**CEDR Transnational Road Research Programme**

**Call 2014: Mobility and ITS**

funded by Finland, Germany, Norway,

the Netherlands, Sweden, United Kingdom

and Austria

**DRAGON: Driving automated vehicle growth on national roads**

**WP 3: Cost Benefits assessment**

Deliverable No 3.1

August 2017

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| TRL, UK | trl_rgb |
| TNO, Netherlands |  |
| IKA, Germany |  |

**CEDR Call 2014: Mobility and ITS**

**DRAGON**

**Driving automated vehicle growth on national roads**

**D3.1 Report on the benefits and costs of automation**

Start date of project: 01/09/15 End date of project: 31/07/17

**Author(s) this deliverable**:

Martijn de Kievit, Evguenie Poliakov (TNO), Peter Vermaat (TRL), Adrian Zlocki, Jan Sauerbier (IKA)

PEB Project Managers: Phil Proctor and Torsten Geißler

Version: final draft, 08.2017

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# Introduction

The overall aims of the DRAGON project are to:

* Set out how vehicle automation will change road transport over the next 20 years
* Identify what cross-border issues will be raised, with a focus on the impacts on National Road Authorities (NRAs) and how these vehicles will affect NRA operations
* Facilitate NRAs in taking decisions on when and how to provide support for automated vehicles

The aim of this report is to better understand the economic benefits that NRAs 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 an important part of the analysis. This is why quite some attention is being given towards these assumptions within the report.

The report first describes the overall assessment methodology in WP2. Building on the standard CBA methodology from DG Regio (European Commission) a number of challenges is identified as well as key aspects that need to be taken into account for a CBA specifically for automated vehicles. This chapter also builds on the Evaluation of Intelligent Road Transport Systems handbook to verify if major impacts that would have been expected are missing.

In chapter 3 the methodology is applied to the use cases and their costs and benefits are described. Within this chapter for every significant impact the line of reasoning as well as the necessary assumptions to come to the monetized values are described.

In chapter 4 the CBA results for the use cases are presented for a given set of indicators (described in the first paragraph). In this chapter also key challenges for research are identified based on the performed sensitivity analysis. The key challenges have been made more specific and formulated into actions for NRA’s especially for aspects where a generalisation for NRA’s is seen as relevant.

Chapter 5 presents the conclusions and recommendations regarding costs and benefits for automated driving from the NRA perspective.

# Assessment methodology

## Approach

The goal of assessing the costs and benefits of a project is twofold.

* First of all it identifies (in a structured manner) the possible costs and benefits related to the project.
* Second the assessment shows if and what amount of financial support of the government is efficient compared to at least a ‘do-nothing’ scenario with the result to support more objective decision making for policy makers.

For DRAGON the projects are defined by the use cases which have been selected in WP1. For each of these use cases the potential impacts for society have been determined in WP2 and are quantified in this report. The policy scenario’s which form the basis for every use case allow for a comparison of costs and benefits of each of the use cases amongst themselves and between each other. The general aspects that need to be taken into account for a CBA regarding Automated Driving (AD) are mentioned below.

Key for every transport project is to identify the objectives: “The next step is to clearly state the main objectives of the transport project. These are generally related to the improvement in travel conditions for goods and passengers both inside the impact area and to and from the impact area (accessibility), as well as improvements in both the quality of the environment and the wellbeing of the population served.”

Within the approach we have used as much as possible available resources to support the expected costs and benefits for the use cases. However, since automation has mainly been a research topic exact details have been hard to find. Therefore within the report significant time is spent on the assumptions underlying the results. This also in turn leads to new research questions of issues that need further attention.

## General costs and benefits

### Identification of costs

Based on ‘the evaluation of intelligent road transport systems: methods and results’ a first general categorization of costs has been developed.

Three costs categories can be identified:

1. Infrastructure operator point of view: Necessary additional investment in infrastructure due to requirements from automated vehicles in addition to the existing situation. These could be special lanes or roads but also investments on the digital infrastructure, this also contains the influence of the use cases on the regular processes from the NRA’s – Design – build – maintain and operate. Last but not least AD is expected to influence traffic management and therefore will require adaptations to existing strategies.
2. Vehicle/individual: being driver training and road user education for the new technologies (as well as maintaining driving skills in a mixed traffic situation), but also additional costs for the vehicle owner (e.g. for trucks) to equip them with the necessary AD technology.
3. Mobility industry:
	1. Highly detailed maps to facilitate automated driving from service providers
	2. Additional costs at the automotive industry in making AD available, e.g. dealer training but also compliance and standardization.
	3. Increase in costs of repair/maintenance due to an increase in complexity of systems
	4. Insurance costs generally assumed to be connected to the number of claims but also related to liability costs in allowing these kinds of systems on the road

Public authorities (next to infrastructure operator costs) will experience the need for additional investments for example in relation to road worthiness testing and certification of vehicles. However these have not been taken into account since they apply to the more general level of automation and are not use case specific. Secondly, at this moment it is unclear how these will develop and what exact costs are involved, therefore these have not been taken into account.

### Identification of benefits

For transport projects a number of typical effects need to be quantified (see as an example the table below) (EC, 2015).

Table 1 Valuation methods for regular transport CBA effects

|  |  |
| --- | --- |
| Effect  | Valuation method |
| Travel time savings | - Stated preferences- Revealed preferences (multi-purpose household/business surveys)- Cost saving approach |
| Vehicle Operating Costs savings | - Market value |
| Operating costs of carriers | - Market value |
| Accidents savings | - Stated preferences- Revealed preferences (hedonic wage method)- Human capital approach |
| Variation in noise emissions | - WTP//WTA compensation- Hedonic price method |
| Variation in air pollution | - Shadow price of air pollutants |
| Variation in GHG emissions | - Shadow price of GHG emissions |

Next to these effects of general transport projects a specific number of effects are expected to take place in relation to automated driving. These are in addition to the effects mentioned above (free from Lu, 2016):

* Increase in attractiveness of transport (resulting in more and longer mileage)
* Changes in experienced comfort of driving
* Improvements in capacity and efficiency due to automation of driving tasks

As can be seen for every impact already possible methods are available for a detailed quantification of these impacts into benefits. Also with the benefits it is important to identify between who ‘receives’ the benefits since this will allow us to quantify not only an overall result for the use cases but also specify costs and benefits for specific stakeholders.

## DRAGON-specific

For every use case the expected impacts have already been classified within WP2. Within WP3 the following steps have been followed to allow for a proper identification of costs and benefits of the specific use cases:

1. Selection of most relevant impacts (in other words the impacts classified as minimum, near minimum or limited have been assumed to be 0 in the quantification).
2. A specific focus has been put on the costs to identify the different costs that could be identified with the limited sources available.
3. For the selected impacts relevant sources have been identified to look for possible ways of quantification. If these numbers are not available expert judgement has been applied.
4. These impacts than have been put onto a timeline within the policy scenario’s that have been defined in order to be able to calculate the relevant CBA outputs (see section 4 for the exact CBA indicators used).

