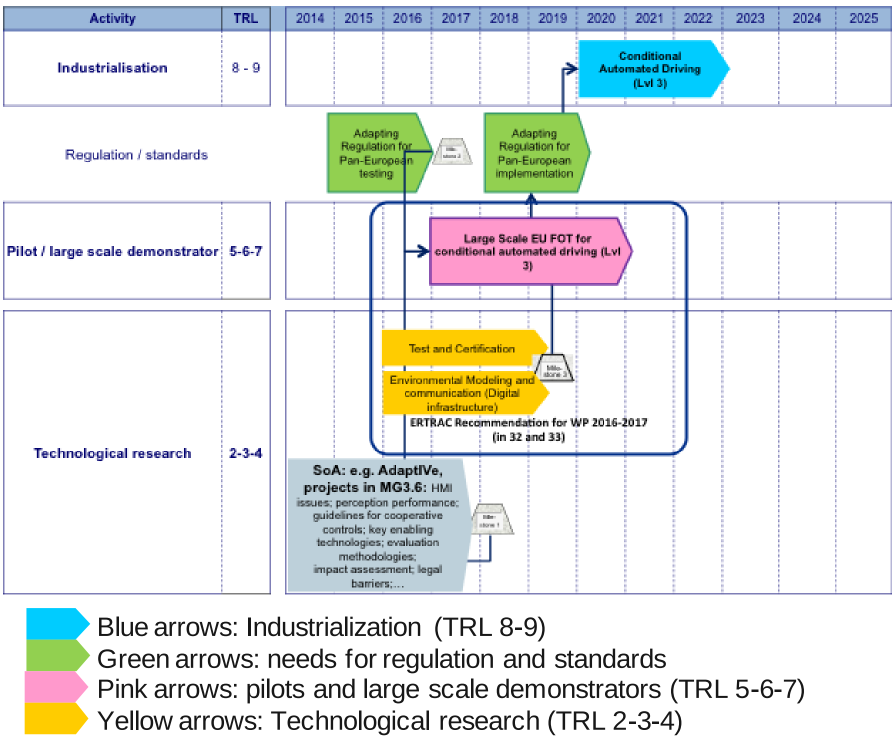
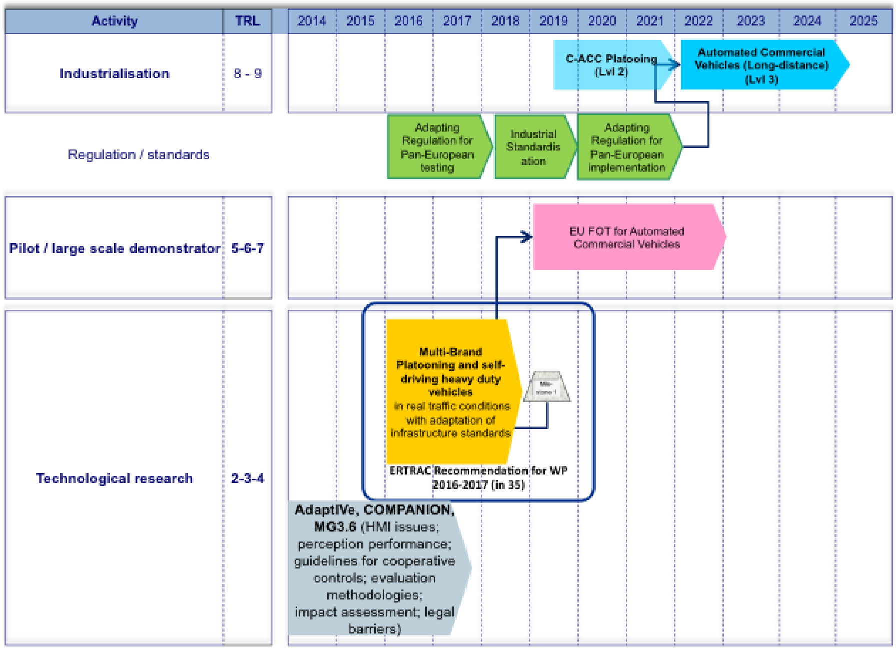
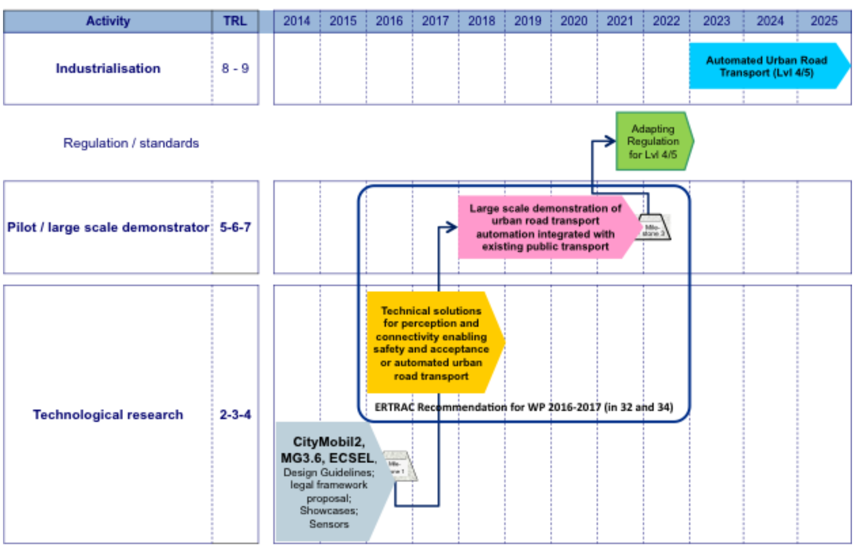


Fig. 2-1: ERTRAC roadmap on Conditional Automated Driving [1]



Blue arrows: Industrialization (TRL 8-9)
Green arrows: needs for regulation and standards
Pink arrows: pilots and large scale demonstrators (TRL 5-6-7)
Yellow arrows: Technological research (TRL 2-3-4)

Fig. 2-2: ERTRAC roadmap on Automated Commercial Vehicles [1]



Blue arrows: Industrialization (TRL 8-9)
Green arrows: needs for regulation and standards
Pink arrows: pilots and large scale demonstrators (TRL 5-6-7)
Yellow arrows: Technological research (TRL 2-3-4)

Fig. 2-3: ERTRAC roadmap on Automated Urban Road Transport [1]

Next to the roadmaps, which provide an overview on possible introduction dates and milestones for higher automation levels the penetration rates and the development of penetration rates are important to estimate in order to get a clear picture of the forecasted situation in 2030. Therefore a deployment function is estimated according to a prediction method used by [2].

