FACULTY OF ENGINEERING
AND ARCHITECTURE

Socio-economic benefits of Vehicle-to-Vehicle (V2V) technology

Teun Deleersnijder
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Counsellors: Thibault Degrande, Dr. Sven Maerivoet (Transport & Mobility Leuven)

Master's dissertation submitted in order to obtain the academic degree of
Master of Science in Industrial Engineering and Operations Research

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Acknowledgements

This masters dissertation is written to finalize the degree of Master of Science in Industrial Engineering and Operations Research. This thesis would not have been possible without the assistance of several people.

First of all, my supervisor, Thibault Degrande, deserves sincere gratitude. He ensured a very good and pleasant cooperation and guidance. Not only did he evaluate the work, but he also guided me into the right direction with his experience in research projects. I wish you the best of luck on completing your PhD.

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The education I received at the University of Ghent and the support of my family and friends will be at the basis of all the opportunities I will have in my later career.

Teun Deleersnijder, May 2020

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Abstract

Nowadays we are stuck in traffic jams everywhere. In Flanders alone, there is an average of 150 kilometers of traffic jams per day. Despite the fact that Europe has a good reputation for road safety, there are still around 26.000 deaths and 135.000 seriously injuries a year. As people have become more mobile, CO_2 emissions from transport have increased. Emissions have been falling in all sectors, except for the transport sector. The positive impact in other sectors has been offset by increasing transport activity and the use of low-capacity road freight transport. In this thesis it is being researched at whether if and to what extent communication services between different cars can influence the road safety, traffic efficiency and the CO_2 emission.

This research will focus on the communication between passenger cars. It is anticipated that communication between cars complement and expand the capabilities of sensors, cameras and radars. Drivers will receive extra information about the vicinity of their car to avoid accidents and improve efficiency.

In this dissertation, benefits for the aforementioned three aspects were modeled for a certain trajectory. A trajectory is defined by two main input parameters, namely traffic volume and the length of the trajectory. This creates the possibility to evaluate any trajectory if these parameters are known.

The benefits for a certain penetration of the services are calculated in the model for the requested trajectory. Saved lives, avoided accidents, eliminated traffic jams and reduced CO_2 emissions will be translated into monetary values. Assuming a 90% penetration in 2035, the net present value of the benefits will be around €80 million in Flanders only. This number can be used by policy makers to subsidize the services and make the motorways in this way a safer place to drive.

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***Abstract*—In this paper it is being researched at whether if and to what extent communication services between different cars can influence the road safety, traffic efficiency and the CO2 emission. It is anticipated that communication between cars complement and expand the capabilities of sensors, cameras and radars. Drivers will receive extra information about the vicinity of their car to avoid accidents and improve efficiency.**

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Assuming a 90% penetration in 2035, the net present value of the benefits will be around 80 million euros in Flanders only. This number can be used by policy makers to subsidize the services and make the motorways in this way a safer place to drive.

***Index Terms*—vehicle-to-vehicle, C-ITS, safety, environment, traffic efficiency**

I. Introduction

Nowadays we are stuck in traffic jams everywhere. As stated in [1], in Flanders alone, there is an average of 150 kilometers of traffic jams per day. Despite the fact that Europe has a good reputation for road safety, there are still around 26.000 deaths and 135.000 seriously injuries a year according to [2]. As people have become more mobile, CO_2 emissions from transport have increased. Emissions have been falling in all sectors, except for the transport sector. The positive impact in other sectors has been offset by increasing transport activity and the use of low-capacity road freight transport. In this thesis it is being researched at whether if and to what extent communication services between different cars can influence the road safety, traffic efficiency and the CO_2 emission.

In order to reduce the traffic deaths, to achieve the goals of the European Union for the CO_2 emission and to decrease the number of traffic jams a solution must be found. Cooperative Intelligent Transport Systems or C-ITS has the potential to play a significant role in achieving the goals to tackle the increasing problems of congestion, transport energy consumption, road safety and emissions. By implementing these new technologies; efficiency, safety and environmental performance of road transport is expected to increase.

C-ITS involves a number of different communication services. When using C-ITS in road transport, it is typically implemented as communication between different vehicles (vehicle-to-vehicle, V2V), between vehicles and infrastructure (vehicle-to-infrastructure, V2I) and/or infrastructure-to-infrastructure (I2I). V2X (vehicle-to-everything) is an umbrella term for all vehicle communications.

Over the past decade, there have been remarkable new developments in technologies that facilitate C-ITS. For example, the availability of advanced driver-assist systems (ADAS), using technologies such as sensors, cameras and radars, has increased in recent years. V2X communication is expected to complement and expand the capabilities of ADAS, and provide additional benefits (such as reduced traffic congestion, improved energy efficiency and lower vehicle emissions).

This paper will focus on vehicle-to-vehicle services in passenger cars on roadways. However, the services that are meant to achieve benefits for urban roads will be omitted from the model, it is still very important to evaluate the benefits on highways. Most deadly accidents and the majority of the traffic jams occur on motorways. Not to mention the emission of CO_2 that could be saved using the services on the motorways. The V2V services have the potential to tackle important road transport issues, such as safety, environmental impact and travel efficiency on the highways. In order to get an idea of the impact of the services, a model can be built that calculates the benefits for a certain trajectory and converts them into monetary values. The importance of the services will certainly become more clear throughout this dissertation.

II. Cost-Benefit analysis for Public Authorities

A. Importance of socio-economic benefits

The term 'socio-economics' refers, as reported by [3], broadly to the use of economics in the study of society. Socio-economic theories differ from conventional economics for they also include e.g. the effect of environment, the well-being of the population,...

Socio-economic benefits (benefits offered to a community) will have long-term impacts on the prevailing economic conditions. These benefits will have an indirect impact on the economic situation. For example, a reduction in the amount of traffic jams will not have a direct impact on the economy in the form of money, but an indirect impact. There will be less traffic jams so cars and trucks can move across the country more efficiently.

B. Method: Cost-benefit analysis

Cost-benefit analysis or CBA is a useful tool to analyse potential socio-economic impact of investments. This technique for evaluating public spending, aims to help public decision-makers invest only in those projects that will be the most profitable for the community. The main idea is to create an overview of all the costs and compare them to the benefits. The goal is to perform the CBA before decisions are made, so different project proposals can be compared and evaluated. To make the comparison, both costs and benefits, must be quantified as much as possible and expressed in monetary terms.

The first step is the monetary evaluation. This step is crucial because it defines the value of each effect that was taken into consideration in the CBA. The monetary evaluation procedure is divided in three phases. First of all, the advantages and disadvantages must be identified. This identification makes it possible to measure the effects. For each measurable effect, a physical measurement scale must be specified. An appropriate procedure for measuring the impact of the effect to be evaluated should be devised and applied to any competing project.

The second phase starts by taking the different possible procedures for assigning a monetary value to each unit identified in the previous phase. These procedures can be based on surveys, contingent valuation or willingness to pay or receive. The procedures may also be based on the behavior exhibited by existing markets, allowing indirect estimates of the impact resulting from the benefits accrued or problems caused.

In the last phase of the evaluation procedure the future changes of a certain number of reference values considered in CBA calculations should be determined exactly. A well developed plan for the future is necessary to forecast the reference values. As mentioned previously, impacts can change over time.

After the monetary evaluation, the reference situation must be defined. The evaluation of the costs and benefits of an investment project requires an accurate reference situation. The advantages and disadvantages are the differences between a situation where the project would be executed and a situation without the project. For example, it is only possible to evaluate the avoided amount of accidents by using C-ITS if the number of accidents that would occur without implementing C-ITS, is predicted.

A cost-benefit analysis will not predict the exact outcome, but it is, despite certain criticisms which are discussed in more detail in [4], a very good tool to make policy decisions with.

III. Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) is a solution that can improve the mobility of road users by using communication and information technology applications. Besides mobility, ITS will also enhance road safety and environmental sustainability. The new technology will be integrated into the management and operation of the transportation system across all modes. ITS can be divided into 2 categories: autonomous ITS and cooperative ITS. Autonomous ITS can be identified by all forms of intelligent transportation systems that not depend on cooperation with other vehicles or supporting infrastructure. Unlike autonomous ITS, cooperative ITS represents the systems where communication between vehicles and between vehicles and infrastructure is applied.

A. Autonomous ITS

For autonomous intelligent transportation systems, no communication between vehicles has to be involved in these systems, only inputs from multiple sources like radars, sensors, computer vision will be consulted.

B. Cooperative ITS

These intelligent transportation systems utilise communication systems to enhance safety and efficiency. This is the main difference between autonomous and cooperative ITS. The communication between vehicles or between vehicles and infrastructure will be used instead or besides the existing radars. C-ITS will enable cars, buses, trucks, roads, other infrastructure, our smartphones and many other devices to "talk" to one another. For example, car A would use short-range radio signals to communicate with other cars so they would be aware if car A is nearby them. Using communication a lot of new features can be installed in vehicle. It will potentially complement on-board sensors by providing enhanced information, such as data from other vehicles, over a longer range.

C-ITS will be implemented in the vehicles in the form of services. The European Commission [5] has produced a list of communication services that must be deployed first. These services are called Day 1 services. Also, in general day 1 applications are used to inform drivers to help them make better decisions on the road. The second list, Day 1.5 services is the next step towards better communication and cooperation between vehicles. The services that will be investigated are listed below.

- Emergency brake light
- Emergency vehicle approaching
- Traffic jam ahead warning
- Slow or stationary vehicle(s)
- Hazardous location notification

IV. The model

In the dissertation [4], benefits for the aforementioned three aspects were modeled for a certain trajectory. A trajectory is defined by two main input parameters, namely traffic volume and the length of the trajectory. This creates the possibility to evaluate any trajectory if these parameters are known. The benefits for a certain penetration of the services are calculated in the model for the requested trajectory. Saved lives, avoided accidents, eliminated traffic jams and reduced CO_2 emissions will be translated into monetary values. More information about the construction of the model can be found in [4]. In the model the penetration rate must be chosen. The penetration rate is defined by the policy followed by the government. In the paper four policies are investigated. Policy 1 is the option where the government does not interfere in the implementation. The second policy involves a moderate intervention based on specifications under the ITS Directive. The third policy involves a strong intervention. Also a mandatory policy is investigated where all the newly sold cars will be equipped with the C-ITS services. More information can be found in [4].

V. CBA: Flanders

The input parameters for Flanders are put in the model to calculate the benefits. The traffic volume on respectively busy and quiet days are 27580 and 19000 cars per day per segment. The length of the motorways in Flanders is 916 kilometer nowadays and an average maximum speed of 120 kilometers per hour is taken. To start, all the factors are set on the factors that have an average impact. The volume parameters are chosen using Flemish statistics [6] but with a pessimistic mindset. Different policy options for Flanders will be investigated. The net present benefits are presented in table I

	Policy 1	*Policy 2*	*Policy 3*	*Mandatory policy*
Safety	3.699.312	11.378.927	34.097.561	68.192.637
Environment	96.739	296.154	883.070	1.761.690
Traffic efficiency	414.736	1.421.004	4.237.755	7.697.776
Total	**4.210.788**	**13.096.086**	**39.218.387**	**77.652.103**

TABLE I
NET PRESENT BENEFITS

Of course the mandatory policy gives the highest net present benefits in 15 years. The fast implementation of the services will ensure, due to network effects, high benefits. However, this implementation is highly encouraged, it is impossible for the car manufacturers to change their factories in one year, and make from than on only cars that are equipped with the services.

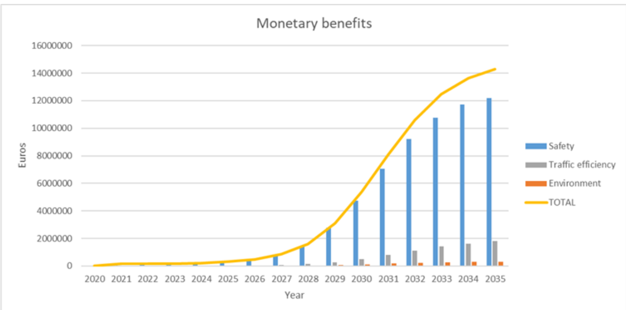

Fig. 1. Benefits Flanders: PO 3

That is why policy 3 is recommended. The car manufacturers have time to implement the services in their cars. They can wait until they have a new version of a specific car to implement the communication services in that specific model.

But it is still recommended to have a fast implementation. The government can choose to use the 40 million to subsidize the end-users. They can pay grants to the consumers that choose a C-ITS car above a car that is not equipped with the V2V services. Policy 3 assumes that after eight years all the newly sold cars will own the services. After six years already more than 70% will own the services. During those six years the grants can ensure a faster implementation because the consumers will choose a C-ITS car. It is actually better to get to 70% faster than slower. Specifically for Flanders, using the 40 million, considering the discount rate, the government can lower the commissioning tax with 60 for each newly sold C-ITS car during those six years. If you know that the cost of a commissioning tax is between the 500 and 1000 and a C-ITS is safer to drive, then that is an attractive offer.

VI. Conclusion

In the dissertation three policies and a mandatory policy are assumed. Policy 1 represents the policy of the government where they apply the lightest intervention and policy 3 where the government will intervene significantly. Of course, the mandatory policy, where all the newly sold cars must own the services, will have the fastest adoption rate. Policy 3 will have the second fastest.

It is estimated that The Day 1 V2V services can generate 34 million in safety benefits if policy 3 is imposed. It is estimated that the services will save 12 lives, prevent 62 seriously injuries and more than 800 slightly injuries. In total this is around 1000 accidents that will be avoided. For a mandatory policy the numbers are even doubled.