The CBA model will monetize the costs and benefits described above. The costs will include investment, operation and maintenance as well as specific costs such as additional periodic testing and training of drivers if applicable.

Benefits will include time savings for trips, potential reduction in fatalities, injuries and property damage; fuel costs savings, reduced externalities (CO2 emissions). These are the standard benefits assessed in transport-related CBA, with standard valuation coefficients readily available. An interesting new benefit is the change in the use of time by the driver of an automated vehicle. Depending on the degree of automation, the driver can use part of the time in the vehicle for administrative and other office related tasks, for instance, presentation preparation for business travellers or routine documentation work for truck drivers. This time can be saved from out-of-vehicle working hours and added to leisure, which also gives the valuation parameter for this benefit.

An interesting issue is the potential employment reduction due to automation. On one hand, you can view it as the reduction of costs for the transport operator. On the other hand, however, the potential layoffs of drivers will cause extra social costs on unemployment benefits and retraining if necessary. In addition, loss of wages will automatically reduce GDP, hence overall social welfare of which GDP is a part. It is an established practice to consider wages earned as social benefits in CBAs of labour market programmes (Campolieti and Gunderson 2005[[1]](#footnote-1)). Therefore, in case of job losses, we need to establish the time profile of newly unemployed: What percentage of laid-off workers will remain unemployed after one, two etc. years? What percentage will be retrained and find jobs in other occupations, e.g. vehicle maintenance? Then, by using data on wages, retraining costs and unemployment benefits, we can calculate costs to society in each year. This is further put in practice in the English use case where truck drivers are laid off.

# Analysis of use cases

This chapter explains in more detail the three use cases of DRAGON and what assumptions have been used for calculating the costs and the benefits. Every sub-section starts with a short description of the use case followed by two paragraphs on the assumptions for the costs and one for the benefits.

## Automated trucks on the A19 (UK)

### Use case Automated trucks on the A19

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 6 miles.

**Concept**

The use case specifically contains the automated control of freight movements on the A19 at night during specified times, without drivers, on a dedicated lane closed to other traffic.

This would require use of the right-hand lane on each carriageway being dedicated for automated freight transport between the Port of Tyne and the Nissan car plant, with the left-hand lane for other traffic.

The use of the right-hand lane is for automated freight only, to be communicated using lane signs on overhead gantries and additional signage explaining about traffic priorities, time of use and method of enforcement / fines (ANPR, CCTV etc).

Automated freight traffic would utilise V2V and V2I communication media to access the dedicated lane.

The automated freight traffic would communicate with the installed infrastructure and traffic, whilst progressing to their final destination, so that other traffic is aware (V2V) and junctions (V2I) can be closed / opened to allow free passage if required.

The automated freight movements would require dedicated infrastructure at each end of the corridor to enable a driver to take over the final stage of the journey or automated bays, and transfer of goods from or to the heavy goods vehicle (not the NRA’s responsibility).

It is expected, that by 2030 additional non-Nissan heavy goods vehicles would be automated and in this use case be able to interact with the V2V and V2I infrastructure around the automated freight lane.

**Intended Impact**

The intended impact of this use case would be the provision of an automated and driverless freight transport link between the Port of Tyne and the Nissan car plant, enabling Nissan to make more effective and efficient use of the A19 carriageway than is currently the case.

### Costs Automated trucks on the A19

***Assumptions***

The costs to be incurred will be the (potentially) higher costs of the automated vehicles, costs incurred in the operation of these vehicles, and infrastructure costs.

It is assumed that the technology required to produce and operate automated freight vehicles exists, i.e. development costs are not included in the assumptions. As the number of vehicles involved is very small, any specialised development required will be vastly more than can be afforded if bespoke technology is required for the vehicles. A further difficulty in estimating technology costs is that, if it is assumed that the vehicles are completely automated, the controls and accommodation required for drivers can be eliminated, leading to a saving in production costs. It is therefore possible that automated vehicles could in fact be cheaper than vehicle requiring drivers, though this is unlikely in the early days of automated vehicle production.

The second assumption is that the vehicle will only be used for the task of transporting newly produced cars from the Sunderland factory to the port area for export.

In terms of operational costs, additional costs incurred are likely to be in enhanced testing required for the higher level of technology required by the vehicles, and costs for services required to support automated driving. The services required will be for monitoring purposes and incident response. Enhanced communications capabilities will comprise the bulk of these costs.

Last but not least it is assumed that the infrastructure costs vary on three different levels (similar to the three different policy scenarios):

1. No infrastructure required as the only difficult parts of the journey are probably at the factory and the port, which will not fall under the jurisdiction of the NRA (it is assumed the vehicles are themselves capable to solve these difficult parts)
2. Minimal infrastructure (only static signage to warn other road users about the potential of encountering automated trucks and the closure of the lane for the duration of the night time). Improved white lining is also assumed to be part of this scenario.
3. Intelligent infrastructure support (hi-resolution digital maps, connectivity to traffic lights to allow vehicles to reliably read traffic signal status and possibly also include priority as well as communication through signage for other road users)

These numbers are provided within the costs part.

This specific use case requires another cost category to be included, knowingly the unemployment costs for society. Since it is assumed there are no drivers needed within this use case these drivers are assumed to be fired in the first year of the project. For these drivers the following assumptions are applied:

1. 70% won’t find a job immediately and therefore will request benefits from the government. After two years all of them will have found jobs in a similar profession.
2. The unemployment benefits in the UK are stated to be 307,= pound per month (calculated to be 4,386.= EUR a year).

For the three scenarios the number of trucks used is equalled to the number of drivers that will be unemployed.

***Numbers used***

The Sunderland plant produces some 500,000 vehicle per year, of which 80% (400,000) are exported (figures from Nissan). We assume that 75% of these exports go through the port, (with a lower and upper bound used of 50% (low estimate) up to a 100% (high estimate)).

If we assume that each truck can accommodate 10 new cars on average, and that the automated vehicles can operate for 7.5 hours/day, and each journey requires 2.5 hours for a round trip (including loading and unloading), the result is a fleet of 34 trucks to move 400,000 vehicles per year, or between 27 and 43 trucks for the low and high estimate of vehicles exported through the port.

The additional technology costs for building an automated vehicle are extremely difficult to estimate. The very small numbers of vehicles involved means that it will never be economically feasible to build vehicle specifically for this task, so we assume that the vehicles will only be implemented once the technology is mature and being used in production vehicles, and will be mass-produced, amortising the costs of a large fleet of vehicles.