Applying this method to automated driving, the following assumptions are taken into account:

- Deployment of level 3/4 automation starts in 2020
- Level 5 systems will not be considered as they are not expected to be deployed in the timescale of this study
- Deployment of automated driving functions will be accelerated due to public awareness
- Automated driving is present in media
- Automated driving is under heavy research
- Experience with ADAS; market penetration of ADAS
- Available technology

It is expected that uptake rate of automated driving will be higher than penetration rates of comparable systems have been in the past

Therefore penetration levels between 5% and 15% are possible in the year 2030 for the low effort scenarios (market introduction of level 3/4 systems in 2020).

Penetration levels between 15% and 35% are possible in the year 2030 for the high effort scenarios (market introduction of level 3/4 systems 2020).

2.2.1 Scenarios for Use Case 1: Automated trucks on the A19 from Nissan plant – Port of Tyne – UK

The use case of Highways England is to look at automation of freight movements between two fixed points on the UK network. The A19 connects the Port of Tyne in Newcastle with the Nissan car plant. The A19 consists of a dual lane carriageway for the whole length, with branch connections, to the port and plant, leading off from controlled junctions with slip roads at either end.

The length of the A19 considered under this use case, has four junctions over or under the dual carriageway, one junction with slip roads feeding off and onto the carriageway and one traffic signal controlled roundabout. The distance covered between the Port of Tyne and Nissan is approximately 10km (6 miles).

This use case is unusual in that it only envisages a very small number of vehicles (between 30 and 40), operating at level 4 automation and only at times of very low traffic, so infrastructure support required is likely to be minimal. However, some support is likely to be required to facilitate early realisation in a safe manner. Note that the trucks are expected to operate without drivers, but as they will only operate on a very restricted route they are considered level 4.

This use case was analysed under the three scenarios, Business As Usual, Low Effort and High Effort scenarios.

Business as Usual

Under this scenario, it is unlikely that the use case can be realised easily, if at all. At the very least it is to be expected that some infrastructure will be required to regulate traffic which will interact with the automated vehicles. Under this scenario, positive impacts can only be expected once automation reaches a level that automated vehicles can freely interact with “manual” vehicles seamless and safely, a situation unlikely to arise in the next decade.

Low Effort scenario

Some effort is expended in the provision of infrastructure which makes it easy for automated vehicles to use the road with non-automated vehicles, including the provision of VMSs for dedicated signage.

Under this scenario, the use case is completely viable owing to the very low numbers of vehicle movements involved.

High Effort scenario

The high effort scenario envisages significant support from the NRA with road layouts changed where appropriate, segregated lanes for automated vehicles, and signalling supporting their operation.

There is little advantage in this use case in the high effort scenario due to the low numbers of vehicle movements involved – a dedicated lane would provide little or no advantage, and the road is probably suitable for automated vehicles without additional roadworks.

The peculiarities of this use case mean that little effort is needed to make the use case viable, and there is little additional advantage to expending a high level of effort. If however the use case were to be extended to geographical locations with higher traffic levels and a greater number of automated vehicles, higher expended effort could lead to greater positive impacts on safety and efficiency.

2.2.2 Scenarios for Use Case 2: Truck Platooning on the A15 – The Netherlands, Rijkswaterstaat

This case concerns truck platooning on the A15 motorway (Port of Rotterdam – Nijmegen). It is partly based on the experiences from the recent Truck Platooning Challenge in Europe and thoughts about the next steps towards multi-brand, multi-haulier truck platooning.

After successful tests with level 1 two-truck platoons, transportation companies and governments are investing time and money so that in 2030 3+ truck platoons are allowed to operate on motorways at SAE level 4 and transport firms are purchasing platooning-ready heavy goods vehicles. Platoons can be multi-brand, multi-haulier, and can be formed on the fly. Trucks drive with gaps of 0.3s, the lead driver is in the loop (though not active, i.e. operating at level 2) and following drivers can rest.

There are also truck platoons operating at L1/L2, using C-ACC and lane keeping functions (and slightly longer gaps). The drivers of the following trucks in these platoons need to be able to take over control quickly.

Again this use case was analysed under the three scenarios, Business As Usual, Low Effort and High Effort scenarios.

Business as usual

Penetration rates are expected to be 0% L4 plus 15% L1/2 for trucks. Some 5% of trucks are expected to take part in platoons. This low penetration rate means that effects on safety, emissions, traffic flows and economics will be negligible.

Low effort scenario

Penetration rates are expected to be 30% L4 plus 30% L1/2. On the road (share of trucks that actually end up in a platoon): 20% L4 plus 15% L1/2. As with the Business as Usual scenario, there will be a negligible effect on traffic flows and safety due to low penetration. There will be some effect on emissions, though quite small. The effect on infrastructure (e.g. pavement wear) is unknown at this stage.

High effort scenario

Penetration rates are expected to be 50% L4 plus 30% L1/2 capable. On the road: 35% L4 plus 20% L1/2 expected to take part in platoons. Small improvements in safety and traffic flows are expected. Economic benefits start becoming significant. Effects on infrastructure are still unknown, though sensors on vehicles provide improved understanding of road condition.

2.2.3 Scenarios for Use Case 3: Autobahn Chauffeur on the A9 – Germany

This case looks at passenger vehicle road automation on the A9 motorway in Germany. The Autobahn A9 was selected as the German pilot project “Digitales Testfeld Autobahn” for research and demonstration of automated and connected driving on German motorways. The A9 is a motorway stretch of approximately 160 kilometres between the cities of Nürnberg and München. Most of the infrastructure is a three lane motorway, with currently some parts with no speed limit and some limited parts with a speed limit of 120 km/h. The main focus will be on "Car-to-Car-" and "Car-to-Infrastructure"-communication. Figure 5 shows the A9; Figure 6 the speed limits on the A9.

Again, this use case was analysed under the three scenarios, Business As Usual, Low Effort and High Effort scenarios.

Business as usual

In 2030, traffic volumes are quite a bit higher than today, due to economic and demographic factors. In the BaU scenario the low penetration rates of L3/L4 systems and the increased traffic volumes result in worsened conditions compared to today. This scenario considers a penetration of about 5% level 4 automation in 2030.