The services can reduce the lost vehicle hours with 2 million hours per year. If a person spends 1 hour per day in traffic jams or traffic delay and that for 260 days a year, the person will waste 160 minutes a year less in traffic jams or delayed traffic. This is a welcome perk for the person in question, but it has also a monetary benefit with a net present value of 4.3 million over 15 years if policy 3 is obliged.

The Day 1 V2V services can help achieving the goals of the European Union. The monetary benefits can not be the only reason to reduce the emission of CO_2. The environment must be saved and every little bit counts. But also here monetary benefits can be shown. The reduction of CO_2 emissions is good for a net present value of the benefits of 0.9 million. This is again if policy 3 is obliged.

In short, doubting whether or not to implement C-ITS services, is not up to scratch. Implementing the services will yield a net present benefit of 40 million for the next 15 years. The policy recommendations are somewhat harder to decide.

However, the net present benefit of a mandatory policy is almost twice as much as the net present benefit when policy 3 is used, it is not necessary to make the services mandatory. But a fast adoption rate is suggested. That is the reason why the benefits of policy 3 are used in this chapter. In this way car manufacturers have time to change their production lines or wait until a new model will be made to implement the services.

If they implement the services according to the adoption rate due to policy 3, there will be an amount of 40 million to invest in the services. This will help increase the penetration rate of the services. The investment can be done by subsidizing the car manufacturers or subsidize the users. Policy 3 assumes that more than 70% of the newly sold cars will be equipped with the V2V services after six years. It is recommended to subsidize the consumers during those first six years of the C-ITS implementation to ensure a fast adoption. This will encourage the buyers of new cars to choose a car with services instead of a car without the services.

The faster the services are implemented, the earlier CO_2 can be reduced, traffic jams can be decreased and lives can be saved. Lives that would be lost without a fast adoption. If the adoption rate is more rapidly there will be higher net present value of the benefits in 15 years. This means that it is recommended to implement the Day 1 V2V services as fast as possible.

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First of all, my supervisor, Thibault Degrande, deserves sincere gratitude. He ensured a very good and pleasant cooperation and guidance. Not only did he evaluate the work, but he also guided me into the right direction with his experience in research projects.

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Glossary

5GAA 5G Automotive Association. 21

ADAS Advanced driver-assist systems. 3, 17

C-ITS Cooperative Intelligent Transport Systems. 3, 4, 6, 7, 10, 11, 13, 19, 22, 27, 28, 38, 39, 74, 76, 80, 83, 84

CBA Cost-Benefit analysis. 9–15, 52, 58

DSRC Direct short range communication. 20

EBL Emergency brake light. xiii, 22, 29, 30, 40, 41, 72

EVA Emergency vehicle approaching. xiii, 22, 40

HLN Hazardous location notification. xiii, 43, 72

I2I Infrastructure-to-Infrastructure. 3, 27

ITS Intelligent Transport Systems. 4, 16, 63

MCA multiple-criteria analysis. 14, 15

MCDM Multiple-criteria decision-making. 14

SSV Slow or stationary vehicle(s). xiii, 40

TJAW Traffic jam ahead warning. xiii, 22, 29, 30, 40, 42, 44, 45, 72

TMCs Traffic management centers. 25

V2I Vehicle-to-Infrastructure. 3, 19, 24, 25, 27, 70, 71

V2N Vehicle-to-Network. 19, 21

V2V Vehicle-to-Vehicle. 3, 19, 21, 22, 24, 27, 28, 39, 61, 70, 74, 80, 83–85

V2X Vehicle-to-Everything. 3, 20, 21

WAVE Wireless access in vehicular environments. 20

Part I

Introduction

Chapter 1

Introduction

1.1 Importance of V2X

The increasing road transport volumes are one of the most relevant current topics. As stated in [1] over the past 3 decades, the demand for use of public roads has grown with approximately 95 percent and this trend is very noticeable in daily life. In Flanders alone, there is an average of 150 km of traffic jams per day. According to [2], those traffic jams are responsible for an economical damage of 4,35 billion euros a year for Belgium. That averages out to approximately 1.150 euro per Belgian household (3 pers.) a year.

These traffic jams are caused in part by accidents, but they themselves can also be the cause of many accidents. The ever increasing number of vehicles on the road also causes an increase in number of accidents. It is clear: traffic is not evolving well in Belgium. Not only traffic jams, but also road safety: based on [3], the number of road fatalities is again rising worryingly. For seven consecutive years, the number of deaths in traffic has fallen, but now that trend has been reversing. If Vision Zero, a goal to achieve zero road deaths by 2050, is to be achieved, action must be undertaken.

As people have become more mobile, CO_2 emissions from transport have increased. However, in 2014 the European Union was able to present very encouraging numbers, with a 5 % reduction in carbon dioxide emissions compared to previous years. Sadly enough 2014, as reported by [4], was also the last positive year, seeing as the pace of emission reduction has slowed down, even coming to a rising trend. Emissions have been falling in all sectors, except for the transport sector. The positive impact in other sectors has been offset by increasing transport activity and the use of low-capacity road freight transport.

Cooperative Intelligent Transport Systems or C-ITS has the potential to play a significant role in achieving the goals to tackle the increasing problems of congestion, transport energy consumption, road safety and emissions. By implementing these new technologies; efficiency, safety and environmental performance of road transport is expected to increase.

C-ITS involves a number of different communication services. When using C-ITS in road transport, it is typically implemented as communication between different vehicles (vehicle-to-vehicle, V2V), between vehicles and infrastructure (vehicle-to-infrastructure, V2I) and/or infrastructure-to-infrastructure (I2I). V2X (vehicle-to-everything) is an umbrella term for all vehicle communications.

Over the past decade, there have been remarkable new developments in technologies that facilitate C-ITS. For example, the availability of advanced driver-assist systems (ADAS), using technologies such as sensors, cameras and radars, has increased in recent years. V2X communication is expected to complement and expand the capabilities of ADAS, and provide additional benefits (such as reduced traffic congestion, improved energy efficiency and lower vehicle emissions).

This paper will focus on vehicle-to-vehicle services in passenger cars on roadways. However, the services that are meant to achieve benefits for urban roads will be omitted from the model, it is still very important to evaluate the benefits on highways. Most deadly accidents and the majority of the traffic jams occur on motorways. Not to mention the emission of CO_2 that could be saved using the services on the motorways. The V2V services have the potential to tackle important road transport issues, such as safety, environmental impact and travel efficiency on the highways. In order to get an idea of the impact of the services, a model can be built that calculates the benefits for a certain trajectory and converts them into monetary values. The importance of the services will certainly become more clear throughout this dissertation.

1.2 Outline

A paper and model cannot be drawn up without expert knowledge. As such starting with a literature study is a requirement. The literature study will be divided into two parts. In the first part the socio-economic modeling and its importance in taking public investment decisions will be examined. The second part will provide information about the subject of ITS. The differences between ITS and C-ITS will be addressed. The different subsections of C-ITS and the different communication services within those subsections will also be examined.

In the part about methodology the different models are explained. The reasoning about the build-up of the model is written down in the first part. The information has been assisted by using different graphs. Also the umbrella model is discussed. In that section it will be more clear how the different models will come together.

In the part about the results, first the most important and uncertain parameters will examined in a sensitivity analysis. Then the model is applied to a situation in Belgium. The parameters of Flanders are used. Flanders will be investigated for different possible policies. After all, a conclusion for Flanders will be made.

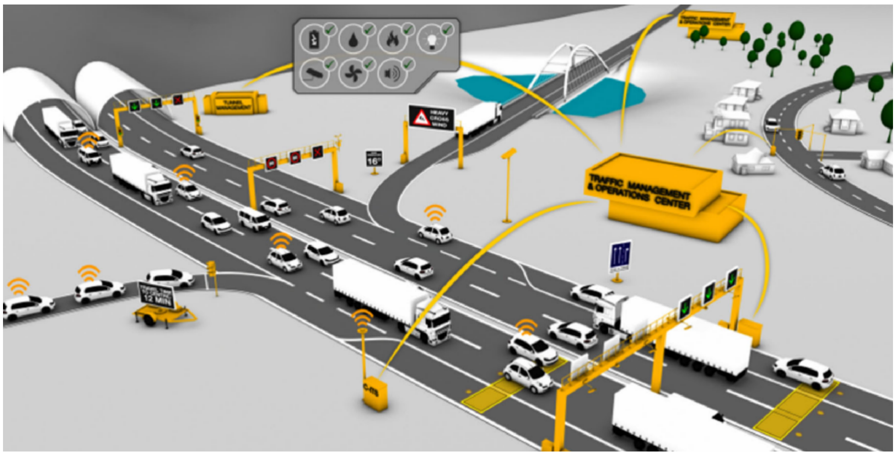


Figure 1.1: Working of C-ITS [5]

Part II

Literature review

Chapter 2

Cost-Benefit analysis for Public Authorities

Transport policy implies making choices, such as pricing policies, setting (new) standards for emissions levels of vehicle categories or safety regulations for vehicles. C-ITS have the potential to tackle important road transport issues, such as safety, environmental impact and travel efficiency. As the required financing for the deployment of C-ITS services is significant, a clear view on the costs, benefits and business models is necessary before investment decisions can be made.

The key factors for achieving an acceptable balance between costs and benefits must be analysed and the findings will show if the investment costs are likely to be higher than the monetised benefits or not. Because these choices must be made, there is a huge need for ex-ante evaluations of choice options.

C-ITS services are relatively new, so there are few field trial results upon which a comprehensive ex-post evaluation of their impacts can be based. Evaluation methods for C-ITS can not be checked. Nevertheless methodologies, used for evaluation of other projects/investments in the transport sector, which have been developed and improved, can be used.

In this chapter the different analysing methods for socio-economic benefits will be investigated. The pros and cons of using the methods in the transport sector will be listed and weighed up. Furthermore the political aspect will be taken into account as well as the influence of uncertainty on specific parameters.

2.1 Public investment decisions

2.1.1 Importance of socio-economic benefits

What are socio-economic benefits?

"Social economics is a branch of economics that focuses on the relationship between social behavior and economics. It examines how social norms, ethics, emerging popular sentiments, and other social philosophies influence consumer behavior and shape public buying trends. It uses history, current events, politics, and other social sciences to predict potential results from changes to society or the economy." (TARVER, 2019, p.1, [6])

The term 'socio-economics' refers, as reported by [7], broadly to the "use of economics in the study of society". Socio-economic theories differ from conventional economics for they also include e.g. the effect of environment, the well-being of the population,...

Socio-economic benefits are all the positive effects of the project or investment for all participants in society. The impact can be social, economic or environmental. If these terms are applied to this paper, the social impact would be the safety for the road users. The most important goal of C-ITS services that will be investigated in this paper is the reduction of road fatalities. Economic impact will, among others, include the reduction of traffic jams, seeing as these are a big economic loss in the transport sector. The environmental impact will naturally be the possible reduction of pollutant emissions.

These benefits are difficult to quantify in monetary values, but reduction in deaths, traffic jams or grams of CO_2 must be changed to a value in euros. Using monetary values it is possible to weigh the benefits against the costs or compare the various proposed options.

Importance

Socio-economic benefits (benefits offered to a community) will have long-term impacts on the prevailing economic conditions. These benefits will have an indirect impact on the economic situation. For example, a reduction in the amount of traffic jams will not have a direct impact on the economy in the form of money, but an indirect impact. There will be less traffic jams so cars and trucks can move across the country more efficiently.

According to [8], traffic jams have a negative impact on employment and investments.

For a company agglomeration effects are very important. It has benefits for the employees: 49% of employees in Flanders and 69% of employees in Brussels commute fewer than 10 km and 20 km respectively. However agglomeration effects also have an influence on customer-supplier relationships: 50% of the distance travelled between suppliers and their customers in Belgium is fewer than 25 km.

Sadly enough these positive effects are cancelled out by the congestion problem. Figure 2.1 shows that, on average, the negative effects of the congestion problem cancel the positive effects of agglomeration out. A 10% increase in traffic congestion encourages a productivity decline of -0.2% on average.

The blue bars represent the effect of agglomeration and the red bars represent the effect of traffic congestion on the productivity of an average company. The black spheres show the net effect of these opposing forces on productivity.

Companies are very important for the country. They provide employment for its inhabitants and the productivity of a company has a direct impact on the country's economy, so socio-economic benefits are important.

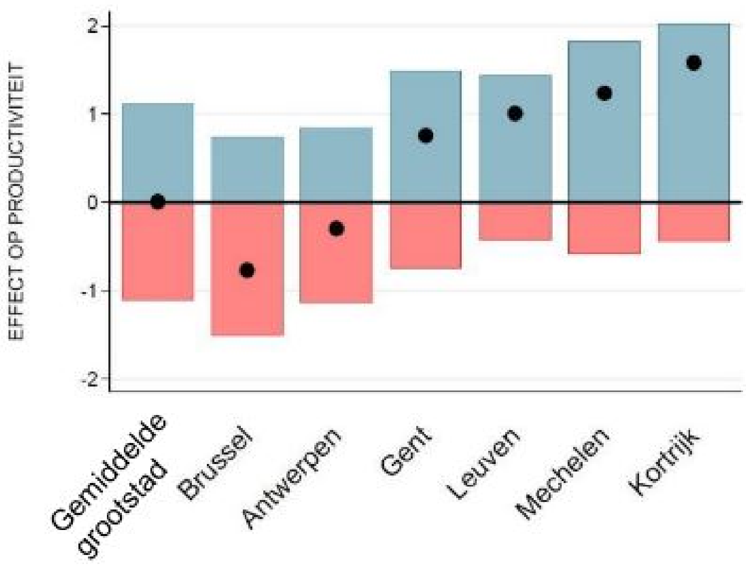


Figure 2.1: Impacts of agglomeration and congestion on the productivity [8]

2.2 Different methods

2.2.1 Method 1: CBA

CBA or Cost-benefit analysis is a useful tool to analyse potential socio-economic impact of investments. This technique for evaluating public spending, aims to help public decision-makers invest only in those projects that will be the most profitable for the community. The main idea is to create an overview of all the costs and compare them to the benefits. The goal is to perform the CBA before decisions are made, so different project proposals can be compared and evaluated. To make the comparison, both costs and benefits, must be quantified as much as possible and expressed in monetary terms.