Bearing in mind the comments made in the previous paragraph, for the purposes of this study, we have assumed that the additional technology costs for automated vehicles will be between 50,000.= EUR and 200,000.= EUR, with a modal cost of 100,000.= EUR. The very small number of vehicles involved in this analysis means that per-vehicle technology costs are quite high, based on the very specific demand that is made. Although it can be safely assumed that technology will become cheaper and this technology will be more widely available it is now assumed that the modification of these trucks can be paid with these numbers.

The additional costs incurred by services required for automation are assumed to be between 250.= EUR per vehicle per year (this assumes the only additional services required will be reliable communications to the vehicle) and 2,000.= EUR per vehicle per year (this assumes an additional permanent staff member is required to monitor operations during the hours of operation). Service like recovery of broken down vehicles are not assumed to be required as these are already required for existing transport vehicles. The modal cost of 250.= EUR per vehicle per year is based on additional communications costs and automated monitoring equipment, but no additional staffing.

As the vehicles are significantly more complex than existing vehicles, we have assumed that an additional cost will be incurred with each annual vehicle inspection. The values assumed are between 250.= EUR per vehicle per year (an additional two and a half hour of inspection time) and 2,000.= EUR per vehicle per year, with a modal value of 500.= per vehicle per year.

Regarding the infrastructure costs the following is assumed regarding the equipment of the road. For the BAU-scenario we assume there are no infrastructure costs for the road operator. For the low effort scenario only static signage is assumed to be put down alongside the road and at the on- and offramps resulting in an investment of approximately 10,000.= EUR for the entire period of the planning horizon of the CBA. Secondly the white lining is assumed to cost 12.= EUR per metre painted and is applied bidirectional for the entire stretch. In the high effort scenario the assumption is made that next to equipping the road with all the functionality as the low-effort scenario also a total number of 20 ITS-G5 units are installed to facilitate the use case on the highway. The costs for these units are estimated at 50,000.= EUR each of which 30,000.= is connecting these units together and to the traffic management centre.

The assumptions for the costs are presented in the table below.

Table 2 Cost assumptions for the English use case

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Description | BAU | Low | High |
| Vehicle | Technology (Euros per truck per 7 years) | 200,000 | 100,000 | 50,000 |
|  | Service provider (Euros per truck per year) | 1,000 | 500 | 250 |
|  | Additional Periodic testing (Euros per truck per year) | 1,000 | 500 | 250 |
| Infrastructure costs | Signs |  | 1,000 |  |
|  | White lining per meter |  | 12 |  |
|  | ITS Unit |  |  | 50,000 |

### Benefits Automated trucks on the A19

***Assumptions***

The benefits expected from using automated tracks on this route are assumed to fall into the following categories:

* Reduction in fatalities, based on the expectation that automated vehicles will be involved in fewer accidents. This is a widespread expectation, and is based on figures which show that more than 90% of accidents are caused by human error, and is one of the main driving forces behind vehicle automation.
* Similarly, reductions in non-fatal serious injuries from accidents, reduction in light injuries from accidents, and reduction in property damage from accidents. Again this is based on the expectation that automated vehicles will be involved in fewer accidents than manually driven vehicles.
* Reduction in CO2 due to more optimal driving characteristics of automated vehicles, leading to a societal benefit
* Reduction in energy consumption due to more optimal driving characteristics of automated vehicles, leading to a cost saving for operators
* Cost saving due to not having to employ a driver for each vehicle.

***Numbers used***

The costs saving from a reduction in fatalities and injuries is based on UK figures for the cost of each fatality and injury to the UK, and the accident figures for UK roads from existing accident statistics.

In the UK, each fatality is costed at 2.6 million EUR, using UK government figures. Using the number of km driven annually, and accident statistics for this road type, we calculate that the number of fatalities reduced will be 0.0057 fatalities per annum, or one fatality every 180 years or so. Clearly this means that the accident savings through reduction in fatalities is to all intents and purposes nil; furthermore, the annual cost saving of 14,500.= EUR is not really realisable as budgets are not normally calculated over such long terms. Nevertheless the figures have been kept in the CBA so that the analysis could be used for other scenarios involving larger vehicle numbers.

Similarly, the reduction in seriously injured amounts to some 0.02 fewer injuries/year, and lightly injured to about 0.12 fewer light injuries/year, and cost savings of 6,100.= EUR and 4,200.= EUR per year respectively. The reduction in damage only incidents is expected to save some 13,300.= EUR per year, and as the number of damage only incidents is expected to reduce by some 3.6 per year, this saving is real.

Using data from existing studies on automated driving, it is expected that energy used by automated vehicles will be between 11% and 14% less than human-driven vehicles, with a modal value of 12%. Using this and the assumed cost of CO2 of 26,= EUR per ton, we can calculate the societal cost saving due to reduced energy usage, as well as the reduction in energy costs to the operator.

Finally, we use the hourly rates for heavy goods vehicle drivers to calculate the savings to the operator of not needing to employ drivers. The values used within this CBA are varied between 24.= EUR and 40.= EUR per hour of productivity time shifted with a modal number of 32.= EUR.

Both these numbers and the CO2 and energy savings are calculated based on the assumption that there are 300 days of operation within a year and that there are between 7 and 9 hours of operation. This is also multiplied by the number of trucks that is used within the respective scenario (between 27 and 43).

## Truck Platooning on the A15 (NL)

### Use case Truck Platooning on the A15

**Introduction**

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.

**Technologies applied**

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) 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.

**Infrastructure**

The (physical and digital) infrastructure has been adapted so that truck platoons can safely and efficiently interact with other vehicles (of all levels of automation). In the high effort scenario, the changes were made based on discussions with truck manufacturers. Digital maps inform the drivers where and when they can drive in platoons. The road markings and design of acceleration lanes, weaving sections etc. support automated driving in (long) platoons.

NRAs invest in truck stops where platoons can be formed. Also, running the back-office could be a business opportunity.

In the high effort scenario, there are dedicated truck platooning lanes on some (complicated) road sections, so that truck platoons almost never have to split up. Also, there is V2I/V2V communication so that platoons know when they need to split up when they share the road with other (non-automated) vehicles.

On on-ramps there are ramp metering installations turning red when a platoon approaches. Near exits, signs indicate that there are truck platoons on this road and that it is recommended for other traffic to move to the right lane well before the exit if they spot a platoon.