Minor impact on infrastructure in terms of clear road markings and clear display of construction and accident sites for level 2 systems is expected in the business as usual scenario. For level 3/4 systems clear road markings and clear display of construction and accident sites necessary. Infrastructure operator will start to improve the infrastructure to be L3/4 ready.

Low effort scenario

In 2030, traffic volumes are quite a bit higher than today, due to economic and demographic factors. If drivers use ACC (adaptive cruise control) in dense traffic, it results in extra congestion, as drivers have to choose larger headways than they would if they drive manually and ACC vehicle following is string unstable.

It is assumed, however, in the low effort scenario, that ACC systems will improve traffic flow and smaller headways are used (comparable to human driving) through the widespread use of V2V communications to enable CACC vehicle following. Furthermore the string instability challenge (consistent longitudinal vehicle control in platoons with more than 2 vehicles) between ACC vehicles is present today, but is expected to be solved in 2030 due to less latency through use of V2V communications. This scenario considers a penetration of about 15% of level 4 functionality in 2030.

Impact on infrastructure in terms of clear road markings and clear display of construction and accident sites is expected.

High effort scenario

The high effort scenario envisages road operators making active investment decisions which facilitate the deployment of increasingly automated vehicles, including adaptations to infrastructure to optimise it for increasingly automated vehicles, and deploying new technologies like dedicated communications networks, high-resolution digital maps and roadside sensors.

The increased deployment of various levels of automated vehicles including use of C-ACC (L1 and L2) increases the capacity of the road and increases stability. On the underlying road network, problems might occur because the increase in capacity there might not be enough to be able to process the higher traffic volumes (of traffic driving to and from the motorway). At the interface between the A9 and the local roads, Bundesstrassen will also play an important role as the higher traffic amounts on the A9 needs to have the possibility of easily accessing and leaving the motorway without causing delays. This scenario considers a penetration of about 35% level 4 automation in 2030.

Next to lane markings and clear display of construction and accident sites, V2I will provide low-latency communications capacity between vehicle and roadside infrastructure enabling additional services supporting automation, particularly at junctions. This will require a communication network along the Autobahn which is also safety relevant and therefore needs to be fail operational and maintained at a high level.

3 Impacts of Automated Vehicles on NRAs

In this section we present the results from an analysis of the impacts and benefits, as well as a complementary analysis of the constraints and enablers at play in the field of automated driving.

3.1 Approach

The impacts and benefits of vehicle automation were derived in a two-pronged approach, which firstly consists of an analysis of current literature combined with input from stakeholder consultation, and secondly on the construction of an impact matrix. An initial scope for the roll out of vehicle automation was given in the previous section, which acts a base from which further literature research was performed focussing on the impacts that vehicle automation is likely to have.

The impacts were analysed by category, these being:

The **mobility** category describes the influence on the high level network performance indicators, such as the level of service of traffic using factors such as the *total network delay*, *road utilisation* (volume-capacity ratio) and the total *time in congestion*.

The **traffic interaction** category describes vehicle movements and interactions. These can be easily described with the three factors: *longitudinal and lateral movement* and *interaction* with other modes, which includes the influence of interaction during manoeuvres such as lane-changing. This category is the most elementary category closest to the vehicles and therefore often acts as an intermediate category for other impacts.

The **safety** category considers the impacts related to risk and consequence of various severity of accidents and considers the well-known distinction between, *fatal accidents, (non-fatal) injury accidents* and other '*PDO*' (property damage only) accidents.

The **environment** category mainly considers the impacts of emissions. Normally these are separated into *CO_2, NO_x and PM-2.5 emissions*. A further impact is that of *noise*, although it may not be readily expected that there is any impact of automated driving for noise.

The **energy** category considers the *consumption of fuel or electricity* by vehicles. This will usually be quantified in Joules.

The **social** category looks at the impacts on aspects that are relevant for perception, but also for general well-being of individuals, but also for society. *Comfort* is an important impact factor that describes the perceived well-being of a driver. *Social equity* describes the opportunity and potential of all parts of society to participate. Both of these impact factors are difficult to quantify and may be best indicated by a relative difference.

The **economic** category considers all aspects of macro-economic influence of a use case scenario. This includes the impacts on the costs and benefits of *infrastructural maintenance*, *vehicle lifetime and maintenance*, but also on *industrial developments* and *labour*, which may be an important indirect effect of scenarios. These factors can be relatively easily stated in monetary terms.

Each category of impact was analysed for the three deployment scenarios, business as usual, low effort and high effort scenarios

For constraints and enablers a STEEPLE analysis was used. This is a strategic planning tool that is used by businesses / project managers to develop forward planning and to determine next steps. It was used here to explore enabling actions and constraints relevant to the introduction of automated vehicles on NRA roads.

Each letter in the acronym STEEPLE highlights one of seven external factors that can affect the market in one way or another.

The **Social** factor encompasses the action that the social environment has in the market, and includes key determinants such as determining cultural trends, demographics, and a population analysis.

The **Technology** factor covers actions that pertain to innovations in and around technology that affect the operations of the industry and market sector favourably or unfavourably.

The **Economic** factors are strong determinants involved in an economy's performance that can directly impact on a company

The **Environmental** factors include all those influences that have a material effect in a sector, that are determined by the surrounding environment it occupies (environment in the sustainable sense of the word).

The **Political** factors determine the extent to which a government may or may not influence the economy or a certain industrial sector, such as; tax policies, fiscal policy, trade tariffs.

The **Legal** factors determine the external business environment in a country, such as administrative regulations to implement laws, and internal policies that companies maintain for themselves.

The **Ethical** factors instil in the process the element of social values and responsibility, which provide a basis for what is right and what is not.

STEEPLE analysis provides a snapshot of the sector or area that enables a business to examine the external environment it operates in, rather than the more commonplace and traditional introspective examination of resources or factors at play in the marketplace.

3.2 Findings

The detailed findings of both the impact analysis and constraints and enablers can be found in deliverable D3.1 of this project.

The STEEPLE analysis found that:

Social - The social aspects that automated vehicles will confer on transport users are significant, once highly automated vehicles become the dominant form of transport in the network. Full acceptance and full automation will in the very long term lead to a transport system that provides for many of the societal needs missing at the present time, such as active social engagement across familial groups, improved time use and the personal interaction missing from today's network.