Both direct and indirect effects, financial and non-financial, must be evaluated in, as previously mentioned, monetary values. These monetary values may occur in different years. Using net present values, the equation between costs and benefits in different years can still be made. Conclusions of the CBA can be drawn using summarizing indicators, such as the difference between costs and benefits, the return on investment, and the cost-benefit ratio.

Performance

The monetary evaluation procedure

The first step is the monetary evaluation. This step is crucial because it defines the value of each effect that was taken into consideration in the CBA. The monetary evaluation procedure is divided in three phases. First of all, the advantages and disadvantages must be identified. This identification makes it possible to measure the effects. For each measurable effect, a physical measurement scale must be specified. An appropriate procedure for measuring the impact of the effect to be evaluated should be devised and applied to any competing project.

As a short illustration of this problem, for pollutant emissions it is difficult to know how many grams of CO_2 in the air are derived from the transportation sector. Clearly, air pollution has multiple effects. Pollution will cause a negative impact on human health, it can produce unpleasant odours and it deteriorates our landscapes. Each impact needs a different evaluation procedure. But the relationship between the amount of air pollution and the different impacts must also be investigated. Furthermore the fact that the impacts are not the same today as they were in the past must also be taken into account.

The second phase starts by taking the different possible procedures for assigning a monetary value to each unit identified in the previous phase. These procedures can be based on surveys, contingent valuation or willingness to pay or receive. The procedures may also be based on the behavior exhibited by existing markets, allowing indirect estimates of the impact resulting from the benefits accrued or problems caused.

In the last phase of the evaluation procedure the future changes of a certain number of reference values considered in CBA calculations should be determined exactly. A well developed plan for the future is necessary to forecast the reference values. As mentioned previously, impacts can change over time.

The reference situation

The evaluation of the costs and benefits of an investment project requires an accurate reference situation. The advantages and disadvantages are the differences between a situation where the project would be executed and a situation without the project. For example, it is only possible to evaluate the avoided amount of accidents by using C-ITS if the number of accidents that would occur without implementing C-ITS, is predicted.

Characterizing a reference situation in the context of a CBA sometimes requires considering investments that are known as eluded because they would not be made if the project is implemented. Investments that must be executed even if the project is not implemented, must also be taken into account.

The return can be divided into two factors, according to [9]. The first factor is the first year's rate of return. This represents the ratio between the stream of social benefits in the first year and also the sum of the discounted costs of the project. The second factor is the internal rate of return. The internal rate of return measures the social discount rate for which the sum of discounted benefits equals the sum of the discounted costs of the investment project.

CBA can also be performed in terms of net social benefits. All the costs and benefits must be accounted over a previously defined time span. To use net social benefits, a social discount rate has to be defined, so present and future costs and benefits can be compared.

Generally, CBA procedures require defining many reference values and specifying a great number of assumptions, thus giving the impression that these procedures are formal and highly technical.

Uncertainty

As mentioned in the previous paragraph, a lot of reference values and assumptions will be made. In the model there will be a lot of uncertainty surrounding certain future values. Does this mean that the model is pointless?

While investigating the benefits for C-ITS, there will be many uncertainties. The reduction factors for safety, travel times and CO_2 emissions are based on projects executed in Europe. But those factors are not a certainty. Other parameters like the forecasts of the demand on the highways and the costs are also uncertain. A study about both systematic and random errors must be made.

A CBA serves to make a decision. Is it possible that the uncertainties as regard to true costs and benefits distort the policy recommendations of the CBA so the CBA is not suitable for use in decision making anymore?

According to [10], the uncertainties with regard to valuations and effects cause a negligible loss of total net benefits. The uncertainties with regard to the investment costs and demand for transport are a bit more important. Still those uncertainties are far from extreme enough to where using a CBA would be useless or misleading. The study also shows that the potential losses due to uncertainty are very small compared to the potential gains of using CBA.

The conclusion is that these uncertainties must be taken into account, but they do not make all the work put into a consistent cost-benefit analysis worthless.

Remarks and perspectives

Perspective of Politicians

The decisions about transport policies will be made by politicians. What do politicians think about CBAs? Will they really listen to the conclusion of a cost-benefit analysis?

In [11] the views of Dutch politicians are discussed. The politicians mention 4 points that are relatively common:

- They indicate that they use CBA information but the information is not decisive.
- The usefulness of the composite number (NPV) is doubted. NPV is incomplete in their view. Politicians seem more interested in a clear picture of the trade-offs.
- They find a CBA non-transparent.
- They suggest process improvements.

The politicians use CBAs but in a non-decisive manner. They find the aggregate outcome (the composite result) of a CBA pretentious. The politicians are more interested in a tool that also shows important trade-offs of a policy instead of just one number that says if an investment is interesting or not. Using the CBA and some extra tools to show the trade-offs would be very helpful for politicians.

Perspective of Ethics

Utilitarianism will be used to discuss the ethical perspective of a CBA. Utilitarianism is the most popular theory of a family of ethical theories called consequentialism.

"Consequentialism is the view that normative properties depend only on consequences." (Stanford Encyclopedia of Philosophy)

"Utilitarianism, more specifically: act consequentialism, is the claim that an act is morally right if, and only if, that act maximizes the good, that is if, and only if, the total amount of good for all, minus the total amount of bad for all, is greater than this net amount for any incompatible act available to the agent on that occasion." (Stanford Encyclopedia of Philosophy)

The perspective of ethics can be important to reduce social exclusion in the cost-benefit analysis. For example, because of a lower income, the willingness-to-pay for some categories of citizens is very low.

There are other ethically relevant critics on CBA according to [12], but they are not relevant for this research. The income of citizens can differ a lot, but this can be taken into account by laying the responsibility for the cost with the car manufactures. In this way, the citizens will not notice this when buying a car.

It is also possible to disburse grants if a C-ITS car is bought. But the main conclusion is that from the perspective of ethics an ex-ante evaluation of a CBA is worth trying to make policy decisions about this subject. In this case for C-ITS, it is possible to take the ethical part into account.

Remarks

As mentioned earlier, some benefits are difficult to quantify in monetary terms. However this remains very important. A CBA aims to express all effects in monetary terms.

Some effects, such as construction costs, or travel time savings, are easier to express in monetary terms than others. In this research most of the benefits are easily expressed in monetary values, so this won't lead to problems.

Conclusion

The conclusion is very simple. A cost-benefit analysis will not predict the exact outcome, but it is, despite certain criticisms, a very good tool to make policy decisions with.

A CBA is very useful in situations where the alternatives to be evaluated are more or less comparable. In this research the situation with the C-ITS project will be compared to the reference situation without the C-ITS project, so those are comparable alternatives. However, it is still preferable to use other tools and be very critical about the outcome.

2.2.2 Method 2: MCA

Multiple-criteria decision-making (MCDM) or multiple-criteria analysis (MCDA) is an evaluation method that evaluates multiple conflicting criteria in decision making.

"Multiple-criteria evaluation problems: These problems consist of a finite number of alternatives, explicitly known in the beginning of the solution process. Each alternative is represented by its performance in multiple criteria. The problem may be defined as finding the best alternative for a decision-maker (DM), or finding a set of good alternatives. One may also be interested in "sorting" or "classifying" alternatives. Sorting refers to placing alternatives in a set of preference-ordered classes (such as assigning credit-ratings to countries), and classifying refers to assigning alternatives to non-ordered sets (such as diagnosing patients based on their symptoms)." (TRIANTAPHYLLOU, 2000, p.320)

"Solving" a multiple-criteria analysis is possible in different ways. The first way is to choose the "best" alternative out of the set of available alternatives. An MCA is very subjective so in this case the "best" alternative means the "most preferred" alternative. Another way to "solve" the analysis is choosing a small set of good alternatives, or grouping alternatives into different preference sets.

An easily noticed weakness of an MCA is that the actor can choose the weighting in however they prefer. Humans are very subjective and this can lead to manipulations, but this can also be seen as a positive point of the MCA. Besides subjectivity, arbitrarity and worries about double-counting effects are the main disadvantages of MCDM, as stated in [11].

A big advantage MCA can offer is that this method also allows factors which cannot be easily expressed as a monetary value, to be included. By using MCDM a certain freedom to include every possible impact is created.

The conclusion is that MCA is a useful tool to choose between comparable alternatives, but not to choose if a project will be executed or not. However, it can be very helpful to make a decision if MCA is used beside a well developed CBA.

2.2.3 Combination of both

One prefers to employ a methodology where a combination of CBA and MCA is used, if a decision must be made between less comparable choice options, or if important ethical aspects are at stake.

Another general recommendation is that if an ethical issue has a big influence on the ex-ante evaluation of transport projects and policies, it is preferable to at least add sensitivity analyses to the standard CBA. The sensitivity analyses estimate to what extent the key figures react to changes in input parameters.

Chapter 3

ITS

As already mentioned in the introduction the demand for the use of public roads has increased sharply. Contrary to the growing demand, the capacity of the roads has stayed relatively constant. To meet the demand, without increasing the capacity of the roads, new solutions must be invented.

Intelligent Transportation Systems (ITS) is a solution that can improve the mobility of road users by using communication and information technology applications. Besides mobility, ITS will also enhance road safety and environmental sustainability. The new technology will be integrated into the management and operation of the transportation system across all modes.

ITS is an overarching name for a wide range of information, control and electronic technologies that can be integrated into the road infrastructure and the vehicles themselves. To improve safety; crash rates, traffic conflicts and traffic law violations must be reduced. Mobility improvements means that the travel times, delays and traffic jams must be eliminated as much as possible. Environmental savings are typically measured by fuel savings and reduced pollutant emissions.

ITS can be divided into 2 categories: autonomous ITS and cooperative ITS. Autonomous ITS can be identified by all forms of intelligent transportation systems that not depend on cooperation with other vehicles or supporting infrastructure. Unlike autonomous ITS, cooperative ITS represents the systems where communication between vehicles and between vehicles and infrastructure is applied.

3.1 Autonomous ITS

For autonomous intelligent transportation systems, no communication between vehicles has to be involved in these systems, only inputs from multiple sources like radars, sensors, computer vision will be consulted. Two of the autonomous ITS will be discussed.

3.1.1 Advanced driver-assist systems

ADAS or advanced driver-assist systems are autonomous ITS that are already used in existing vehicles. ADAS is used to automate vehicle systems so human errors can be avoided. Some examples can be found below. Keep in mind that there exist many more advanced driver-assist systems.

- **Forward collision warning**
  This system is designed, as the name implies, to avoid forward collisions. Using cameras and sensors the system will warn the driver when a vehicle or obstacle in front of the vehicle, is getting to close. This feature will return in section 3.2 , but communication technology will be used instead of sensors and cameras.

- **Adaptive cruise control**
  The adaptive cruise control system adjusts automatically the speed of the vehicle to maintain a safe distance and avoid collisions with vehicles in front of the vehicle.

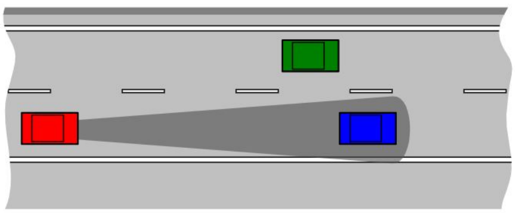


Figure 3.1: Adaptive cruise control and Forward collision warning [13]

- **Anti-lock braking system**
  This system is a safety system that prevents the wheels from locking up during braking, so slipping will be avoided. The optimal braking force is at the point when the wheel just begins to slips, but beyond this point the wheels must be unlocked again to avoid sliding.

- **Parking sensor**
  Parking sensors are proximity sensors that are invented for vehicles to warn the driver of obstacles while parking. Either electromagnetic sensors or ultrasonic sensors, where the distance is measured by using acoustic pulses.

- **Traffic sign recognition**
  Forward-facing cameras can analyse traffic signs on the road. After analyzing the sign, speed limits, prohibition signs and so on, will be shown on the dashboard of the vehicle. To identify the different signs neural networks can be trained and used.

3.1.2 Brake assist system

This system increases the breaking force when an emergency occurs. It is different then the forward collision warning. A research, carried out by Mercedes-Benz in 1992 [14], showed that in 90 % of the emergency situations, the drivers failed to brake hard enough to avoid the collision. The brake assist system interprets the force and the speed with the driver pushes the brake pedal to detect whether an emergency situation is occurring or not. If the system detects an emergency situation, it will automatically increase the breaking force, so the stopping distance will be reduced. Nowadays a extra radar in front of the car is used to calculate the distance to the vehicle in front (subsection 3.1.1 : forward collision warning).