### Costs Truck Platooning on the A15

***Assumptions***

The costs have been divided into two parts:

* Equipment of the vehicles
* Equipment of the infrastructure

For the first category of costs the additional equipment costs for the trucks are assumed to be different for the three different scenarios. The average costs are estimated to be 2,000.= EUR, since there is a high level of sensor provision on the vehicles already available, therefore the additional costs to allow platooning to be possible are deemed rather limited. Secondly the trucks are assumed to be renewed every 7 years therefore these investment costs return every seven years in the cost benefit analysis. The total numbers of trucks equipped is a growth curve based on the assumption that 35% of new trucks is equipped every year and that already equipped trucks that are scrapped will be replaced also with equipped trucks. In total at the end of the horizon of the CBA (2030) 70% of the total number of trucks is equipped (based on a vehicle fleet of 155 thousand vehicles).

In addition to investment costs for the vehicle there are operation and maintenance costs for the system to be operated. For the operational costs 150.= EUR per year is assumed to be paid to a service provider to be able to use the service. This service includes finding trucks for forming a platoon, redistribution of the accumulated benefits and other necessary communication including for example billing. In the category of maintenance the costs are assumed to be 150.= EUR on a yearly basis, this is based on the assumption that a yearly test will be performed where (if necessary) equipment will be replaced. Last but not least, part of these costs is the training of drivers for these trucks, this is assumed to be 75.= EUR per year. This is based on the assumption that in the first year (when the truck is equipped) there will be more intense training, but also a couple of retraining modules will be implemented when the service is used.

For these numbers lower and upper bound numbers have been chosen as well to be able to compare the three policy scenarios. In Table 3 these costs are shown in more detail.

For the infrastructure side the equipment at the roadside is an important part with the different scenarios that are compared. The assumption at this moment is that ITS-G5 communication units will be used to facilitate truck platooning on the A15. The estimated costs of these units vary largely, but a study report from GPO in the United States estimated that an average solely installed unit could add up to 50,000.= USD (here estimated to be equal to 50,000.= EUR). A large part of these costs are connecting these unit to the traffic management centre (approximately 30,000.= EUR). For the Netherlands (since a large part of the network is already equipped with communication equipment) therefore the average costs of an ITS unit is assumed to be 20,000.= EUR. This includes the operation and maintenance costs of these units for their lifetime.

For the BAU scenario (as stated in D2.1) no infrastructure equipment is assumed. Within the low effort scenario only a limited number of 20 units is assumed to be deployed at the ten major intersections in two directions with a cost of 20,000.= EUR. For the high effort scenario a total deployment of 100 units is assumed but with a costs of 10,000.= due to economies of scale. The lifetime for the units is assumed to be 10 years where the deployment of the units for the low effort scenario is done within the first year and for the high effort scenario over a period of 10 years.

Table 3 Costs assumptions for the Dutch use case

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Description | BAU | Low | High |
| Vehicles | Technology (Euros per truck per 7 years) | 1,000 | 2,000 | 5,000 |
|  | Service provider (Euros per truck per year) | 100 | 150 | 200 |
|  | Additional Periodic testing (Euros per year per truck) | 100 | 150 | 200 |
|  | Training drivers (Euros per year per truck) | 50 | 75 | 100 |
| Infrastructure | Costs per unit (Euros) | 50,000 | 20,000 | 10,000 |

### Benefits Truck Platooning on the A15

The main categories for benefits regarding truck are:

* Safety (expressed in reduction of accidents leading to less fatalities, injuries and property damage)
* Environment (reduction of CO2 emissions)
* Energy (savings in fuel use of trucks driving in a platoon)
* Economical (possibility to use productivity within the truck for something else when platooning)

For the safety category the basis has been a study report from 2012 from the national organisation for safety (“Onderzoeksraad voor de veiligheid”) regarding accidents with trucks on the national highways. This report indicates the number of accidents with trucks and related fatalities and injuries including a typology of the kind of accident. For the typology it has been decided which number of accidents potentially would be preventable by the truck platooning application. This number was then furthermore scaled down to only the A15 based on the truck mileage driven on the A15 compared to the rest of the Dutch network (i.e. 5% of the truck mileage is driven on A15). For property damage accidents (PDO) the general division for accidents over fatalities versus PDO in the Netherlands was used to estimate the number of PDO accidents from trucks (i.e. 600 PDO accidents).

To estimate the benefits from safety the monetary values for each category was chosen as displayed in the following table. Here also the number of total accidents is displayed (please note these haven’t been reduced yet for the vehicle mileage).

Table 4 Safety assumptions Dutch use case

|  |  |  |
| --- | --- | --- |
| Safety indicator | Accidents (preventable) | Monetary value (EUR) |
| Fatality | 24 (15) | 2,612,000 |
| Severe injury | 62 (33) | 281,000 |
| Slight injury | 247 (132) | 90,000 |
| Property damage only | 300 (150) | 35,000 |

For the environment the key assumption is based on the truck platooning challenge and the related studies performed earlier. This leads to the same assumption as for the UK-use case in which a potential reduction between 11% and 14% has been used as the key assumption for trucks driving in a platoon. To calculate the benefits it is assumed that on average 200 kilometres are travelled on a daily basis for 350 days in a year. The estimated emission of CO2 has been set at 0.0006 ton kilograms per kilometre with a price of 26.= EUR per ton.

Regarding energy consumption the same assumptions apply with the addition that the potential reductions for truck platooning are between 10% and 14% as lower and upper bound numbers (with a modal number of 12%). The average diesel use (in litre per kilometre) is estimated to be 0.3 with an average diesel price of 1.20 EUR per litre.

From the economical point of view the shift in productivity of the truck drivers is an important quantifiable benefit. Here, different from the truck platooning in the UK case, it is assumed that drivers still are necessary within the vehicle. Therefore the time the driver spends in the truck can be used as productivity for something else. We have assumed that truck platooning would occur 1, 2 or 3 hours a day (depending on the type of scenario) and that the platoon size would vary from 2 to 4 based on the scenario as well (allowing for more drivers to do other things in the same platoon). Since the time spent in the truck is used for different productivity the value of time used is 38,38 EUR per hour based on the national statistics of the Netherlands.

## Autobahn Chauffeur on the A9 (D)

### Use case Autobahn Chauffeur on the A9

**Introduction**

This case looks at passenger vehicle road automation on the A9 motorway in Germany.

**Location: Autobahn A9**

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.

**Autobahn** **Chauffeur Function**

The Autobahn Chauffeur is a system which allows passengers to drive at automation level 3 on the German Autobahn with speeds up to 130 km/h. The system was introduced in the HAVE-it project (EU) and in the BASt study “Rechtsfolgen zunehmender Fahrzeugautomatisierung” (National). Currently the system is under research in the German project PEGASUS (National) and in the BASt study “Potentieller gesellschaftlicher Nutzen durch Fahrzeugautomatisierung” (National), which focuses on the potential benefit of vehicle automation on society.