Technology - The development of vehicle automation is in its early stages, with some automated systems available as options on some vehicles. However, over the next few years, the technologies are expected to become more prevalent, becoming an everyday and inclusive part of the vehicle and our transport network. Many of the present constraints are developmental problems, but some will require fundamental technological breakthroughs that could potentially be accomplished, provided there is enough time and push from the manufacturers, infrastructure providers and the authorities.

Economics - Funding of any new innovative and important technology is key to its overall success. Automated vehicles are no different and are seen as a solution to many of the shortfalls that have befallen the global transport system at the present time. The private sector is funding significant development costs in the vehicles themselves, but to provide the roadway infrastructure support, they require developmental funding to be made available for transportation infrastructure upgrades.

Environment – This has been a key factor in enabling the development and subsequent deployment of automated transport, because of the perceived and generally acknowledged benefits that they will provide to the global environment. This will be particularly true, if concerns that surround their increased usage and numbers on the road are counterbalanced by improvements in efficiency per vehicle mile travelled, but the net effect remains uncertain.

Political - Effective roll-out of these innovative technologies requires significant political will on the part of all parties in governments. Early planning, development and deployment of the necessary infrastructure to cope with the mass deployment of these vehicles, needs to be a continuous and on-going process. If not, then there is a possibility that we will see limited acceptance and usage of these vehicles.

Legal - Legal and regulatory processes can provide a drag on deploying new and untested technologies, but are there for a reason. Laws, regulations and standards will require a thorough reviewing process to be undertaken and updated where necessary to provide a robust framework that automated vehicles can then operate in, effectively and safely.

Ethics - There are a number of distinct issues around the mass deployment of these vehicles onto the public road network, before they are fully ready. The safety of the general public and all road users is paramount, and even allowing for the long term benefits that these vehicles will eventually provide, this should not cloud our short term view of their use, if they are subsequently shown to be dangerous. The design of the automation systems needs to be done with conscious consideration of ethical decision making and the values that are embedded, sometimes unconsciously, in the decisions that will be made by automation software.

4 Cost Benefit Analysis

Based on the results of the analysis of costs and benefits of the specific use cases that have been performed, specific actions are formulated that need further attention before actual decision making regarding the implementation of automated driving can take place. In this chapter we describe the main results of the CBA performed and indicate the specific recommendations formulated per use case.

4.1 Automated trucks on the A19 (UK)

The CBA results for the English use case show there is most likely a profitable business case to invest in the use case from an overall perspective. However if the costs and benefits for the road operator are compared the Expected Net Present Value (ENPV) as well as the B/C ratio is not evidently positive (in the BAU scenario only the unemployment benefits are costs that society will bear currently assigned to the road operator explaining the relatively positive B/C ratio within this scenario).

If the three scenarios are then compared it is quite evident that neither a small nor a large investment (low versus high effort scenario) in the infrastructure pays off for the road operator. This is based on the fact that the benefits which solely can be assigned to the Nissan factory operator (time savings and fuel savings) are deducted from the total benefits. In other words, if Nissan was to be interested in this use case and if they are allowed they could actually benefit quite significantly and take on low or high infrastructure investment and still benefit.

Therefore the major recommendation of this use case is to not invest from a road operator perspective. However it could be foreseen that more of these specific use cases can be found and by grouping these use cases the deployment of this technology could be stimulated. This would however mean that the NRA would allow a private operator to apply specific necessary technology to public roads - which needs to be investigated to ascertain what legal development may be required.

There are two major issues that need further research in this use case, these are the costs of technology and how these will develop and the potential savings that can be realized by operators and how this impacts society as a whole. In more detail, the costs of the technology have currently been assumed based on expectations of newly developed vehicles, if these costs are significantly higher or lower this has a large impact on the results of this analysis. On the other side there is the issue of savings generated by abandoning drivers from the vehicles, which (next to the legal possibility to do so) delivers significant benefits, but also puts pressure on society as a whole. The recommendation here therefore would be to prepare for this transition to take place (including defining job opportunities for laid off drivers) by finding possible other specific situations where this technology can be tested in order to see if these benefits indeed can be realized and what role the NRA actually needs to play to realize this use case.

4.2 Truck Platooning on the A15 (NL)

The results of the overall CBA result show a positive Economic Net Present Value and positive B/C which grows with more effort from the government (in other words if the government invests more there is an increase in the CBA indicators). However if the road operator perspective is taken, the additional investment from the road operator in the infrastructure doesn’t pay off. In this case the very low (and maybe too low) investment of the low effort scenario is highly beneficial due to the relatively high number of safety benefits realised. This shows that an investment by the road operator does benefit the overall B/C ratio based on a faster uptake and faster realization of benefits, however the break-even point of this investment needs to be identified. In other words, up to what level of investment from the road operator does the uptake and realisation of benefits indeed speed up?

The fact that both operator as well as societal benefits can be realised with this use case shows that it is an interesting case to study further. Within this further study attention needs to be paid by the road operators to properly understand the level of investment in the infrastructure that is necessary to realise these benefits. At this time the necessary investment is largely built on assumptions and expert judgement. Therefore before the decision to invest in infrastructure can be taken, further research is necessary in e.g. the exact capabilities (technical and functional) of the roadside units, the number of units that is necessary to realise the use case as well as the costs for integration within existing systems.

In further research the steps towards the realisation of the productivity savings (including how realistic they are currently assumed) as well as the exact necessary investment in the infrastructure to realise the use case are of key importance. The productivity time savings can be split into the ability to do something else (including the possible necessary legal changes) as well as the drivers' behaviour and options to do something productive during this time. Besides this, further research needs to be performed for in which situations platooning can't be allowed due to road safety of other road users, for example in complex weaving sections and how this will be organised.

4.3 Autobahn Chauffeur on the A9 (D)

The overall numbers generated within this use case are much higher compared to the numbers from the Dutch or English use case (the ENPV is e.g. 5 billion EUR in the high adjusted scenario). This is mainly due to the equipment path that is chosen for the complete fleet of vehicles with resulting in a total of 12 million vehicles equipped in 2030 (of 45 million in total). In the scenarios of the German case study a differentiation has been made between the normal and the adjusted scenario (where for the latter the technology costs are depreciating by 10% per year). The impact of technology becoming cheaper (the normal versus the adjusted scenario) is quite significant on all indicators for the CBA. The B/C ratio gets closer to 1 for the low effort adjusted scenario and is larger than 1 in the high adjusted scenario, meaning that the use case is positive for society. For the other two CBA indicators there is also a positive impact of technology depreciation, the ENPV gets closer to 0 and the Economic Rate of Return are improving significantly (0% for the low effort scenario and 9% for the high effort scenario).