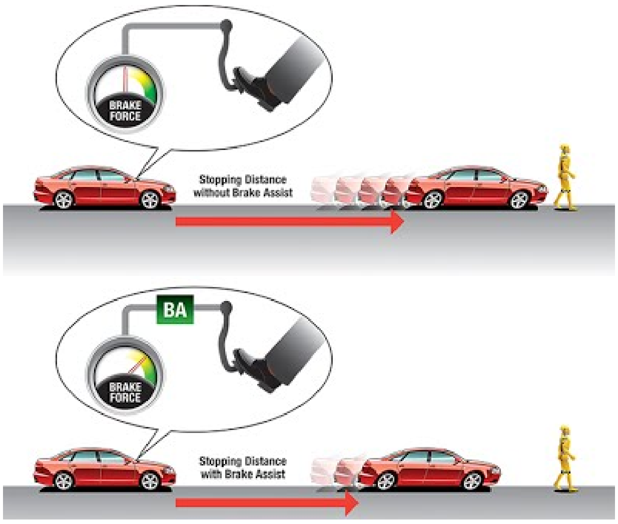


Figure 3.2: Brake assist system [15]

3.2 Cooperative ITS

These intelligent transportation systems utilise communication systems to enhance safety and efficiency. This is the main difference between autonomous and cooperative ITS. The communication between vehicles or between vehicles and infrastructure will be used instead or besides the existing radars. C-ITS will enable cars, buses, trucks, roads, other infrastructure, our smartphones and many other devices to talk to one another. For example, car A would use short-range radio signals to communicate with other cars so they would be aware if car A is nearby them. Using communication a lot of new features can be installed in vehicle. It will potentially complement on-board sensors by providing enhanced information, such as data from other vehicles, over a longer range.

Communication between vehicles is represented by V2V and will be discussed in subsection 3.2.2. In subsection 3.2.3 the communication services and technology between vehicles and infrastructure will be discussed. If cellular technology would be used, also V2N can be implemented.

C-ITS will be implemented in the vehicles in the form of services. The European Commission has produced a list of communication services that must be deployed first. These services are called Day 1 services. Also, in general day 1 applications are used to inform drivers to help them make better decisions on the road. The second list, Day 1.5 services is the next step towards better communication and cooperation between vehicles. Figure 3.4 presents a complete list of all the Day 1 and Day 1.5 services, both for V2V and V2I services. The information that is used, was gathered from [16], [17], [18] and [19].

3.2.1 Network systems

Figure 3.3 gives already a good view on the difference between cellular connectivity and direct short range communication. A lot of information is found in [20].

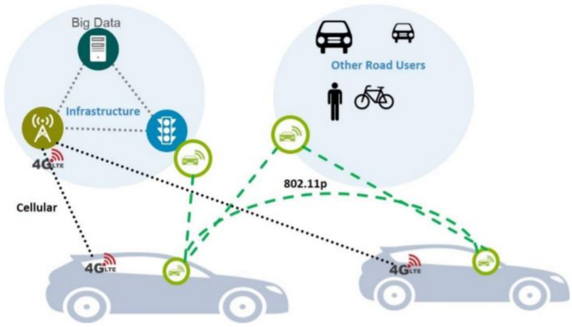


Figure 3.3: Difference between ITS-G5 and cellular connectivity [20]

Direct short range communication

Direct short range communication (DSRC) are communication channels that are designed for automotive use. DSRC, that is based on the IEEE 802.11p standard is also called ITS-G5. ITS-G5 is today the standard for V2X communication technologies. IEEE 802.11p is an approved amendment to the IEEE 802.11 standard (also known as Wi-Fi). IEEE 802.11 or Wi-Fi includes a collection of standards for wireless networks. The extension of IEEE 802.11 standard to complete the IEEE 802.11p standards, is 'wireless access in vehicular environments' (WAVE), a vehicular communication system. This extension supports ITS applications.

DSRC allows to communicate in a very specific way. This direct form of communication uses a free frequency band and works without masts or telecom providers. It gives information about the speed of the vehicle, the position of the vehicle and the direction the vehicle is heading. This form of ITS is largely focused on preventing accidents. There is also a difference between active and passive DSRC. Passive DSRC will only show a warning to the driver, where active DSRC will automatically take action when it is necessary.

Cellular technologies

In contrast to Wi-Fi, cellular technology is a completely different sort of wireless technology. Cellular technology can cover a range of several kilometers instead of several tens of meters for Wi-Fi. Cellular technology spreads their signals by using cell towers. C-V2X is a technology developed by the Third Generation Partnership Project (3GPP) to deliver V2X services, using two modes of communication.

First there is a direct vehicle-to-vehicle and vehicle-to-infrastructure mode, called PC-5. LTE-V2X or PC-5 is the newest version, proposed by the 5G Automotive Association (5GAA) and is an alternative short distance protocol to ITS-G5. PC-5 focuses on direct communication and works without using the known (provider bound) cellular 5G network.
The second mode is a network communications interface for vehicle-to-network (V2N) communication using existing mobile networks. It means that this mode will use existing cellular infrastructure and, in the future, 5G networks.

Using cellular technology for V2X communication has potential to bring additional benefits by combining the features with the applications of V2N.

3.2.2 Vehicle-to-Vehicle

Vehicle-to-vehicle communication is the data transmission between two vehicles. The communication can be done using ITS-G5 (section 3.2.1) or Cellular-V2V (section 3.2.1). V2V devices would use the dedicated short range communications (DSRC) to transmit data, such as location, direction and speed, to nearby vehicles. That data would be updated and broadcast up to 10 times per second to nearby vehicles, and using that information, V2V-equipped vehicles can identify risks and provide warnings to drivers to avoid imminent crashes. V2V communication can create benefits far beyond todays on-board sensors.

Safety benefits are not the only impact of V2V communications. The communication between the vehicles can ensure better use of the road. Cars can form little ad hoc road trains, following each other as little as 1 meter nose to tail. This makes vastly better usage of the existing road infrastructure. These trains can also provide some environmental benefits. For example, it could gain some aerodynamic benefits for the cars in that train. Also, because of improved efficiency, cars can drive a constant speed. They do not have to brake and pull up, so some impact on the emissions and fuel consumption can be added to the benefits.

Communication services of V2V

As already mentioned, C-ITS will be implemented in cars by using different services. V2V services are more specifically the services that will use communication between different vehicles. Accidents can be prevented by those services. A lot of motorway accidents are caused by rear-end collisions. These accidents can be avoided, for example, by the service: forward collision warning. In general terms, the services can provide the driver with enhanced abilities to address additional crash situations. The services can detect dangerous situations at a much further distance than the driver or on-board sensors ever could be detect.

Below, the Day 1 V2V services will be further explained. The services that will be discussed are more specifically for use on highways. A complete list of the V2V services can be found at figure 3.4.

Emergency brake light

Emergency Electronic Brake Light (EBL) warns drivers of heavy braking ahead in the traffic queue. EBL makes it possible to warn other vehicles if a vehicle brakes heavy, even if the drivers visibility is limited or obstructed so the driver can not see the braking vehicle.

Emergency vehicle approaching

Emergency vehicle approaching (EVA) aims to prevent priority vehicles from being delayed. When a priority vehicle approaches a car with the service EVA, this vehicle will receive a notification. As a result of this notification, the driver knows a long time in advance that a priority vehicle is approaching and can take this into account by moving aside. The emergency vehicles can now drive on without being held up by other vehicles. This can be a very important application, knowing that in case of an emergency every second counts.

Traffic jam ahead warning

Traffic jam ahead warning (TJAW) aims to reduce the risk of potential accidents where a vehicle drives in the direction of a stationary traffic jam tail. By this way, the drivers can adapt their driving behaviour. This warning can be very useful, for example when the traffic tail is behind a curve or hill tip or the drivers of the vehicles are inattentive.

Slow or stationary vehicle(s)

Accidents often occurs during bad weather or bad visibility conditions. By these conditions slow or stationary vehicles are difficult to see, so high risk of accidents occurs. On highways, this can lead to emergency stops or serious accidents. If an accident is avoided by braking anyway, traffic jams can still form. This means that slow or stationary vehicle(s) warning does not only reduce the risk of accidents but contributes also to the elimination of traffic jams.

Hazardous location notification

The service is to warn road users about potentially hazardous situations or events on the road. Warnings include information about the location and type of a hazard, distance to the hazard, its expected duration, etc.

3.2.3 Vehicle-to-Infrastructure

Vehicles can also communicate with the infrastructure around them. By communicating with roadside infrastructure, drivers will be alerted when they are entering a school zone, a dangerous intersection will be crossed, if workers are on the roadside and if an upcoming traffic light is about to change.

Also V2I services are divided into different groups. Just like the V2V services, only the Day 1 services will be discussed in more detail.

In-vehicle signage

In-Vehicle signage is a message format to deliver information about the infrastructure to vehicles. The service provides information about existing, fixed and dynamic traffic signs to passing vehicles. It must help to improve the drivers awareness and reduce the number and severity of traffic accidents.

In-vehicle speed limits

In-vehicle speed limits are intended to prevent speeding violations and to increase safety by informing drivers about the speed limits so they will drive slower.

Probe vehicle data

The service is to provide vehicle-generated data about vehicles, road conditions and traffic situations to road users and road operators.

Shockwave damping

Shockwave damping aims to smoothen traffic flow in dense traffic conditions. The service will recommend the optimal speed, so the optimal capacity of the roads will be reached. The service will reduce the harmonisation of traffic flows and prevent the formation of shockwaves.

Shockwaves can occur very often in dense traffic. Little impacts can lead to long-term disruption of the traffic flow. Little impacts in dense traffic can already form shockwaves, which spreads and lead to long-term disruption of the traffic flow. This will be encouraged by less proactive way of driving and acceleration, which can lead to new shockwaves or a standstill.

Roadworks warning

This service utilizes roadside equipment to broadcast alerts to drivers warning them to reduce speed, change lanes, or watch for stationary traffic ahead within work zones.

Weather conditions

Weather-related crashes are defined as crashes that occur in adverse weather (i.e., rain, sleet, snow, fog, severe crosswinds, or blowing snow/sand/debris) or on slick pavement (i.e., wet pavement, snowy/slushy pavement, or icy pavement). Based on [21], around 22 percent of all the crashes occur under bad weather conditions. Safety is not the only factor that will be negatively affected. Also traffic flow will be affected, the traffic times will increase.

The communication service will avoid the negative affects of the weather by use advisory, control, and treatment strategies. Advisory strategies provide information about the circumstances to both transport managers and drivers. Control strategies change the state of the road to arrange traffic flow and regulate the capacity of the road. The last strategy provide the resources to minimise or eliminate the effects of the weather. This can include maintenance and emergency services.

Traffic management

Vehicles that passes V2I roadside stations will transmit messages that can be received by stationary roadside units. Those units are connected with traffic management centers or TMCs. The roadside units can forward the received messages from the bypassing vehicles to the connected TMCs. The TMCs can aggregate cooperative messages and can use the information to drastically improve the situational traffic awareness provided by stationary sensors.

Service bundle	C-ITS Services	Rationale
Bundle 1 ***Day 1, V2V, ITS-G5***	• Emergency brake light • Emergency vehicle approaching • Slow or stationary vehicle(s) • Traffic jam ahead warning • Hazardous location notification	• Day 1 safety-based V2V services based on ITS-G5 communication, likely to be deployed to vehicles supported by US legislation
Bundle 2 ***Day 1, V2I, mainly applicable to motorways***	• In-vehicle signage • In-vehicle speed limits • Probe vehicle data • Shockwave damping • Road works warning • Weather conditions	• Day 1 V2I, services that deliver most benefit to motorways. Some services listed here may also be applicable to other road types
Bundle 3 ***Day 1, V2I, mainly applicable to urban areas***	• Green Light Optimal Speed Advisory (GLOSA) / Time To Green (TTG) • Signal violation/Intersection safety • Traffic signal priority request by designated vehicles	• Day 1 V2I, services expected to only be applicable in urban areas. Therefore, these services are in a separate bundle to those in Bundle 2
Bundle 4 ***Day 1.5, V2I, Parking Information***	• Off street parking information • On street parking management and information • Park & Ride information • Information on AFV fuelling & charging stations	• C-ITS services intended to provide information regarding parking (and refuelling) to drivers
Bundle 5 ***Day 1.5, V2I, Traffic and other information***	• Traffic information and smart routing	• C-ITS services intended to provide traffic information to drivers
Bundle 6 ***Day 1.5, Freight specific services***	• Loading zone management • Zone access control management	• Zone management services
Bundle 7 ***Day 1.5, V2X (mainly applicable to urban areas), likely to be ITS-G5***	• Vulnerable road user protection (pedestrians and cyclists)	• V2X service expected to be post day 1. Communication method is likely to be ITS-G5. Main benefits are likely to be seen in urban areas.
Bundle 8 ***Day 1.5, V2V, likely to be ITS-G5***	• Cooperative collision risk warning • Motorcycle approaching indication	• Post day 1 V2V services that are likely to be based on ITS-G5. As for Day 1 services, V2V and V2I services are in separate service bundles.
Bundle 9 ***Day 1.5, V2I***	• Wrong way driving	• Post day 1 V2I service. As for Day 1 services, V2V and V2I services are in separate service bundles.

Figure 3.4: Communication services [22]

Chapter 4

Impact of C-ITS

4.1 Benefits

Various problems occur by the increasing road traffic. Nowadays road traffic is the main source of gases and air pollution. However the traffic has become a lot safer than in the past, it is also the the cause of many road fatalities. Moreover, congestion costs the economy an enormous amount of money. All those problems together cause an enormous damage to the society.

C-ITS is a new technology for more safer and greener road transport. The intelligent systems can communicate with each other. The systems can be implemented in infrastructure or in vehicles, that means that there can be communication between vehicles and infrastructure (V2I), between different infrastructures (I2I) but the communication is usually between vehicle-to-vehicle (V2V). This allows for a wide range of information exchange and cooperation services. As already mentioned this research will focus on the vehicle-to-vehicle services and benefits.

The benefits of C-ITS are very diverse: safer traffic, less congestion, more efficient transport, more mobility, more reliable services, lower energy consumption, less damage to the environment and more economic development.

There is also a negative impact that has to be suppressed. Possible negative effects are increased traffic demand, drivers suffering from an overload of information, cyber security or privacy risks.

In the paragraph of subsection 2.1.1 about the importance of socio-economic benefits, the mobility benefits are already discussed.