The system has the following characteristics:

* Highly automated driving (Level 3 according to SAE Standard J3016, Level 3 according to VDA-definitions),
* For passenger vehicles without trailers,
* On Autobahn or Autobahn-like roads (motorways with minimum speed limits of 60 km/h), if they comply with German standards,
* Velocity range between 0 and 130 km/h,
* At day or night,
* In normal weather conditions,
* Including automated vehicle following scenarios in traffic jam situations (stop and go traffic),
* Including automated lane changes and take over manoeuvres,
* Including automated emergency braking and emergency evading by steering,
* Excluding automated entry and exit ramps,
* Excluding automated exit of the Autobahn,
* Excluding automated driving at low friction or limited line of sight.

### Costs Autobahn Chauffeur on the A9

The following assumptions have been made in order to calculate the respective costs for the described use case:

* No training costs are assumed based on the fact that we are talking about an in-car system in vehicles which can be purchased by any customer. At this moment there is also no training involved in e.g. the use of Adaptive Cruise Control Systems in vehicles.
* No service costs because the underlying assumption is that this is part of the costs for the vehicle itself, in other words this is calculated in the vehicle purchase price.
* No infrastructure costs assuming that the system will use existing infrastructure and no additional infrastructure will be installed specifically for this system.
* Therefore only technology costs are taken into account as the major costs parameter within this use case.

The costs per vehicle are broken down on the length of the considered part of the A9 compared to the total motorway length in Germany. The considered part of the A9 is 127 km vs. 12,993 km of the total motorway length in Germany.

It is assumed that in the low effort scenario a penetration level of 35% of automated vehicles is available.

In order to estimate detailed technology costs the following assumptions are considered:

* Technology costs per vehicle (estimation based on today’s costs for assistant systems from BMW, Daimler, VW and Audi):
	+ Upper bound: 1,500.= EUR per vehicle
	+ Modal: 2,250.= EUR per vehicle
	+ Lower bound: 3,000.= EUR per vehicle

Currently a total of 3.21 million cars are registered per year in Germany. The number is more or less constant and it is assumed that an equal number is available in the target year. Based on the assumption that 35% of new vehicles will be equipped with this system from 2019 onwards a total penetration rate of the vehicle fleet will be 27% in 2030.

Since the use case focuses only on deployment on the A9 test case a deployment path has been sketched for further roll out of the system on the rest of the German motorway. The test case is expected to last from 2019 – 2021. In the next nine years it is assumed that the total network for Germany will be equipped with infrastructure with a growth rate of 10% per year, resulting in approximately 80% of the network being able to host these kinds of vehicles in 2030. The main reason behind this growth path is the fact that users buy a vehicle in Germany which will not only drive on the test track of the A9 but also on the rest of the network and thus additional benefits will be created. This is also is based on the fact that we assume a positive outcome of the test with a decision to allow vehicles on other stretches of the road network. As indicated before, no infrastructure costs are assumed since this will be a vehicle based system only.

The technology costs are the main cost component within this use case and technology tends to become cheaper over the years. In this use case the average technology depreciation rate of 10% per year is assumed for the costs in order to take this factor into account. This results in technology in 2030 only costing 39% of the original assumption for 2020.

### Benefits Autobahn Chauffeur on the A9

Regarding the benefits for the German use case the following four categories of benefits have been identified as quantifiable:

* Safety expressed in the reduction of fatalities, serious injuries, light injuries and property damage.
* Environmental expressed in the reduction of CO2 emissions.
* Energy expressed in the reduction of energy consumption of the vehicles by using less fuel.
* Economical expressed in the productivity time shift basically stating that the system allows drivers to perform other tasks during their trip.

The basis for the benefit estimations are the following statistics, which are provided by DESTATIS (Statistisches Bundesamt, 2015), BASt (Bundesanstalt für Straßenwesen) and the KBA (Kraftfahrt-Bundesamt, 2015) in Germany:

* Accidents on German motorways (DESTATIS)
	+ Fatalities: 414
	+ Seriously injured: 5,834
	+ Lightly injured: 26,540
	+ Property damages: 140,299
* Car driver responsibility for accidents: 76.9% (DESTATIS)
* Total amount of cars in Germany: 45.1 million (KBA)
* Mean distance travelled yearly: 14,259 km (KBA)
	+ Percentage motorway: 33.7% (KBA)
* Costs for accidents (BASt)
	+ Fatality: 1.035 million EUR
	+ Severe injury: 111,000 EUR
	+ Light injury: 4,400 EUR
	+ Property damage only: 19,000 EUR

Furthermore it is assumed that a potential reduction of accidents because of automation up to 30% (lower bound) and up to 40% (upper bound) is possible.

The reduction of fuel consumption because of automation is assumed to be 8% (lower bound) and up to 12% (upper bound). The costs for CO2 are assumed to be 26 EUR per ton. A fuel use of about 5 litres/100 km and a fuel price of 1.30 EUR is assumed.

The total number of hours travelled on the motorway are up to 1768 million hours (based on the average speed and kilometres driven). The value of time for car drivers is estimated at 60 EUR per hour in case the work in the car is for business purposes. Furthermore it is assumed that 25% of driving time is used for work purpose and the system is used 50% of the time of driving.

# Results of the cost-benefit analysis

## Introduction

Within this chapter we present the results of the main CBA indicators. These are:

* Net present value (the current value of the use cases subtracting the costs from the benefits, all expressed in million euros)
* The Benefit cost ratio (the rate in which benefits overarch costs for the project lifetime)
* Economic Rate of Return on investment (displaying if positive a % for the rate that produces a zero value for the Economic Net Present Value).

Please note that (as stated in the DG Regio CBA guide) “The ENPV is the most important and reliable social CBA indicator and should be used as the main reference economic performance signal for project appraisal. Although ERR and B/C are meaningful because they are independent of the project size, they may sometimes be problematic. In particular cases, for example, the ERR may be multiple or not defined, while the B/C ratio may be affected by considering a given flow as either a benefit or a cost reduction.” As can be seen within the English and Dutch use case the ERR doesn’t always produce a positive value.

Secondly, whilst calculating costs and benefits for the project lifetime, the cut-off for 2030 (assumed for all use cases) leaves part of the investments with a residual value after the project lifetime. These are presented as residual values within the use cases.

Per use case we discuss two situations for the three scenarios where we look at for example a differentiation between road operators and the total use case as well as differentiation between two major assumptions.

In the second part of the chapter we focus on the sensitivity of the results presented. More specifically we focus on the sensitivity for varying key factors and the impact on the results, the comparison between the scenarios as well as the possible PM posts that could have a significant impact. For every use case we have varied the numbers used with 1% to find the numbers which have the largest impact on the B/C ratio (as one of the CBA indicators). The B/C ratio of the complete use case is used in this case as a comparison. In the paragraphs below we present in a table the four input numbers with the highest in % of change compared to the Base Case scenario. A special focus has been put onto the discount rate that has been assumed, since this percentage of 5% is rather high for the countries under study. Especially since the 5% discount rate from the DG Regio handbook is mainly intended for cohesion regions, the impact of a discount rate of 4% and 3% is part of the analysis. Next in the table we have also compared the BAU & High effort scenario with the low effort scenario, which allows (if possible to calculate elasticities for different factors).