The key recommendation for the road operator in this use case would be to further investigate if there is a need to roll out services supporting automation if the test proves successful and if this roll out is feasible. The roll out for the rest of the network would allow for the further generation of the benefits.

The large investment costs that are necessary within this use case for the vehicles are something that needs more attention especially in connection to the roll out scenario that has been foreseen at this moment. Since this roll out scenario allows for the realisation of the benefits in a reasonable time frame. In other words, the choice of only accounting for costs on the vehicle side shows the need for roll out on the complete network if a significant level of penetration needs to be realised. People cannot be expected to buy a system in their car which they only can (or will) use on a specific test site.

Also here the possible time savings that can be realised and what people will actually do with these time savings are of key importance since they contribute greatly to the benefits within this use case.

5 Conclusions and Recommendations

A detailed analysis of a range of roadmaps has shown that it is expected that the uptake of automated driving at levels 3 and 4 will be higher than penetration rates of comparable systems have been in the past. Penetration levels between 5% and 15% are possible in the year 2030 for the low effort scenarios (market introduction of level 3 systems in 2020). Penetration levels between 15% and 35% are possible in the year 2030 for the high effort scenarios (market introduction of level 3 systems in 2020).

Globally, the mass deployment of automated vehicles requires a significant cooperative and collaborative engagement among all the stakeholders in the supply chain – from the innovators and technology developers, the OEMs / industrial suppliers, to the political and legal establishment and not least from the general public, who will, ultimately, use the transport. Significant bridges remain, that require crossing. These range from developing an inherently safe, cost effective and efficient transport system, the not insubstantial level of funding for network infrastructure upgrades, the determination of robust regulations and standards effective in law, to the successful engagement of the end users.

A comprehensive cost benefit model was developed where the aim was to give NRAs a better understanding of the economic benefits that could derive from the implementation of automated systems as vehicle deployment rates change, and to analyse the expected costs associated with the implementation, so that benefit-cost ratios can be explored. The report builds on the impacts that have been identified within WP2 and quantifies the significant impacts into monetary values. Monetization of the impacts has been done based on the description of the use cases and by making a number of key assumptions. Since automated vehicles are surrounded by a large amount of uncertainty regarding their impact, these assumptions are key in the analysis.

The CBA indicators which have been presented lead to the overall conclusion that there are definitely economic benefits to be derived for both NRAs as well as other stakeholders. However it is also indicated that higher benefits are not per se correlated with a higher investment in the infrastructure. There are also four key points that need further attention if decision making regarding automated vehicles and the related necessary investments needs to be done.

These conclusions are:

- The time and productivity time savings that form a large share of the benefits are based on a large number of assumptions (incl. assumptions regarding human behaviour)
- The division of costs and benefits over stakeholders (e.g. in the English case where Nissan get most of the benefits, even to such an extent that they could bear the necessary infrastructure investment costs) needs to be determined
- The costs of technology itself; not only is this an issue that returns in the sensitivity analysis in all three use cases, it is also based on many assumptions therefore raising the level of uncertainty
- The necessary information for NRA decision making is insufficient at the moment, further research is needed

Although this project has only examined three specific use cases in depth, the lessons learned in studying these use cases are more broadly applicable regardless of the differences among the driving automation functions and the environments in which they are applied. The broader lessons that should be kept in mind whenever planning for implementation of driving automation systems on motorways include:

(1) Recognise the diversity of driving automation systems and their use cases rather than assuming them to be a single homogeneous entity. Each driving automation system will be different from the others in terms of functionality and connectivity, so they need to be considered individually in assessing the impacts that they are likely to have and how they will be integrated with the rest of the transportation system. The primary attributes to use to understand the differences among the systems are their SAE level of automation (defining the distribution of functions between the system and the user), the extent to which they actively cooperate with other vehicles and/or the roadway infrastructure, and their Operational Design Domain (ODD) limitations. The ODD limitations are particularly significant, because these can vary widely and include considerations such as the quality of signage and pavement markings, degree of physical segregation from other road users, traffic density and speed, lighting and weather conditions. Some of these are directly under the control and responsibility of the road operators, who can thereby help to determine which driving automation systems are capable of operating on their facilities.

(2) For the foreseeable future, driving automation systems will continue to require the active engagement of human drivers for at least some portions of their trips unless they are confined to extremely restricted ODD conditions. Even if a system is capable of driving a vehicle without human intervention under ideal motorway conditions, it is likely to need a driver for the other portions of its trip, which is in turn likely to require staging areas at motorway access and egress locations to make the transitions between operating modes (especially if truck drivers need to enter and exit the vehicles under the economic model for driverless motorway operations).

(3) New features enter the motor vehicle market gradually, typically beginning with the highest-end premium vehicles. It normally takes a few decades for a new vehicle feature to advance from being an option available only on new high-end vehicles to being standard equipment on new mass-market vehicles. It takes a few more decades for the vehicle fleet to turn over to get to the point that the new features are available on a major fraction of the vehicles actually using the road network. Therefore, the time between the first market introduction of a driving automation function and its availability on a large fraction of the vehicles using the road network is likely to be several decades. It can be speculated that transitions may occur more rapidly in particular markets and territories where vehicle owners switch to accessing a shared pool of highly automated vehicles managed by a fleet operator. In this situation, the fleet operator has responsibility for managing a pool of (heavily utilised) vehicles and can cost effectively upgrade the fleet to ensure customers have access to the latest technologies. In this light the possibilities of upgrading vehicles with new software unlocking new automated driving functions needs to be taken into consideration, which could influence the normal gradual take-up.

(4) Related to the preceding point about the slow shift in the mix of vehicles on the road, realistic plans for the future need to recognize that the motorway environment will be shared between conventional manually driven and vehicles with varying

levels of automation capabilities for many decades to come. Motorway operators will need to serve the needs of “normal” drivers for the foreseeable future. Many of the operational improvements that will facilitate use of motorways by highly automated vehicles (better visibility of pavements markings and signage, improvement of geometry at blind curves, etc.) will also benefit manual drivers.