V2V Safety Applications will make sure that their will be less road fatalities and injuries. Implementing the day 1 V2V services in Belgium can prevent 6 out of 17 deaths and 39 out of 70 serious injuries each year. Not only is this an emotional benefit for the society, but a life has also a monetary value for the government and society. Avoiding casualties and injuries is, bluntly stated, good for the economy.

Not only the crashes, fatalities and injuries are some safety benefits, but also avoided medical care costs and productivity losses, as well as property damage to the vehicles. Furthermore, after an accident there is a possibility that there will be damage to the infrastructure. If there is an injury, this person can lose a year of school or be occupational disable. It can all be brought back to a monetary value

In terms of the environment, there are also advantages for the use of C-ITS. It is not the main goal of the V2V services, but they will provide smoother traffic. The smoother traffic ensures that cars can slow down earlier and have to accelerate less. As a result there will be less pollutant emissions. Cars will also be greener because they will be more economical in the use of fuel.

C-ITS can provide a lot of benefits in general. Apps can help you find open parking spaces, warn you to a car in your blind spot or icy roads ahead, locate available last-minute ride-share partners. C-ITS can provide speed recommendations to help eliminate unnecessary stops for traffic lights for example, and that point vehicles reach optimal fuel efficiency. The potential benefits of connected vehicle applications are tremendous.

4.2 Impact of the Day 1 V2V services

4.2.1 Safety impact

Emergency vehicle approaching

According to [23], 0.8% of the fatal accidents and 1.1% of the injury accidents includes an emergency vehicle. The number of accidents that could be prevented is estimated at 50% - 70% of the fatalities and injuries at intersections and 60% - 80% on links. In this case only highways will be examined, so the accidents at intersections will be left out. The service was assumed to be more effective on links as the driving situation is there less complex. Drivers can react easier to approaching emergency vehicles on links.

Traffic jam ahead warning

No one will deny that we have a huge congestion problem. One would expect congestion to have a positive effect on road safety: in a traffic jam the speed is by definition low. Nothing could be further from the truth since many vehicles drill at the back of traffic jams or swerve to avoid them. This might lead to rear-end collisions, side-by-side collisions or other accident types because of panic manoeuvres.

The warning system will alert the driver even before the traffic jam could be noticed by the driver himself. That gives the driver time to react safely and in time. The positive effects are that the driver will slow down earlier and to a lower speed than without TJAW. If the driver does not slow down earlier, the driver will still be able to react faster when (s)he approaches a traffic jam. The driver will brake more smoothly when reaching a traffic jam or can change lanes safely and on time.

Also non-users can experience positive benefits of the warning system. Drivers with the system will brake more smoothly and safely, so drivers behind the users of the system are likely to follow their lead. But besides the positive effects, the system can also lead to a negative effect. Drivers can be less attentive to potential traffic jams, because they rely on the traffic jam ahead warning system. Drivers must be aware that not all the traffic jams can be covered.

Emergency brake light

The emergency brake light system will take over a certain percentage of the system TJAW. EBL also aims to avoid rear-end collisions. The systems warns the driver if a collision is possible due to a late reaction. The focus of EBL is to warn not only the first car behind the braking car but also the following cars behind the first car. Therefore the system should provide more time to react for the following cars, still before the brake lights of the vehicle in front of them would light up.

This system can, just like TJAW, have positive benefits for non-users. Drivers with the system will brake more smoothly and safely. Most of the non-users that are driving behead users will follow their lead. Also EBL can has possible negative effects. In case of high traffic flow, drivers can do panic manoeuvres at the last moment, that can lead to side-by-side accidents or other accidents types.

Slow or stationary vehicle(s)

Slow or stationary vehicle(s) signal to nearby vehicles to warn approaching drivers of their presence. The message can then be sent to the following drivers. The drivers can change lanes, take an alternative route, or make evasive manoeuvres well in advance. The system will ensure a better traffic fluidity and safety and will deliver efficiency benefits.

Hazardous location notification

Hazardous locations are automatically detected by the services and then the information will be sent to other drivers. The system will warn the other drivers so they can chance their driving behaviour or change lanes. For example, if a car brakes rapid and change their vehicle direction, a sharp bend may be detected. A pothole can be detected using a vehicles electronic stability control system. The information concerning the specific location and type of danger will be retained and sent to vehicles in the surrounding area, warning of the hazard. In this way accidents will be avoided.

4.2.2 Impact on environment and traffic efficiency

The services will ensure a smoother traffic. The systems avoid vehicles to brake very hard. In this way cars can slow down and accelerate smooth. This will ensure lower CO_2 emissions.

Abrupt emergency brakes can result into crashes and accidents but also into traffic jams if there is a high traffic density. If drivers are already warned, they would not have to brake abrupt. This will result into a smoother traffic and a better traffic fluidity.

Part III

Methodology

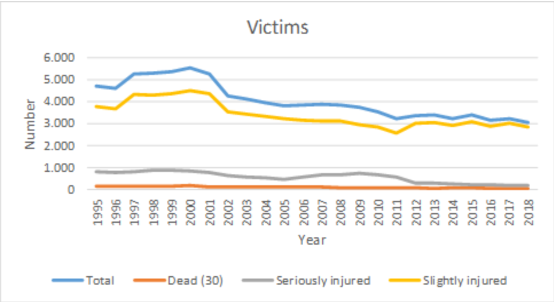
Chapter 5

Safety model

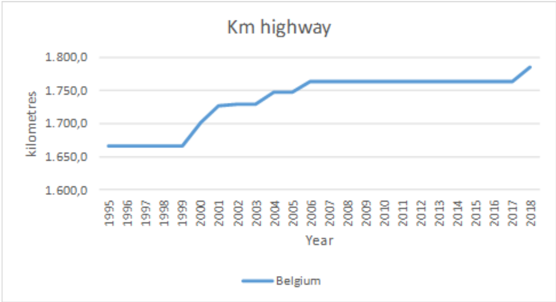
5.1 Data

The safety model is based on Belgian data [24]. Using the statistics of Belgium a top-down model is made. The accidents in Belgium are split up into fatal accidents (30), seriously injuries and slightly injuries. Fatal accidents (30) are the accidents where the victim is directly dead together with the accidents involving fatally injuries (the victims that will die within 30 days after the accidents). Using the amount of kilometers highway, the data is transformed to an number of accidents per kilometer.

Figure 5.1a shows the amount of victims of traffic accidents in Belgium. In figure 5.1b the amount of kilometers highway in Belgium is represented. This information is used to calculate the number of accidents per kilometer.



(a) Victims in Belgium



(b) Kilometers highway in Belgium

The accidents are divided into different types of accidents. Each type is also split up into the different degree of severity of the accident, just like figure 5.1a.

- Rear-end collisions
- Frontal collisions
- Collisions from the side
- Collisions with a pedestrian
- Collisions with an obstacle (within or outside the roadway)
- 1 driver, no obstacle
- Other

Figure 5.2 shows the different types of accidents, fatalities and injuries together. By way of example, the division of the fatalities and injuries of the rear-end collisions are plotted in figure 5.3.

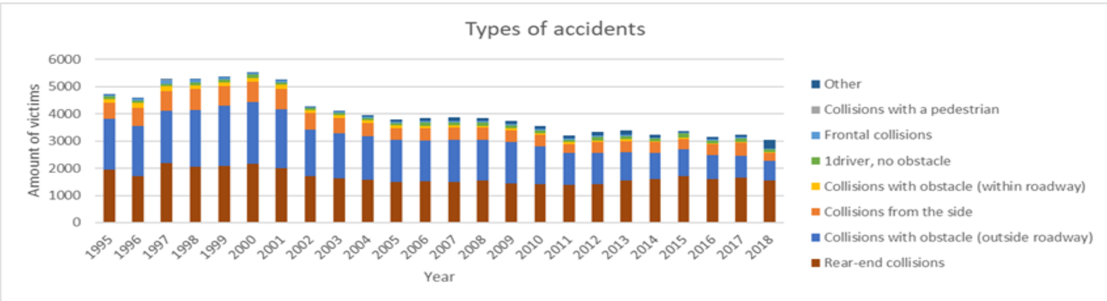


Figure 5.2: Different types of accidents

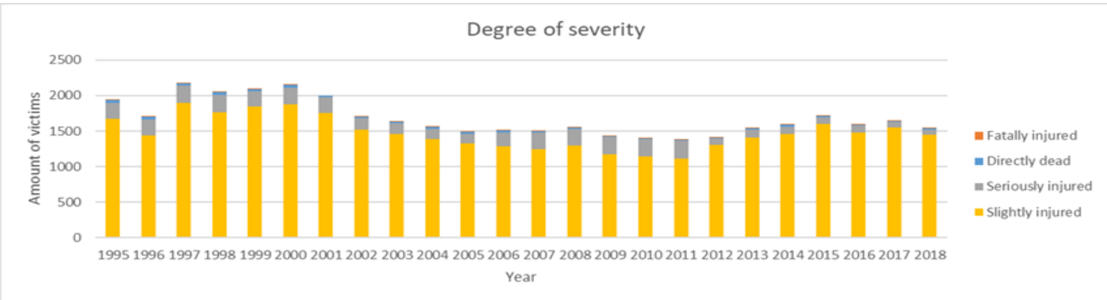


Figure 5.3: Degree of severity Rear-end collisions

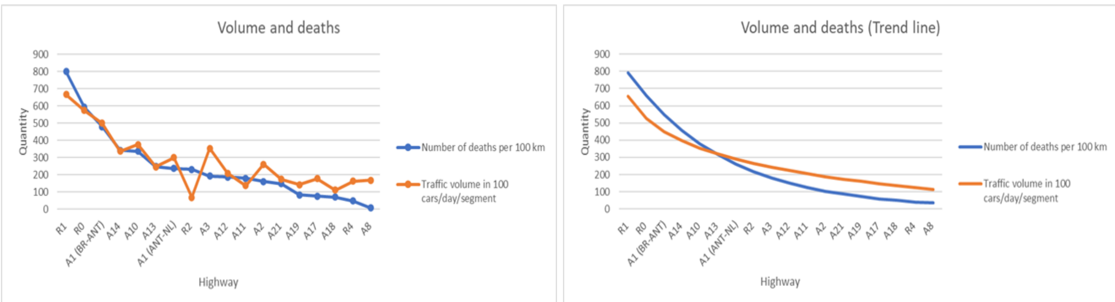
5.2 Input parameters

As mentioned in section 5.1, the model is based on Belgian data. Using this data, a model is made where 2 input parameters take a central role. The parameters are the volume of the cars per day and the length of the trajectory in kilometers.

First of all the data is used to calculate all the important information in percentages and amounts that are dependent on the length of the trajectory. The amount of victims per year are divided through the total length of the Belgian highways in that year. From now on it is very easy to calculate the average of the number of fatalities and injuries for a specific route or trajectory, given its length.

The types of accidents and the quantity of the different types is known. Using this knowledge the percentages of the different types of accidents and there division into fatalities and injuries are calculated for each year. If the length of a route is entered in the model, the quantity of the different accidents will be calculated using the percentages in that year.

Another important parameter to take into account is the traffic volume of the trajectory. A correlation between the traffic volume and the quantity of accidents and victims is calculated.



(a) Correlation between volume and deaths

(b) Correlation: Trend lines

Figure 5.4a shows for each highway in Flanders the number of deaths per 100 kilometers and the volume in 100 cars per day per segment on that highway. On the x-axis the different highways have been placed in order of most to least deaths (blue line). Also for each highway the traffic volume is plotted and it is clear on the figure that there is a relation between the traffic volume and the number of deaths.

To make the graphs more evident and attractive to look at, the trend lines of both graphs are plotted in figure 5.4b. This is better to examine, because the relation between traffic volume and deaths may also depend on the tediousness of the highway, the condition of the infrastructure, the amount of trucks and so on.

The formula for the relation can be calculated by transforming the data to a percentage above or below a reference value. The reference value is the average of the number of deaths and the average amount of cars per day per segment. The reference value in percentage is 0% and for example, a doubling of the reference value is in that case 100%.

The relation between the percentage above or below the reference value for the traffic volume (x-axis) and the percentage above or below the reference value for the number of victims (y-axis) is shown in figure 5.5. The calculations are done using the date from [25] and [26].

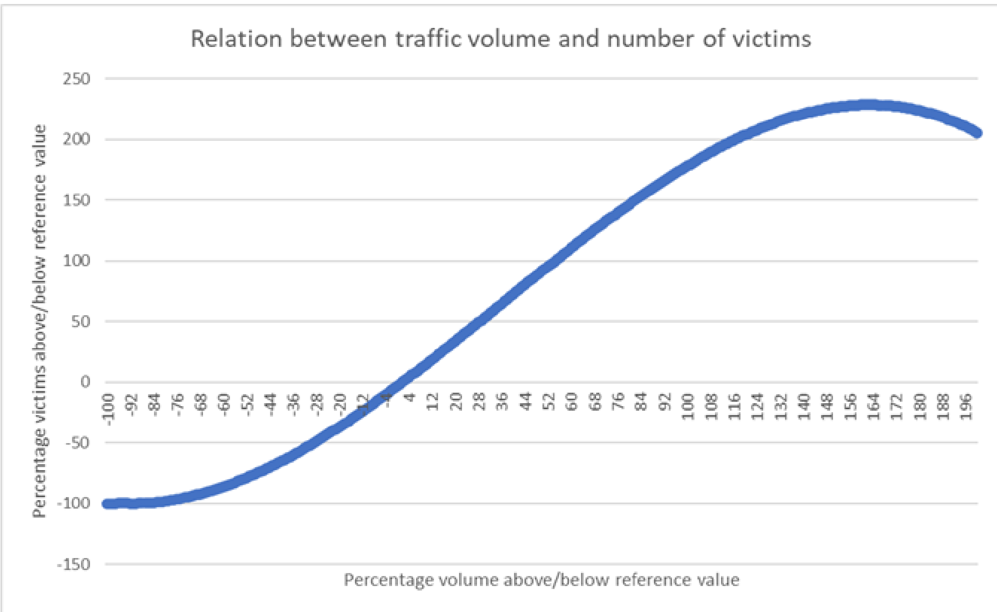


Figure 5.5: Relation traffic volume and number of victims

The graph in figure 5.5 is also quite logical from an intuitive point of view. In the middle of the graph there is a linear correlation between volume and number of victims. The more cars there are on the track, the more accidents will occur because of the high density and more risks. But in the beginning the curve starts flat, cause a certain density is required to have more accidents. Around an increase of 150% the curve will flatten and decrease again. That is because the maximum capacity is exceeded and the cars are practically standing still in traffic jams. However there are still accidents, for example cars that drive into the traffic jams or perform unexpected manoeuvres to avoid rear-end collisions with the traffic jam, but cause other types of accidents instead.