Last but not least within this section for every use case it is indicated what the main next steps are for further analysis and quantification. In other words which assumptions need further analysis in order to support further decision making regarding the implementation of Automated Driving for NRAs.

## Results use cases

### CBA results Automated trucks A19 (UK)

For the case of the automated trucks on the A19 in the UK, we have done a CBA to determine the BCR for the operator and excluding the operator, to understand whether there is a benefit to society as well as the operator.

#### Overview of main CBA indicators

The main results from the CBA are shown in Table 5. The table describes in the rows the three policy scenarios as discussed before. It shows than for each of these scenarios the Economic Net Present Value, the Benefit Cost ratio and the Economic Rate of Return for the use case under investigation. For these three factors a division is made between the total benefits and costs for the use case as well as the benefits and costs solely for the road operator.

Table 5 CBA results English use case

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | ENPV total (M EUR) | ENPV road operator (M EUR) | B/C total | B/C road operator | ERR total | ERR road operator |
| BAU | 11.43 | 0.20 | 1.72 | 2.00 | 25% | 18% |
| Low | 21.04 | -0.30 | 4.16 | 0.39 | 200% | -13% |
| High | 0.13 | -1.21 | 8.11 | 0.20 | -4% | - |

As can be seen there is quite some variation in the results for both the entire use case as well as the road operator perspective. In general the Economic Net Present Value of the use case is positive in all three scenarios as well as the benefit cost ratio. This means 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 ENPV as well as the B/C ratio is not evidently positive (in the BAU scenario only unemployment benefits are pressing on the road operator/society explaining the relatively positive B/C ratio). This also goes for the Economic Rate of Return which in this instance does not seem to give reasonable values. In the high effort scenario the ERR shows that no value can be calculated for this indicator, which is caused by two investment sequences for the roadside units (displayed in Figure 1) as well as the low number of benefits generated.

Figure Net benefits over the years for the scenarios of the road operator

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.

As can be seen in Table 6 on the costs side the investment in the vehicles is the most substantial cost part (compared to the operational and maintenance as well as the infrastructure investments). On the benefits side the productivity savings (in essence the unemployment of drivers) is by far the largest share in benefits. This shows that the CBA indicators are very sensitive for the expected time savings that have been assumed. In other words, if this can be realised by a company to such an extent the investment that is necessary to realise this technology becomes profitable rather quickly. However the societal impact of unemployment as well as the return of this workforce to find new jobs is of major concern and should be taken into account when considering the implementation of such a use case.

Table 6 Main cost and benefits English use case

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Category | M EUR |  | Category | M EUR | % |
| Investment vehicles |  6.80  |  | Safety |  0.24  | 1% |
| Investment infrastructure |  0.33  |  | Environment |  0.02  | 0% |
| Operation & maintenance |  0.48  |  | Energy |  0.50  | 1% |
| Residual Value |  -  |  | Time savings |  36.56  | 98% |
| Unemployment benefits | 0.16 |  | Total |  37.31  |   |

#### Risk analysis

Regarding the sensitivity the numbers that are expected to impact the most have been used to perform the analysis. The results are shown in Table 7 in which the first three rows show the relative change of the B/C ratio for the overall use case implementation. The four columns with % change are compared to the respective policy scenarios. In the following two rows the BAU & High effort scenario are each compared to the low effort scenario (again for the changed numbers as indicated in the columns.

Table 7 Results sensitivity analysis English use case

|  |  |  |
| --- | --- | --- |
|  | B/C | % change compared to Base case |
|  | Base case | 3% discount rate | 4% discount rate | 1% higher value of time | 1% higher technology costs  |
| BAU |  1.72  | 5.54% | 2.71% | 0.98% | 0.92% |
| Low |  4.16  | 5.73% | 2.79% | 0.98% | 0.87% |
| High |  8.11  | 6.56% | 3.18% | 0.97% | 0.92% |
|  | %change compared to low |
| BAU | -58.57% | -56.28% | -57.45% | -58.17% | -58.96% |
| High | 94.91% | 107.70% | 101.11% | 96.79% | 93.11% |

In the table it can be seen that the B/C ratio is mainly sensitive for selecting a different discount rate, in other words, the valuation of money in the future has the largest impact of all the assumptions compared to the other assumptions. As was to be expected the impacts of value of time and technology costs are number 3 and 4 with rather lower percentages in change.

If the BAU and High effort scenarios are then compared to the low effort scenario, mainly the high effort scenario varies more (compared to the BAU scenario) which indicates that the assumptions made in the high effort scenario are more sensitive (amongst others due to the higher investment costs that are done compared to the low effort scenario).

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.

### CBA results Truck Platooning on the A15 (NL)

#### Overview of main CBA indicators

For the truck platooning use case the results of the CBA are shown in Table 8. Similar to the use case in the UK a differentiation has been made between the overall result and the specifics for the road operator. A separation here also has been made between the three policy scenarios as defined before.

Table 8 CBA results Dutch use case

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | ENPV total (M EUR) | ENPV road operator (M EUR) | B/C total | B/C road operator | ERR  | ERR |
| BAU | 1 | -152 | 1.00 | 0.33 | 0.0 | - |
| Low | 167 | 7 | 1.44 | 16.07 | 0.3 | 1.0 |
| High | 731 | -296 | 2.81 | 0.27 | 0.8 | - |

The table shows a positive Economic Net Present Value and positive B/C for the overall case, which grows with more effort from the government. However the additional investment from the road operator in the infrastructure doesn’t pay off if the scenarios are taken into account from the road operator perspective. In this case the very (and maybe too low investment) of the low effort scenario is highly beneficial due to the relatively high number of safety benefits. 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 of the road operator does the uptake and realization of benefits indeed speed up. In in Figure 2 the ERR is explained in more detail.

Figure 2 Net benefits over the years for the road operator in the Dutch use case

As can be seen in the overview of the numbers behind the CBA results in Table 9 the major costs are incurred by the truck owner. The major investments necessary for the vehicles as well as necessary costs for operation and maintenance are quite large compared to the number of trucks equipped (approximately 100,000 trucks in 2030). What also can be seen here is that the two major benefit categories lie within the productivity savings as well as the energy savings for a truck platoon. These benefits are mainly for the operator of the trucks, therefore if the productivity savings can be realised by means of truck platooning this becomes a highly interesting case for truck operators. However this is based on the assumption that drivers will do something productive behind the wheel while in a platoon. This is also based on the assumption that this of course is legal as well as that there is something productive for drivers to do behind the wheel.