(5) The most significant limitations in the safety and performance of the driving automation systems are associated with their need to accommodate bad driving behaviours by human drivers of other vehicles and the unpredictability of bicyclist and pedestrian motions. Motorways already have an advantage in simplifying the driving environment by prohibiting pedestrians and bicyclists and limiting access to well-controlled entry ramps. Motorway operators could greatly enhance the simplification of the driving environment if they could segregate the connected and automated vehicles from the other traffic, so that the driving automation systems would only need to interact with other vehicles that are following the same well-defined behaviour rules. Such a segregation strategy could accelerate the introduction of highly automated vehicles by making it easier for them to achieve safe operations without needing extremely complicated hazard detection and response software to manage the full range of driving hazards. This segregation could be accomplished in time or space, depending on the specific physical and operational characteristics of the motorway. Time-based segregation would limit use of the motorway facility by highly automated vehicles to certain times of day when other traffic could be excluded. Space-based segregation would require construction of physical separations between the lanes used by the automated and non-automated vehicles so that they could be driving at the same time, but without crossing each other’s paths. Any decision to implement physical segregation of motorways in order to enable or facilitate automated driving functionality must factor in the cost and potential reduction in network capacity when only a small proportion of the vehicle pool will be capable of taking advantage of the segregated environment.

(6) The importance of communication and cooperation by driving automation systems cannot be over-emphasized because it is essential in order for these systems to achieve their hoped-for benefits in safety, efficiency and traffic congestion relief. The communication may be vehicle-vehicle (V2V) or between vehicles and the roadway infrastructure (I2V and V2I), each of which can provide different operational advantages. Just as importantly, if automation is implemented autonomously, without communication and cooperation it is likely to lead to losses in efficiency and traffic flow when large numbers of vehicles are equipped. Vehicles that can only sense the motions of the immediately preceding vehicle, without benefit of information communicated from other vehicles further ahead, will be at a significant disadvantage compared to vigilant human drivers, who look several vehicles ahead in traffic in order to anticipate the actions of those vehicles.
Communication/cooperation between the roadway infrastructure and the vehicles can be valuable for improved traffic management functions such as metering the entry of vehicles to the motorway and providing speed advisories or controls to adjust the vehicle cruising speeds to maximize traffic flow stability and throughput, maximizing the utilization of the motorway infrastructure. Roadside infrastructure is

also expected at specific complex locations to be able to allow for safe operation of these situations, e.g. at weaving sections with high intensity/capacity numbers.

(7) The introduction of driving automation systems is likely to have a wide range of effects on both the supply and demand sides of the transportation system. At this early stage, when only a few of the lowest-level driving automation systems have been introduced to public use, the general types of effects can be guessed at, but predictions of quantitative impacts will remain speculative until more research and practical experience have been completed. The demand-side impacts to consider include:

- Improved information about traffic conditions permitting more efficient traffic management and route choices by travellers
- High automation levels making “driving” more attractive compared with rail and air for longer trips, since “drivers” can make productive or enjoyable use of the travel time rather than being required to pay full attention to driving
- High automation enabling car trips by travellers who currently cannot drive
- Reduction of truck operating costs through energy savings and possibly reduced driver responsibilities making trucking more price competitive with other freight transport modes
- Improved motorway traffic conditions enabling faster and more reliable trucking service, increasing attractiveness to shippers.
- Management of shared, highly automated vehicles may include a road-pricing structure that accounts for route choice and time of trip. This provides roads authorities with an opportunity for revenue collection and for the use of fares as a means to manage demand.

The supply side impacts are somewhat less challenging to predict based on results of vehicle experiments and traffic simulations. These are likely to include:

- Reduction of crash rates helping to reduce non-recurrent congestion associated with crashes
- More efficient traffic management and incident response, helping to reduce congestion
- Enabling new traffic management strategies using I2V/V2I communication, such as variable speed limits, speed harmonization, and active coordination of traffic merging, to reduce congestion problems at motorway bottlenecks
- Increased capacity and smoother traffic flow dynamics, enabling each motorway section to handle higher traffic volumes with reduced delays
- Increased traffic speeds without loss of safety.

(8) Planning for the use of motorways by more highly automated vehicles needs to be founded on an explicit recognition of the unavoidable uncertainties surrounding the directions that the development of the automation technology will take, including essential unknowns such as:

- How soon will each automation functionality become available for use? What ODD limitations will it have?

- What safety and performance levels will the driving automation systems be able to achieve?
- How quickly will the market penetration grow for each kind of driving automation system?
- What effects will the introduction driving automation systems have on the demand for passenger and freight transport by motorway?

(9) The savings generated by removing drivers from the vehicles, assuming the legal possibility to do so, delivers significant benefits to the fleet operators, but also puts pressure on society as a whole. It is therefore important to prepare for this transition, including defining job opportunities for laid off drivers. A second step would be to find possible other specific situations where this technology can be implemented (in a demonstration setup) in order to see if these benefits indeed can be realised and what role the NRA actually needs to play to realize this use case.

(10) The productivity time savings can be split into the ability to do something else (including the possible necessary legal changes) as well as the drivers' behaviour to how this possibility will be used (which might not always be something productive). Besides this, further research needs to be performed in which situations platooning can't be allowed due to road safety of other road users, for example in complex weaving sections and how this will be organised.

(11) The large investment costs that are necessary in the German use case for the vehicles are an important aspect that needs more attention especially since this is strongly connected to the roll out scenario that has been foreseen at this time. But also, the choice of only accounting for costs on the vehicle side shows the need for role of the specified use case on the complete network for a significant level of penetration to be realised. This requires specific actions from the NRA to not only allow them on the road but also define activities that can support this roll out scenario.

Appendix 1: Answers to research questions

The research questions that were the starting point for the DRAGON project are listed below. Answers given do not repeat the DRAGON deliverables but instead give references to the relevant deliverable.

A. What are the likely timescales for the introduction of vehicles with different levels of automation on NRA roads? How will developments differ for passenger cars vs. goods vehicles? Will the development be gradual or disruptive? What does this depend on and what role can NRAs play in these developments?

The likely timescales for the introduction of vehicles with different levels of automation are discussed in D1.1. The timescales depend on the available technology (the time of deployment of vehicles of the various levels of automation), public awareness of this, the presence of automated driving in the media, and the previous experiences with and market penetration of ADAS.

Historically, new features enter the motor vehicle market gradually, typically beginning with the highest-end premium vehicles. It normally takes a few decades for a new vehicle feature to advance from being an option available only on new high-end vehicles to being standard equipment on new mass-market vehicles. It takes a few more decades for the vehicle fleet to turn over to get to the point that the new features are available on a major fraction of the vehicles actually using the road network. While the pace of change is different for different technologies, the above observations mean that the time between the first market introduction of a driving automation function and its availability on a large fraction of the vehicles using the road network is likely to be several decades.