This relation can be implemented in the model. Now a trajectory can be modelled by entering the traffic volume and length. The number of victims will be calculated for those input parameters. Figure 5.6 shows the graphs for the number of victims for different traffic volumes on a trajectory with a length of 1000 kilometers.

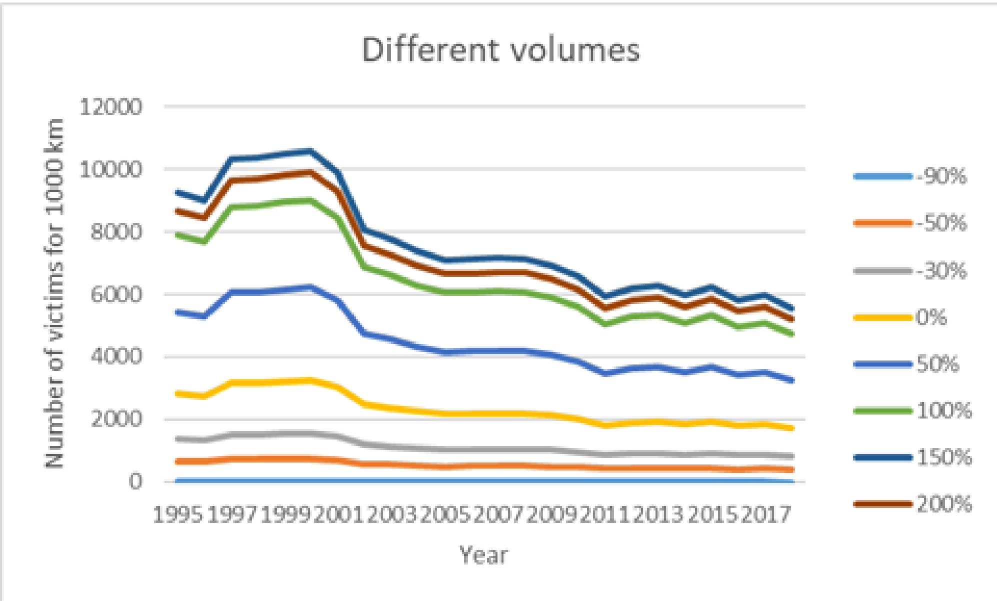


Figure 5.6: Different Traffic volumes for 1000 kilometers

The model will calculate the benefits for each of the coming years. A year consists of busy and quiet days, for example the difference between weekdays and weekends. It is possible to put two different volumes into the model for the different types of days. The amount of busy and quiet days is also changeable. For the further calculations the volume will set on an average weekday in Belgium, for both types of days. Although it does not matter because the same volume has been chosen, there will be 260 busy days and 105 quiet days per year in the calculations during this section.

5.3 Forecasting

The model calculates the different types of accidents and for each type the amount of fatalities, seriously and slightly injuries in the years where the information is available, but the quantity in the following years should be estimated.

All the the types of collisions are estimated for the next years. Also the different degrees of severity, so fatalities, seriously injuries, slightly injuries. Figure 5.7 shows the different types of collisions for each year from 1995 until 2035. The parameters that are used in the model to make the graph, are a length of 1000 kilometers and a reference traffic volume. From 2019 until 2035, a forecast for the different collisions is plotted. The number of victims are the injuries and the fatalities together in the graph.

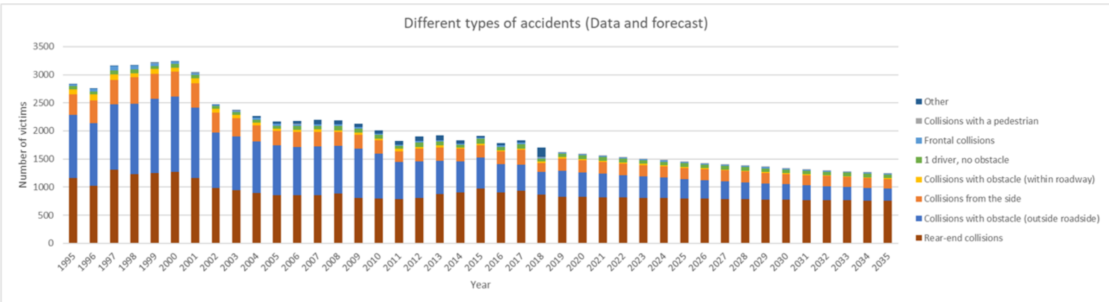


Figure 5.7: Different types of accidents (data and forecast)

By way of illustration, the different severity of the accidents for collisions with an obstacle outside the roadway is shown in figure 5.8. The graph represents again the victims for a trajectory with a length of 1000 kilometers and a normal traffic volume. The number of fatally injuries, deaths, seriously and slightly injuries can be seen in the figure. In the model the division is calculated and estimated for all the different types of collisions.

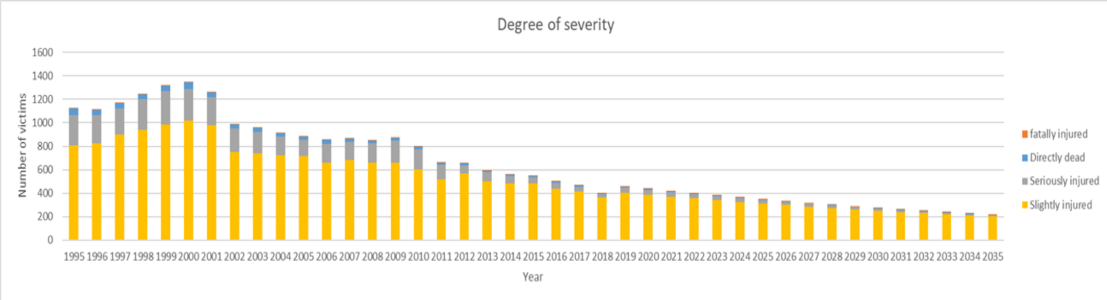


Figure 5.8: Degree of severity Collision with obstacle outside roadway (data and forecast)

Those forecasts will be used as reference situation for the cost-benefit analysis. This would be the situation if the C-ITS services would not be implemented. There is already a decreasing trend, possible explanations are improved infrastructure, safer cars,... But the goal is to reduce it more.

5.4 Reduction

If the day 1 V2V services are implemented into the vehicles, there will be a reduction in the amount of accidents. Less accidents means less fatalities and less injuries. The reduction will depend on the C-ITS penetration of the service.

The C-ITS V2V services will become more valuable to the existing users as more vehicles would own them. A C-ITS service has a network effect. The effects work because vehicles with the services can interact with the increasing number of vehicles as the underlying service is adopted. Measuring the precise strength of network effects is rather difficult. Its not an exact science.

The adoption of the communication services have network effects that resembles an S-curve. An intuitive explanation is that the services will not have a big effect with a low adoption, because the chance that a car with the service would be warned by another car with the service is very small. But the more vehicles own the service, the more valuable the service is. When the adoption is high the curve starts to flatten. This can be reasoned with the inverse reasoning for a low adoption. If there is a high adoption there would be only a very small chance that a vehicle with the service would not be warned because there is not one car on that segment with the service. A curve for the effect given an adoption percentage is shown in figure 5.9. In the model the sigmoid function is used to implement the S-curve.

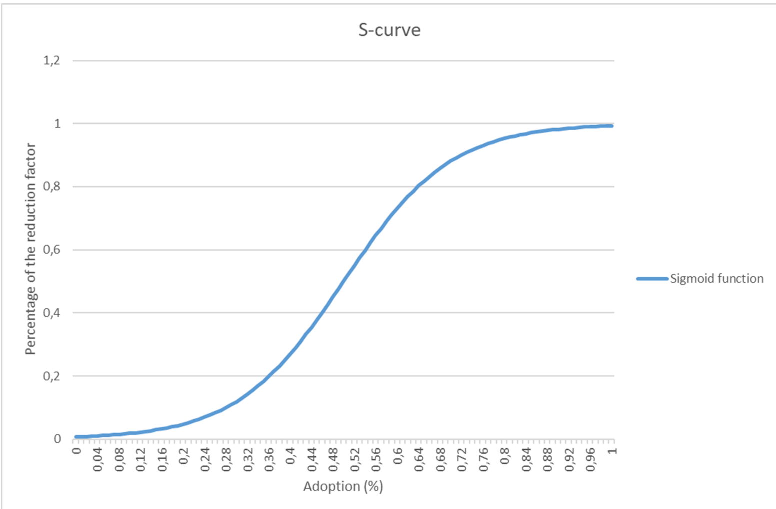


Figure 5.9: Effect in function of adoption

The S-curve tells the percentage of the possible reduction when a service is 100% implemented. The reduction factors for a 100% penetration will be discussed. Table 5.1 shows the reduction percentage for the number of victims that could be avoided by implementing the service emergency vehicle approaching. According to [23], 0.8% of the fatal accidents and 1.1% of the injury accidents includes an emergency vehicle. It is estimated that 60% - 80% of the accidents on links could be prevented.

It is estimated that 10-20% of accidents with an object, other than pedestrians, the object would be a broken-down vehicle on the road. According to [22], 70% - 90% of those accidents could be prevented by using the slow or stationary vehicle(s) service on motorways. Those reduction factors can be found in table 5.2.

Tables 5.3 and 5.4 shows the reduction percentages of the accidents that can be avoided using respectively the services emergency brake light and traffic jam ahead warning. In the tables it is clear that those services focus on the prevention of rear-end collisions. Also other types of collisions can be prevented, those could occur because of unexpected manoeuvres to avoid a rear-end collision. The overlap in avoiding accidents must be taken into account. As reported in [22], EBL will avoid 25% of the accidents that TJAW would avoid.

The reduction factors of the service hazard location notification is shown in table 5.5. The focus of this service is on the collisions with obstacles. The service tries to avoid collisions or accidents that involve dangerous obstacles.

Total .	Total number of victims	0,0061
	Directly dead	0,0049
	Fatally injured	0,0049
	Directly dead or after 30 days	0,0049
	Seriously injured	0,0073
	Slightly injured	0,0073

Table 5.1: Reduction factors EVA

Total .	Total number of victims	0,0230
	Directly dead	0,0265
	Fatally injured	0,0265
	Directly dead or after 30 days	0,0265
	Seriously injured	0,0194
	Slightly injured	0,0194

Table 5.2: Reduction factors SSV

Rear-end collisions	Total number of victims	0,1115
	Directly dead	0,123
	Fatally injured	0,123
	Dead (30)	0,123
	Seriously injured	0,10
	Slightly injured	0,10
Frontal collision (or crossing)	Total number of victims	0
	Directly dead	0
	Fatally injured	0
	Dead (30)	0
	Seriously injured	0
	Slightly injured	0
From the side	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	Seriously injured	0,015
	Slightly injured	0,015
With a pedestrian	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	Seriously injured	0,015
	Slightly injured	0,015
Against an obstacle (within roadway)	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	seriously injured	0,015
	Slightly injured	0,015
Against an obstacle (outside roadway)	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	Seriously injured	0,015
	Slightly injured	0,015
1 driver, no obstacle	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	Seriously injured	0,015
	Slightly injured	0,015
Other	Total number of victims	0,0165
	Directly dead	0,018
	Fatally injured	0,018
	Dead (30)	0,018
	Seriously injured	0,015
	Slightly injured	0,015

Table 5.3: Reduction factors EBL

Rear-end collisions	Total number of victims	0,0835
	Directly dead	0,073
	Fatally injured	0,073
	Dead (30)	0,073
	Seriously injured	0,094
	Slightly injured	0,094
Frontal collision (or crossing)	Total number of victims	0
	Directly dead	0
	Fatally injured	0
	Dead (30)	0
	Seriously injured	0
	Slightly injured	0
From the side	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015
With a pedestrian	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015
Against an obstacle (within roadway)	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015
Against an obstacle (outside roadway)	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015
1 driver, no obstacle	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015
Other	Total number of victims	0,0130
	Directly dead	0,011
	Fatally injured	0,011
	Dead (30)	0,011
	Seriously injured	0,015
	Slightly injured	0,015