Table 9 Main costs and benefits Dutch use case

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Category | M EUR |  | Category | M EUR | % |
| Investment vehicles | 327.15  |  | Safety |  6.66  | 1% |
| Investment infrastructure | 0.80  |  | Environment |  5.36  | 1% |
| Operation & maintenance | 306.70  |  | Energy |  123.66  | 15% |
| Residual Value | -93.47  |  | Productivity savings |  686.65  | 84% |
|  |  |  | Total |  822.34  |   |

#### Risk analysis

Regarding the sensitivity the numbers that are expected to impact the most have been used to perform the analysis. The results are shown in Table 10 in which the first three rows show the relative change of the B/C ratio for the overall use case implementation. The four columns with % change are compared to the respective policy scenarios. In the following two rows the BAU & High effort scenario are each compared to the low effort scenario (again for the changed numbers as indicated in the columns.

Table 10 Results sensitivity analysis Dutch use case

|  |  |  |
| --- | --- | --- |
|  | B/C | % change compared to Base case |
|  | Base case | 10% deflation of technology costs | 3% discount rate instead of 5% | 4% discount rate instead of 5% | 1% higher technology costs  |
| BAU | 1.00 | 19.6% | 2.2% | 1.1% | 0.4% |
| Low | 1.43 | 24.1% | 2.2% | 1.1% | 0.5% |
| High | 2.79 | 20.6% | 3.6% | 1.8% | 0.5% |
|  | %change compared to low |
| BAU | -30.3% | -16.6% | -28.7% | -29.5% | -30.5% |
| High | 95.2% | 135.5% | 102.2% | 98.6% | 94.2% |

As can be seen here the impact of the technology costs (first and last column) is a factor that is represented twice in the sensitivity analysis. This shows that the impact of these costs on the results of the CBA is significant. Especially the first factor (deflation of technology costs by 10%) shows that a significant change in this factor has a large impact on the B/C ratio. In other words the costs of the technology will need to be part of further analysis in order to be able to realise the potential benefits of this use case. The fact that the CBA is sensitive to the costs assumptions also explains why the two discount rate variations also feature in this table as number 2 and 3 of largest impact.

In the comparison of the BAU, in the low and high effort scenarios the same is indicated again where the impact of the high investment by the road operator for the high effort scenario explains the higher impact of these factors (compared to the BAU scenario).

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 to investigate 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 as well as the interaction of other road users with platoons, since safety issues could occur here.

### CBA Results Autobahn Chauffeur on the A9 (D)

#### Overview of main CBA indicators

In Table 11 the outcomes of the general CBA indicators for the German use case are presented. Within this case the two situations compared is the difference between no technology deflation and application of deflation of technology costs.

Table 11 CBA results German use case

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | ENPV total | ENPV adjusted | B/C  | B/C adjusted | ERR  | ERR adjusted |
| BAU | -9941 | -5554 | 0.45 | 0.59 | -9% | -7% |
| Low | -3550 | -260 | 0.74 | 0.97 | -4% | 0% |
| High | 2847 | 5041 | 1.32 | 1.74 | 5% | 9% |

As can be seen 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 of the complete fleet of vehicles with a total of 12 million vehicles equipped in 2030. It can also be seen that the impact of technology becoming cheaper (the normal versus the adjusted scenario) is quite significant on all indicators for the CBA. The B/C gets closer to 1 and is higher in the high adjusted scenario as well as a less negative ENPV and higher ERR for both the low and high effort scenario.

The impact of this deflation mainly indicates that the CBA is sensitive to the assumptions made for the expected costs of the technology. This will further be elaborated in the sensitivity analysis.

For comparison purposes we also have put the expected benefits and related costs next to each other in the Table 12 for the low effort not adjusted scenario. This gives an indication of the share of the benefits as well as the costs that have been used to generate the CBA indicators numbers.

Table 12 Main costs and benefits German use case

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Category** | **M EUR** |  | **Category** | **M EUR** | **%** |
| Investment vehicles |  27,806.63  |  | Safety |  23.25  | 9% |
| Investment infrastructure | 0 |  | Environment |  1.09  | 0% |
| Operation & maintenance | 0 |  | Energy |  22.65  | 9% |
| Residual Value |  -13,903.31  |  | Time savings |  213.16  | 82% |
|  |  |  | Total |  260.15  |  |

As can be seen the costs only consist of the vehicle investment costs and the residual value due to the break-off in 2030. Regarding the benefits, the share in time savings is by far the largest benefit that is generated by the use case, so the effect that the application has on how people will use their time in an automated vehicle is of large importance here, since this largely affects the results for the CBA. So again this strongly depends on how people will behave in the car once this is equipped with automated driving functionality.

#### Risk analysis

Regarding the sensitivity the numbers that are expected to impact the most have been used to perform the analysis. The results are shown in Table 13 in which the first three rows show the relative change of the B/C ratio for the adjusted use case implementation (different compared to the English & Dutch use case). The four columns with % change are compared to the respective policy scenarios. In the following two rows the BAU & High effort scenario are each compared to the low effort scenario (again for the changed numbers as indicated in the columns).

Table 13 Results sensitivity analysis German use case

|  |  |  |
| --- | --- | --- |
|  | B/C | % change compared to Base case |
|  | Base case | 3% discount rate instead of 5% | 4% discount rate instead of 5% | 1% higher technology costs  | 9% deflation instead of 10% |
| BAU |  0,59  | 14,29% | 6,78% | 3,58% | 2,62% |
| Low |  0,97  | 14,29% | 6,78% | 3,58% | 2,62% |
| High |  1,74  | 14,29% | 6,78% | 3,58% | 2,62% |
|  | % change compared to low |
| BAU | -39,21% | -30,52% | -35,08% | -41,38% | -40,80% |
| High | 78,52% | 104,03% | 90,63% | 72,13% | 73,85% |

The four major factors which influence the B/C ratio in the adjusted scenario are all connected to the costs assumptions that are used, although the discount rate of course also influences the value of the benefits in the future. Interestingly the impact of changing the discount factor is rather high within the sensitivity analysis, which shows a large sensitivity for this factor.

In the rows comparing the BAU and High effort scenario with the low effort scenario the same is confirmed with the discount rate being the major factor playing a role here.

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. 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 (and therewith realising a significant number of benefits). People cannot be expected to buy a system in their car which they can (or will) only 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 largely to the benefits within this use case.