As can be seen in D3.1 the roll out and therefore the potential impacts that can be realized can be influenced by the NRAs, however the specific actions that can be taken are not uniform for the specific use cases that have been under investigation. Furthermore, at this moment the exact technological requirements from these respective systems are unclear and therefore it is hard to provide detailed actions for NRAs to take. What has been found is that the cost of technology has a large impact on the CBA indicators and therefore any activities that will reduce either the risks around these costs or the costs themselves will stimulate in the end the deployment.

B. Do automated vehicles need to be segregated from non-automated vehicles to achieve maximum benefits? Will automation reduce congestion and smooth traffic flows and improve efficiency. What will be the impact on accident risk and safety? Would this be enforced?

The most significant limitations in the safety and performance of the driving automation systems are associated with their need to accommodate bad driving behaviors by human drivers of other vehicles and the unpredictability of bicyclist and pedestrian motions. Motorways already have an advantage in simplifying the driving environment by prohibiting pedestrians and bicyclists and limiting access to well-controlled entry ramps. Motorway operators could greatly enhance the simplification of the driving environment if they could segregate the connected and automated vehicles from the other traffic, so that the driving automation systems would only need to interact with other vehicles that are following the same well-defined behavior rules. Such a segregation strategy could accelerate the introduction of highly automated vehicles by making it easier for them to achieve safe operations without needing extremely complicated hazard detection and response software to manage the full range of driving hazards. This segregation could be accomplished in time or space, depending on the specific physical and operational characteristics of the motorway. Time-based segregation would limit use of the motorway facility by highly automated vehicles to certain times of day when other traffic could be excluded. Space-based segregation would require construction of physical separations between the lanes used by the automated and non-automated vehicles so that they could be driving at the same time, but without crossing each other's paths.

One of the use cases discussed in DRAGON does not foresee any segregation of the automated vehicles (Autobahn Chauffeur). The truck platooning use case assumes dedicated platooning lanes on some complicated road sections in the high effort scenario. The penetration rates in 2030 do not seem to justify implementing dedicated infrastructure in many places and the expectation is that the impacts on safety of mixed traffic will be very small. Some additional roadside systems or digital infrastructure are assumed to be needed. The third case (automated trucks for short-haul transport) discusses segregation between automated and non-automated vehicles using a lane management system (enforced using ANPR/CCTV), In this case, the automated vehicles only use the (existing) infrastructure at night, so effectively no capacity is taken away from the road network for non-automated vehicles.

C. Does the physical infrastructure need to be adapted? This could mean either the reduction of infrastructure (fewer and / or narrower lanes needed because of more efficient traffic flow) or adapting the infrastructure to accommodate demanding situations, e.g. by making acceleration lanes or changes to entry and exit ramps.

See the use cases (D2.1) for descriptions of what changes to the infrastructure are expected. In 2030, the vehicle fleet will consist of vehicles of all levels of automation up to level 4 (see D1.1). This means that on all roads (partially) manually driven vehicles will be present, which in turn means that the infrastructure design still needs to be based on the capabilities and limitations of human drivers. Also, automated driving is only assumed to be allowed on those parts of the infrastructure where this is not likely to cause conflicts with other vehicles. Some parts of the infrastructure have been adapted to make interactions between automated vehicles / platoons and other (manually driven) vehicles safer. It should be noted that many of the operational improvements that will facilitate use of motorways by highly automated vehicles (better visibility of pavements markings and signage, improvement of geometry at blind curves, etc.) will also benefit manual drivers.

D. Is there a need to change traffic monitoring, traffic management and incident management strategies? For instance, is there a need to better distribute vehicles over various routes (taking into account their suitability for automated driving), to open lanes for automated vehicles only, or to deal with a malfunction of automated vehicles?

The introduction of driving automation systems is likely to have a wide range of effects on both the supply and demand sides of the transportation system. At this early stage, when only a few of the lowest-level driving automation systems have been introduced to public use, the general types of effects can be guessed at, but predictions of quantitative impacts will remain speculative until more research and practical experience have been completed. The key demand-side impact to consider w.r.t. traffic and incident management is improved information about traffic conditions permitting more efficient traffic management and route choices by travelers.

The supply side impacts are likely to include:

- Reduction of crash rates, especially for the lower levels of automation, helping to reduce non-recurrent congestion associated with crashes
- More efficient traffic management and incident response, helping to reduce congestion
- Enabling new traffic management strategies using I2V/V2I communication, such as variable speed limits, speed harmonization, and active coordination of traffic merging, to reduce congestion problems at motorway bottlenecks
- Increased capacity and smoother traffic flow dynamics, enabling each motorway section to handle higher traffic volumes with reduced delays
- Increased traffic speeds without loss of safety.

In the DRAGON use cases, some traffic monitoring and management is assumed, e.g. lane control in the UK case, ramp metering or something similar in the NL case (see D2.1). These measures would not necessarily be needed in the current situation. V2V and V2I communication could also be used to achieve at least part of what the roadside systems are intended to do.

Better distribution of vehicles over various routes has not been a topic in any of the use cases (only individual roads were looked at). There are no data about the frequency of occurrence of malfunctions of automated vehicles, so it is not clear if there is a need for e.g. additional incident management strategies or shoulder lanes/breakdown havens where automated vehicles can park themselves.

E. Would regulation or financial incentives initiated by NRAs be enablers to accelerate the deployment of automated vehicles? What other enablers could be envisaged? What constraints are there currently in how NRAs operate? What is needed to ensure interoperability across Europe?

Enablers were discussed in D2.1. – in general and for the 3 use cases.
As a result from WP3 there are a couple of enablers that can be defined:

1) The adaptation of the legal framework to allow drivers to do something different when their vehicle is in automated mode. This is based on the fact that the major benefits in all the use cases consist of productivity and time savings. As part of the enabling of course the (possible negative) side effects need to be taken into account.
2) The reduction of technology costs by encouraging pilot tests for testing the technology and therefore creating more robust system development.

Use case specific constraints and enablers as mentioned in the presentation:

- UK case: Status of driver, some dedicated infrastructure needs to be funded, support from local and national government needed, better utilisation of trucks
- Dutch case: Status of driver, increased comfort on long-haul trips, legislation (exemptions; driving and resting time), load impacts (bridges), clear business case (reduced fuel costs)
- German case: System frees up time, purchase costs, connected or not (consequences for road capacity), legislation

Interoperability has not been researched in DRAGON. The use cases were all national ones.