Table 5.4: Reduction factors TJAW

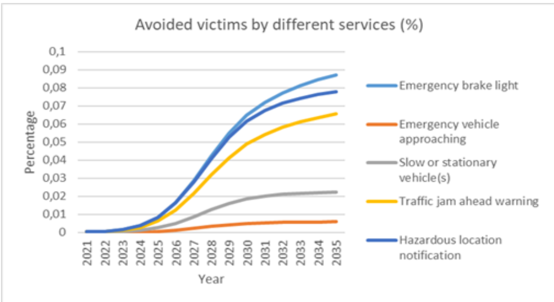
Rear-end collisions	Total number of victims	0,0595
	Directly dead	0,07
	Fatally injured	0,07
	Dead (30)	0,07
	Seriously injured	0,049
	Slightly injured	0,049
Frontal collision (or crossing)	Total number of victims	0,0285
	Directly dead	0,04
	Fatally injured	0,04
	Dead (30)	0,04
	Seriously injured	0,017
	Slightly injured	0,017
From the side	Total number of victims	0,0645
	Directly dead	0,102
	Fatally injured	0,102
	Dead (30)	0,102
	Seriously injured	0,027
	Slightly injured	0,027
With a pedestrian	Total number of victims	0,02
	Directly dead	0,016
	Fatally injured	0,016
	Dead (30)	0,016
	Seriously injured	0,024
	Slightly injured	0,024
Against an obstacle (within roadway)	Total number of victims	0,0995
	Directly dead	0,094
	Fatally injured	0,094
	Dead (30)	0,094
	Seriously injured	0,105
	Slightly injured	0,105
Against an obstacle (outside roadway)	Total number of victims	0,0995
	Directly dead	0,094
	Fatally injured	0,094
	Dead (30)	0,094
	Seriously injured	0,105
	Slightly injured	0,105
1 driver, no obstacle	Total number of victims	0,045
	Directly dead	0,05
	Fatally injured	0,05
	Dead (30)	0,05
	Seriously injured	0,04
	Slightly injured	0,04
Other	Total number of victims	0,022
	Directly dead	0,035
	Fatally injured	0,035
	Dead (30)	0,035
	Seriously injured	0,009
	Slightly injured	0,009

Table 5.5: Reduction factors HLN

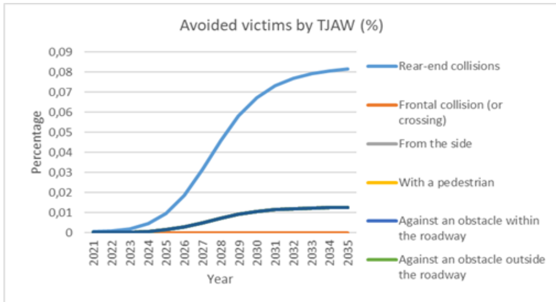
Year	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
Adoption (%)	0,01	0,03	0,12	0,21	0,30	0,38	0,45	0,52	0,58	0,64	0,70	0,75	0,79	0,83	0,87
Sigmoid	0,01	0,01	0,02	0,05	0,12	0,22	0,38	0,55	0,70	0,81	0,88	0,92	0,95	0,96	0,98

Table 5.6: Penetration rate and sigmoid function

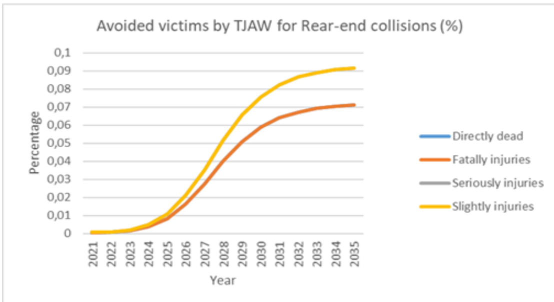
If the sigmoid function, shown in figure 5.9, is used for the mandatory penetration rate (table 5.6), next graphs can be found. Figure 5.10a represents the percentage avoided victims, fatalities and injuries together, by each service. Figure 5.10b shows the percentage avoided victims for the service TJAW only, but split up for each type of collision. The graph shows that TJAW has the most influence on rear-end collisions. A better look on the rear-end collisions, avoided by TJAW, is taken in figure 5.10c. A distinction between the fatalities, seriously and slightly injuries is made in this figure.



(a) Avoided victims by all services (%)

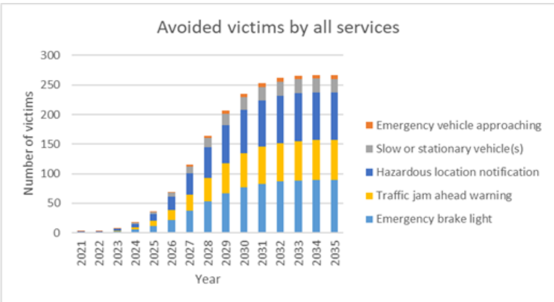


(b) Avoided victims by TJAW (%)

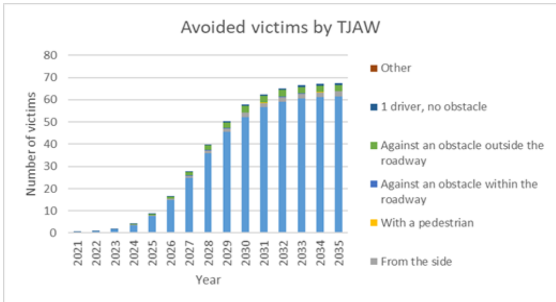


(c) Avoided victims by TJAW for Rear-end collisions (%)

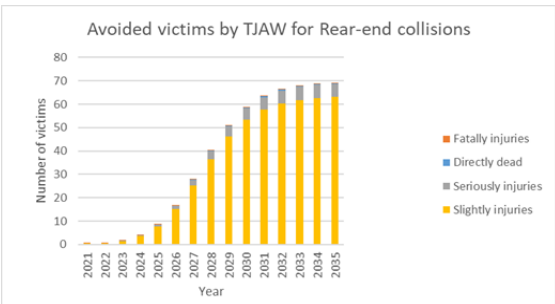
Here below, some graphs are plotted by way of illustration. The coming 3 figures are again for a mandatory implementation of the systems. The previous graphs are applied on the forecasts for a trajectory of 1000 kilometers and a reference traffic volume. Figure 5.11a shows the number of avoided victims, fatalities and injuries together, for the all different services. Figure 5.11b shows the service TJAW applied to the different types of collisions. Still, the fatalities and injuries are kept apart in the model, so as example the service traffic jam ahead warning applied to rear-end collisions is plotted to look at it in more detail. Figure 5.11c shows the number of avoided fatalities and injuries separately for the rear-end collisions avoided by the traffic jam ahead warning system.



(a) Avoided victims by all services



(b) Avoided victims by TJAW



(c) Avoided victims by TJAW for Rear-end collisions

5.5 Monetary

The European Commission estimates the cost of one traffic death at an average of 2,178 million euros. For a seriously and slightly injured person it is 330 400 euros and 21 300 euros respectively. [27]

The blue line is the benefit in euros for the mandatory penetration rate. To calculate the blue line, the monetary values are applied to figure 5.11a.

Figure 5.12 shows also the benefits for all the services for other penetration rates. Table 5.7 gives the net present values for the different penetration rates over 15 years with a discount rate of 5%.

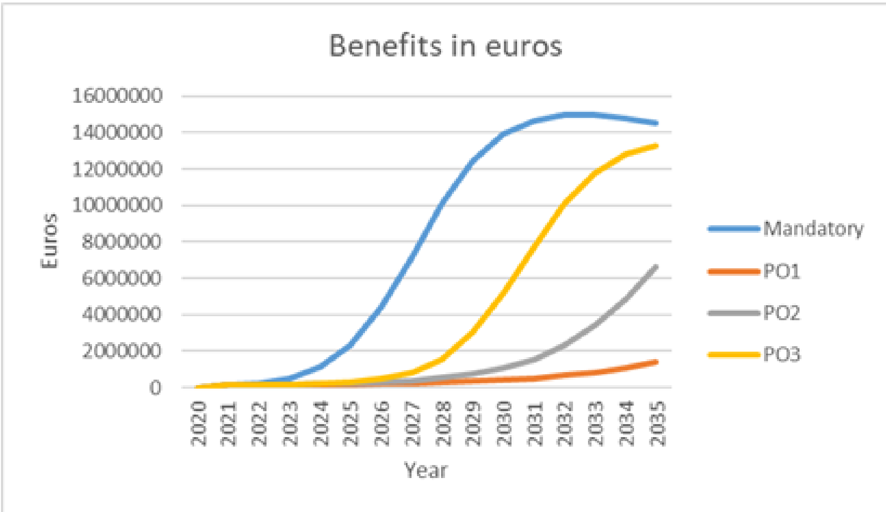


Figure 5.12: Monetary benefits

	NPV
Mandatory	€ 74.446.110
PO1	€ 4.038.551
PO2	€ 12.422.410
PO3	€ 37.224.412

Table 5.7: Net present values

Chapter 6

Environment model

6.1 Data

The environment model is just like the safety model based on Belgian statistics [28]. The Belgian vehicle fleet is used to make a top-down model. The fleet is divided into different types of fuels.

- Benzine
- Diesel
- Plug-in hybrid
- Hybrid
- LPG
- CNG
- Electric

Figure 6.1 shows the percentage of the Belgian vehicle fleet from 2000 until 2018. Benzine and diesel are, of course, the fuels that dominate.

Diesel and benzine cars are split up into the different Euro standards. Figure 6.2 represents the percentage of the different Euro standards for the Belgian vehicle fleet. The data is only available from 2012 until 2018. Those percentages can be applied to the diesel and benzine cars.

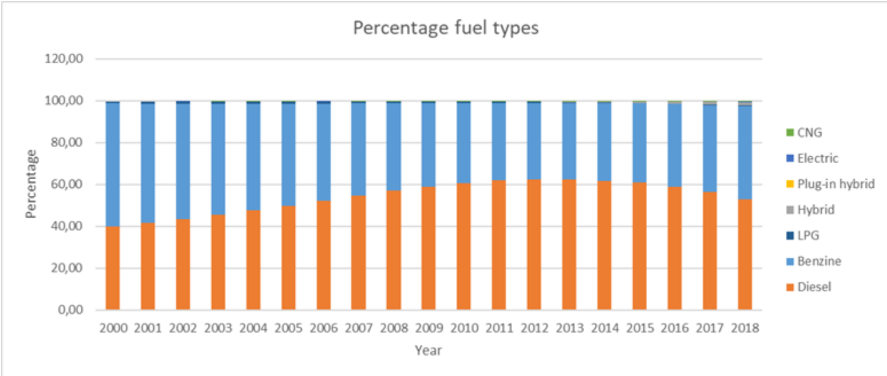


Figure 6.1: Percentage different fuel types

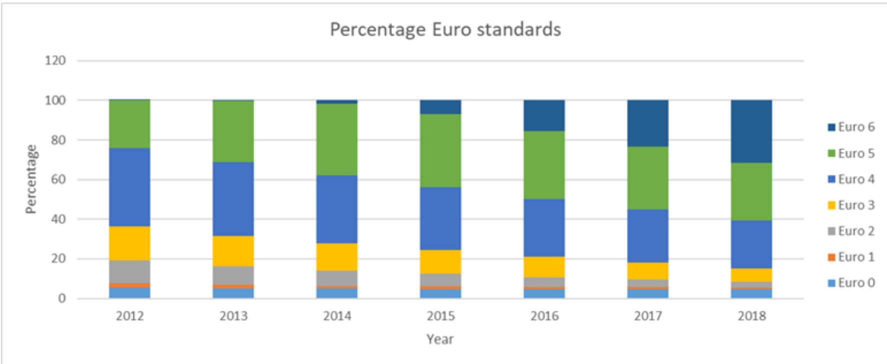


Figure 6.2: Percentage different European emission standards

European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in the European Union. For example, a diesel car sold in 2006 in the European Union can have a maximum emission of 144 gram CO_2/kilometer because it has to satisfy the Euro 4 standards. This number is for cars with a cylinder capacity between 1400 and 2000 cc. There are lower and higher bounds for cars with a respectively lower or higher cylinder capacity, but the boundary for the cars with a cylinder capacity between 1400 and 2000 cc is taken as an average. A complete overview of the different CO_2 emissions for the different types of cars is shown in table 6.1. The values in the table are based on values found in [29], [30], [31], [32] and [33].

Diesel	Euro 0	174 g/km
	Euro 1	173 g/km
	Euro 2	163 g/km
	Euro 3	151 g/km
	Euro 4	144 g/km
	Euro 5	125 g/km
	Euro 6	117 g/km
Benzine	Euro 0	213 g/km
	Euro 1	211 g/km
	Euro 2	200 g/km
	Euro 3	185 g/km
	Euro 4	172 g/km
	Euro 5	159 g/km
	Euro 6	150 g/km
Plug-in hybrid	-50% Euro 6 diesel	59 g/km
Hybrid	-25% Euro 6 diesel	88 g/km
CNG	-11% Euro 6 diesel	104 g/km
LPG	-5% Euro 6 diesel	111 g/km
Electric		0 g/km

Table 6.1: CO_2 Emissions

6.2 Input parameters

This model is built around 2 parameters. The traffic volume, in cars per day per segment, and the length of the trajectory in kilometers. A trajectory is divided into different segments. The traffic volume gives the amount of cars that drives on average on a segment. It is possible that some segments are more busy than others or that cars use more than one segment. But this can be simulated by the volume per segment per day that drives through the whole trajectory.

The model will calculate the benefits for the coming years. A year consists of busy and quiet days, for example the difference between weekdays and weekends. The model will take this division into account. The amount of busy and quiet days is also changeable. For the further calculations the volume will set on an average weekday in Belgium, for both types of days. Although it does not matter because the same volume has been chosen. In this section, one will use 260 busy days and 105 quiet days per year.

6.3 Forecasting

Table 6.1 also includes the emission of cars, diesel and benzine, with Euro standard 6. The data for the years 2012 until 2018 gives the percentages of the different Euro standards and the different fuel types. The permitted emission gram CO_2/kilometer for Euro 0 until Euro 6 is already fixed in those years, but within a few years a new Euro standard will be introduced and required. It is necessary to forecast the permitted emission of CO_2 in the coming years for new cars. Based on [34], a forecast for the CO_2 emission of new cars is made. Figure 6.3 shows the amount of gram CO_2 emitted per kilometer for a car, diesel or benzine, that is sold in the year on the x-axis.