## Overall remarks

The CBA indicators for all the use cases lay within the reasonable numbers, every use case has shown its specifics and remarks have been made regarding every use case. The three policy scenarios have proven interesting in showing that even with no effort on the part of the NRAs, automation still can deliver a positive CBA indicator, even for an NRA. It also has shown that a high investment in the infrastructure does not necessarily pay off in a more positive CBA results. However other considerations could be taken into account when investing in the infrastructure anyway but more importantly the necessary investments are still surrounded with quite some uncertainty. For all three use cases the following can be said:

1. Time or productivity savings are a key benefit within all of them, although with a high sensitivity to the underlaying assumptions. This points to a need for further research within this domain, since a lot is still unclear about this. Research within this domain should definitely focus on the behaviour of drivers who are given the possibility to perform other tasks, but also to the legal framework that is necessary to allow this to take place (e.g. in the case of truck platooning)
2. The division of costs and benefits for the involved stakeholders needs specific attention since benefits are often solely appointed to one specific stakeholder in the use case, whilst investments are assumed for the other. As stated already it could be worthwhile to investigate how these costs and benefits can be shared more equally for the involved stakeholders or if other ways of sharing these more equally can be explored.
3. The costs of technology are still largely unknown; the numbers used within this study have been built up based on input from different studies as well as experts that have been consulted. In each sensitivity analysis the costs have proven to be the major component that sensitivity has been high for.
4. Last but not least, regarding the decision making for NRAs it can be said that at this moment there is too much uncertainty regarding the use cases that are presented to safely make an investment decision (let alone which investment decision should be taken). However the numbers also show that there is potentially a large benefit to be realised which should not be neglected and which should (if possible) be realised by the correct actions from NRAs.

# Conclusions

The aim of the report is to give NRAs a better understanding of the economic benefits that could derive from the implementation of automated driving 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. This is why quite some attention is being given towards these assumptions in chapter 3.

The CBA indicators which have been presented in chapter 4 lead to the overall conclusion that there are definitely economic benefits to be derived for both NRAs as well as other involved stakeholders. However within the chapter it is also indicated that higher benefits are not per se correlated with a higher investment in the infrastructure. Within the chapter 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 points are:

* The time and productivity time savings that form a large share of the benefits are based on a large number of assumptions (including 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)
* 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 decision making and necessary information for NRAs is insufficient at the moment, further research is therefore needed

However this doesn’t mean that nothing can be done, out of every use case a number of things have been defined that need further attention. These are:

* The savings generated by removing 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). But also 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.
* The productivity time savings can be split into the ability to do something else (including the possible necessary legal changes) as well as the driver’s behaviour and options to do something productive during this time. 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 more specifically how this prohibition of platooning will be organised.
* The large investment costs that are necessary within the German 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 by a system in their car which they can (or will) only use on a specific test site.

# References

**General**

Costs for ITS Units (http://www.driverlesstransportation.com/each-v2i-site-could-cost-51650-11736)

European Commission, Directorate-General for Regional and Urban policy (2015) Guide to Cost-Benefit Analysis of Investment Projects, Economic appraisal tool for Cohesion Policy 2014-2020, ISBN 978-92-79-34796-2

Lu, M. (2016) Evaluation of Intelligent Road Transport Systems: Methods and Results, ISBN: 978-1-78561-172-8

**UK case:**

|  |
| --- |
| General input |
| Route length | Google |
| Cars produce annually in Sunderland | Source: Nissan |
| % exported | Source: Nissan |
| White lining | http://www.wiltshire.gov.uk/costwiltshighwaysworks.htm |
| Accidents & costs |
| Motorways | RAS20005 |
| Single carriage ways | RAS20005 |
| Cost units | RAS60002 |
| Total cost of damage only accidents | RAS60004 |

**Dutch use case:**

|  |  |
| --- | --- |
| Technology costs | Janssen 2015 (TNO report) |
| Accidents with Trucks | OVV report 2012 |
| Vehicle mileage. % freight transport | INWEVA. 2015 |
| Emissions | CPB (2014) edited from VU & CE (2014) and Wever en Rosenberg (2012) |

German Use case:

|  |  |
| --- | --- |
| Safety | Source |
| Fatalities | destatis 2015 (46241-0003) |
| Seriously injured | destatis 2015 (46241-0003) |
| Lightly injured | destatis 2015 (46241-0003) |
| Severe property damage accidents | destatis 2015 (46241-0001) |
| Light property damage accidents | destatis 2015 (46241-0001) |
| % main responsibility: car driver | destatis 2015 (46241-0011) |
| Other input |  |
| route length "Digitales Testfeld" A9 | Google Maps |
| total length motorway | https://de.statista.com/statistik/daten/studie/2972/umfrage/entwicklung-der-gesamtlaenge-des-autobahnnetzes/ |
| total amount of cars in germany (million) | http://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand\_node.html |
| mean distance travelled yearly (cars) in km | https://www.kba.de/SharedDocs/Pressemitteilungen/DE/2015/pm\_15\_15\_jaehrliche\_fahrleistung\_deutscher\_pkw\_pdf.pdf?\_\_blob=publicationFile&v=5 |
| percentage motorway | https://de.statista.com/statistik/daten/studie/155732/umfrage/fahrleistung-auf-autobahnen-in-deutschland/ |
| registration of new cars per year (million) | http://www.kba.de/DE/Statistik/Fahrzeuge/Neuzulassungen/neuzulassungen\_node.html;jsessionid=9B5D19737C19FD6CCE72F8B784B3A492.live21304 |
| yearly traveled distance (million) | https://www.kba.de/SharedDocs/Pressemitteilungen/DE/2015/pm\_15\_15\_jaehrliche\_fahrleistung\_deutscher\_pkw\_pdf.pdf?\_\_blob=publicationFile&v=5 |
| yearly traveled distance by cars (million) | <https://www.kba.de/SharedDocs/Pressemitteilungen/DE/2015/pm_15_15_jaehrliche_fahrleistung_deutscher_pkw_pdf.pdf?__blob=publicationFile&v=5> |
| traffic jam hours on motorways | https://www.adac.de/\_mmm/pdf/statistik\_staubilanz\_0216\_231552.pdf |
| average speed on the motorway (km/h) | https://en.wikipedia.org/wiki/Autobahn |
| costs (in Million EUR) |  |
| fatality | http://www.bast.de/DE/Publikationen/Foko/2011-2010/2010-17.html |
| severe injury | http://www.bast.de/DE/Publikationen/Foko/2011-2010/2010-17.html |
| light injury | http://www.bast.de/DE/Publikationen/Foko/2011-2010/2010-17.html |
| property damage only | http://www.bast.de/DE/Publikationen/Foko/2011-2010/2010-17.html |

1. Campolieti, Michele and Morley Gunderson. 2005. “Cost-benefit analysis applied to labour market programmes”, In Robert Brent, ed.: Handbook of Research on Cost-Benefit Analysis, Cheltenham, UK: Edward Elgar, pp. 161-184. [↑](#footnote-ref-1)