F. What changes in legislation are needed to allow tests with automated vehicles on public roads, and what additional changes would be needed at a later stage to allow automated driving of any level (e.g. the Vienna Convention)? Which countries can serve as examples, having already implemented legislation allowing automated vehicles on the road under certain conditions (e.g. Sweden, Germany, the Netherlands)?

This topic was addressed in a limited way in D2.1 (Analysis of constraints and enablers / Legal). The use cases made some assumptions about legislation changed to facilitate automated driving, e.g. changes to driving & resting times in the truck platooning case. In all cases it was assumed that vehicles without a driver would be allowed on the road. For testing purposes, legislation is being prepared in several countries to allow testing without a driver in the vehicle. No overview of all necessary changes to legislation was made.

G. Is the traffic demand expected to increase or decrease, and what are the differences between passenger and freight transport forecasts?

The introduction of driving automation systems is likely to have a wide range of demand side impacts. At this early stage, when only a few of the lowest-level driving automation systems have been introduced to public use, the general types of effects can be guessed at, but predictions of quantitative impacts will remain speculative until more research and practical experience have been completed. The demand-side impacts to consider include:

- High automation levels making "driving" more attractive compared with rail and air for longer trips, since "drivers" can make productive or enjoyable use of the travel time rather than being required to pay full attention to driving
- High automation enabling auto trips by travelers who currently cannot drive
- Reduction of truck operating costs through energy savings and possibly reduced driver responsibilities making trucking more price competitive with other freight transport modes
- Improved motorway traffic conditions enabling faster and more reliable trucking service, increasing attractiveness to shippers.

Traffic demand is expected to have increased by 2030, just as it has been increasing over the past years. DRAGON did not make any predictions about the general impact of automated driving on traffic demand, as the available literature does not give any useful information – depending on the scenario assumed, demand can either increase or decrease. Two of the use cases assume there might be some effect on total mileage as a consequence of automation (as costs per km decrease), but other factors such as the traffic conditions are also important (in a very heavily used network, demand is not likely to increase, unless the capacity of the network increases and congestion is reduced because of the automation, which is not expected yet in 2030).

H. What traffic situations are very demanding for automated vehicles and non-automated vehicles alike (especially at peak loading), and will automated vehicles of different levels perform more efficiently and safely in those situations (in regular situations such as entering and exiting a motorway, weaving sections, traffic close to breakdown, but also in irregular situations such as incidents, road works, or adverse weather)?

There is still very little information about how automated vehicles of various levels will perform in busy traffic (not much is known about how they behave in light traffic, either). The levels that are currently on the road do not seem to perform very well at peak loading, because they have to be programmed to behave like extremely timid, cautious drivers based on the performance limitations of the technology. There are examples (though not discussed in literature) of state-of-the-art prototype vehicles having trouble finding a suitable gap to enter a highway, for instance. None of the existing prototype vehicles are capable of handling the irregular situations such as traffic incidents, road works or severe weather conditions. V2V and V2I communication are supposed to help in many 'difficult' situations (e.g. C-ACC is assumed to have a stabilizing effect on traffic flows; V2V communication could help to create suitable gaps at on-ramps or weaving sections), but estimations of benefits of communication are hard to find and sometimes unrealistic (because based on unrealistic assumptions about the vehicle's capabilities and behavior, and the reactions of drivers of other vehicles). In DRAGON, we had to work with our own assumptions, where possible based on available literature that we trusted (that was transparent about their own assumptions or sources of data) and lengthy discussions with the project team.

I. What kind of map data (static and dynamic) or data about the road network would be used by automated vehicles to support on-board sensors, and will NRAs need to play a role in providing this information (e.g. data about road works and lane closures)? What can connectivity / cooperation contribute to the functioning of automated vehicles and road trains (and their interaction with non-automated vehicles)? In what situations is cooperation required in order to avoid negative side effects?

In DRAGON, the low and the high effort scenarios were used to compare a situation without much communication with a situation in which communication plays a much bigger role. Higher benefits are expected in the high effort scenario (see D2.1, D3.1). As mentioned before, at the moment manufacturers do not want to depend on remotely communicated information only, but it seems logical that if good quality information is offered, automated vehicles would use it in addition to their sensors. Some of the information will probably still come from road authorities in 2030, but private partners could also supply information or be commissioned to provide information now provided by road authorities. The Talking Traffic partnership in the Netherlands is an interesting example of public-private collaboration in this respect. At the EU level, there is only limited regulation regarding (map) data. There is regulation concerning safety data (but this only needs to be provided if available and is under discussion what this exactly contains) and discussion regarding the use of standardized data messages.
Furthermore, the DRAGON consortium is aware of the development of HD maps by various industry stakeholders, but at the moment it is unclear to us how much interaction there is between map makers and road authorities.

J. At present, automated vehicles driving autonomously, must keep longer headways than most human drivers would do in busy traffic, causing loss of network capacity and non-automated vehicles to cut in in front of automated vehicles. Is short range communication needed and does this require the installation of road side units?

The importance of communication and cooperation by driving automation systems cannot be over-emphasized because it is essential in order for these systems to achieve their hoped-for benefits in safety, efficiency and traffic congestion relief. The communication may be vehicle-vehicle (V2V) or between vehicles and the roadway infrastructure (I2V and V2I), each of which can provide different operational advantages.

Vehicles that can only sense the motions of the immediately preceding vehicle, without benefit of information communicated from other vehicles further ahead, will be at a significant disadvantage compared to vigilant human drivers, who look several vehicles ahead in traffic in order to anticipate the actions of those vehicles.

In the use cases we have discussed examples of V2V communication (C-ACC) as well as examples of I2V (ramp metering in the truck platooning use case, a communication network along the Autobahn in the German case). The road side units are mostly assumed to be needed for safety reasons (but could also be said to be mainly for efficiency of comfort reasons, as long as we don't know how well automated vehicles perform in heavy traffic and how drivers of other vehicles react to their maneuvers), and are assumed to be needed most along busy sections of the road network and at construction and accident sites.

At present, certain applications have been identified which require or benefit from the installation and use of road-side units, though the maximum benefit of these are more likely to be in urban environments. The debate about short range communication (ITS-G5) versus cellular is still on-going, as well as a new debate on the most suitable technology for short range (ITS G5 vs. Cellular V2X)

See also the response to question I.