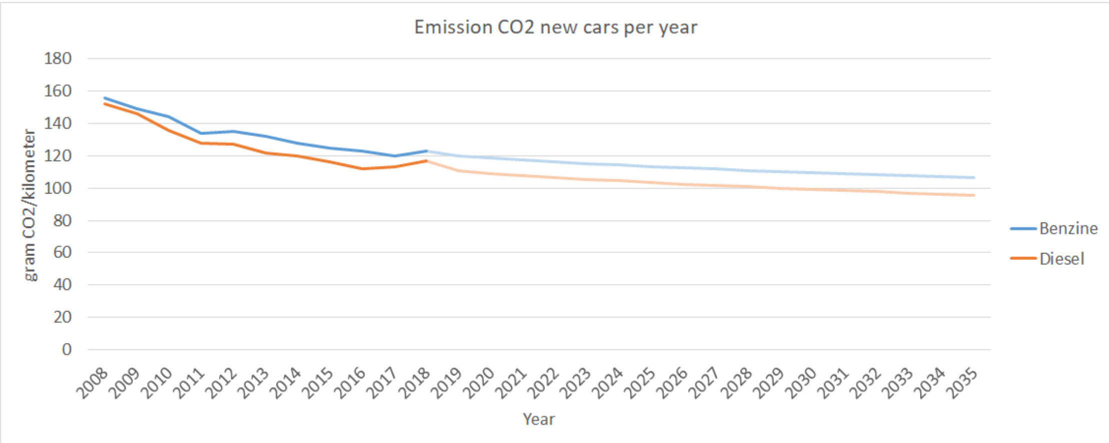


Figure 6.3: Percentage different European emission standards

The subdivision of the vehicle fleet should also be forecast. Figure 6.2 shows that the trends for the percentages for Euro 0 until Euro 5 will decrease and for Euro 6 will increase. Because the historical data goes back to the time where Euro 6 was not mandatory yet, it is possible to use the percentage of Euro 6 cars as the percentage of Euro 6 cars and later generations. This percentage will be predicted using the forecasts of the decreasing percentages of the cars with a lower Euro standard than the Euro 6. Using this mindset to forecast the percentages, the emissions predicted in 6.3 can be used and applied in the model.

The percentage of the different fuel types still have to be forecast. It is very difficult to forecast these percentages. For example, it is not known when, if at all, electric cars will boom. To make the forecast, the reference points, shown in table 6.2, are used.

The table is based on a research [35] done by 'Het Federaal Planbureau', where the percentages for the Belgian vehicle fleet are investigated and estimated.

	2030	2040
Benzine	29,0 %	28,0 %
Diesel	34,0 %	29,0 %
Hybrid	27,3 %	23,5 %
Plug-in Hybrid	3,7 %	7,0 %
Electric	5,0 %	12,0 %
CNG	0,4 %	0,5 %
LPG	0,2 %	0,01 %

Table 6.2: Percentage different fuel types forecast

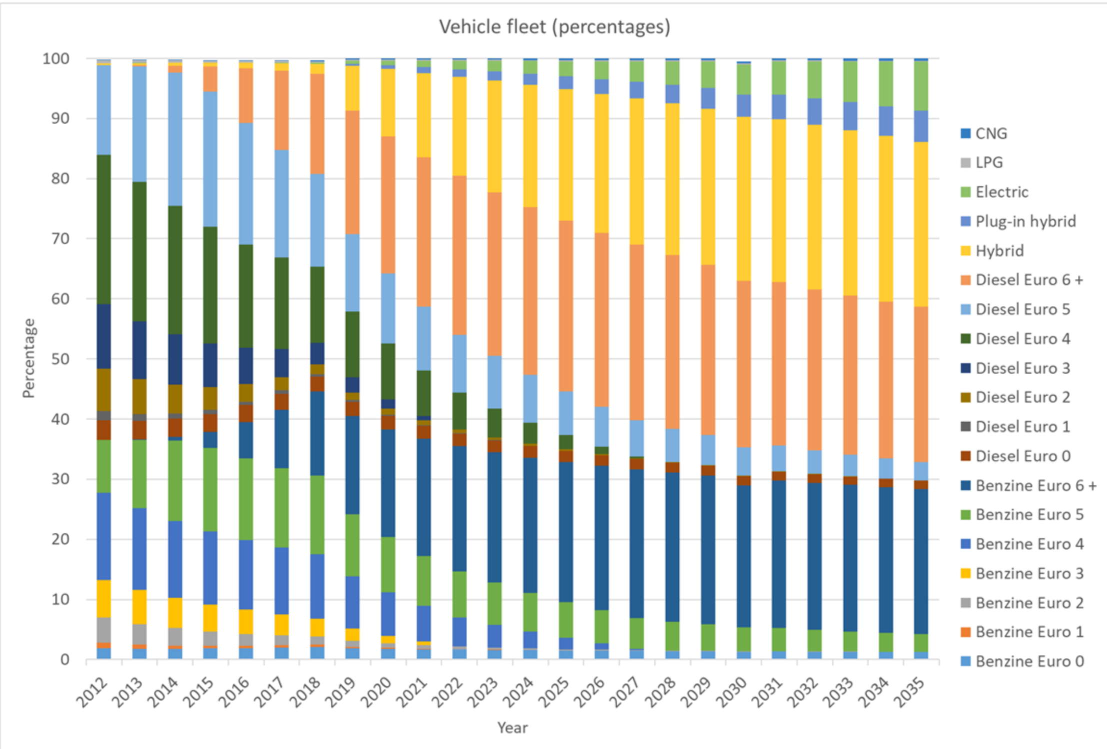


Figure 6.4: Percentages vehicle fleet

Using those reference points, table 6.2, a forecast can be made. Also the evolution of the percentages for the different Euro standards will be calculated. The percentages of the whole vehicle fleet from 2012 until 2035 are shown in figure 6.4. The historical data goes from 2012 until 2018 and the forecast of the percentages starts in 2019. Euro 6 + represents the percentage of cars that satisfy the Euro 6 standard or in the later years the predicted value from figure 6.3.

If the data, from table 6.1 and 6.3, is applied to the forecasts, presented in figure 6.4, the total emission of CO_2 can be calculated. The calculation for a trajectory of 1000 kilometers is presented in figure 6.5. In the example the average traffic volume is used and there is no distinction between busy and quiet days.

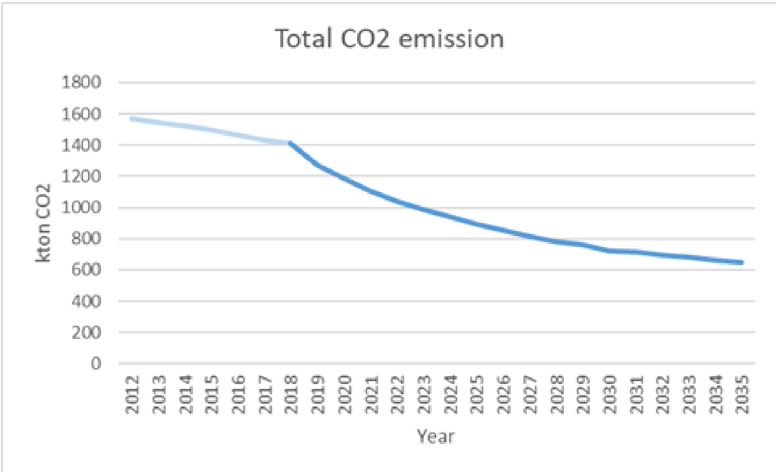


Figure 6.5: Emission CO_2 for 1000 kilometers

The light blue line represents the values calculated by the model, using the emissions from table 6.1 and 6.3, for the historical data of the vehicle fleet. The dark blue line symbolizes the predicted breakdown of the vehicle fleet. Figure 6.5 shows a decreasing line, this is necessary because the percentage of electric cars increases and the emissions of the new diesel and benzine cars must decrease. This is the reference situation that will be used in the CBA.

6.4 Reduction

The curve in 6.5 is already decreasing, but to achieve the goal of the European Union, this curve has to fall sharper. The services focus on the safety benefits but will cause a smoother traffic. This will generate a reduction of the CO_2 emission. In this section, a reduction of 3% is assumed. This parameter will be investigated in more detail in a later section.

Just like the advantages for the safety model, the benefits of the environment model will depend on network effects. The more cars that will use the services, the more benefits will become noticeable. Also here the sigmoid function, see 5.4, is implemented.

In figure 6.6, the services are implemented under the mandatory penetration rate and the same input parameters as in figure 6.5.

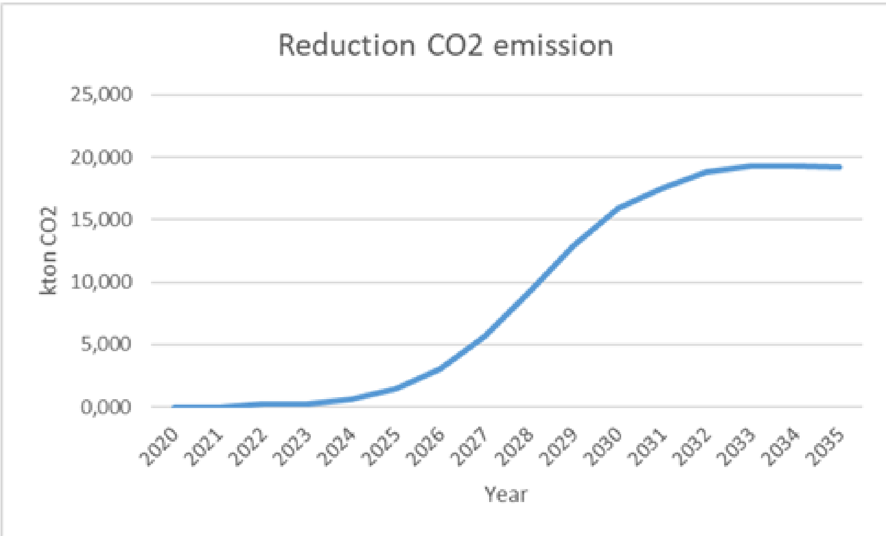


Figure 6.6: Reduction of emission CO_2 for 1000 kilometers

6.5 Monetary

Emission trading is trading in emission rights. According to [36], the current cost of a CO_2 duty (= 1 tonne of CO_2) is finally on the rise and currently fluctuates between 18,- and 22,- euro. The European Commission selects the German trading platform EEX [37] as platform to look at the current price. In this section 1 tonne of CO_2 costs 22,- euro.

The blue line is the benefit in euros for the mandatory penetration rate. To calculate the blue line, the monetary values are applied to figure 6.6.

Figure 6.7 shows also the benefits for the reduction of CO_2 emission by implementing the services under other penetration rates. Table 6.3 gives the net present values for the different penetration rates over 15 years with a discount rate of 5%.

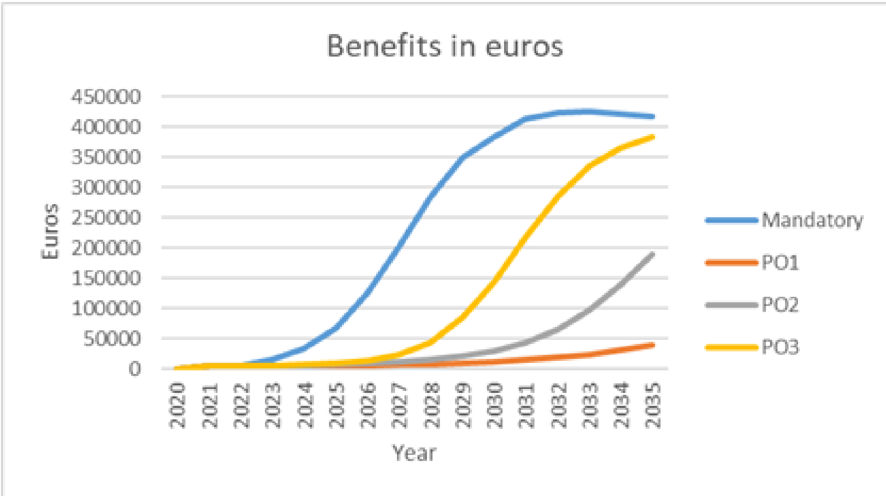


Figure 6.7: Monetary benefits

	NPV
Mandatory	€ 2.112.277
PO1	€ 115.991
PO2	€ 355.091
PO3	€ 1.058.807

Table 6.3: Net present values

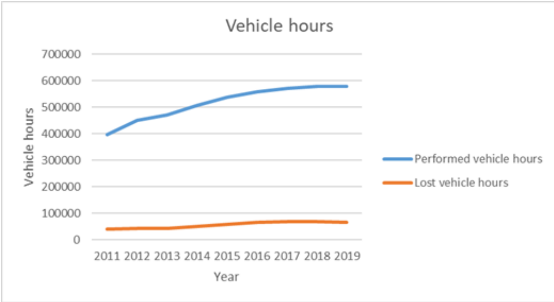
Chapter 7

Mobility model

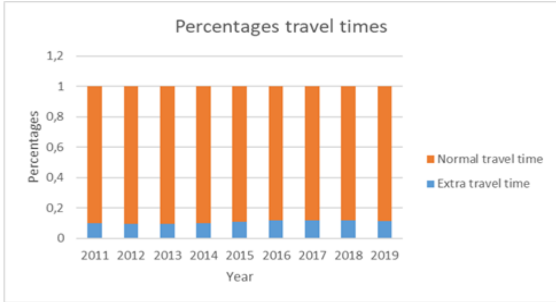
7.1 Data

The mobility model is based on Flemish statistics [25] because of a lack of data for the whole country. The model is based on the vehicle loss hours per day and the performed vehicle hours. The indicator performed vehicle hours indicator quantifies the time spent by the vehicles together on average (average day) on the road network. The indicator vehicle loss hours quantifies the time that all the vehicles together lose, on average (average day), due to delayed traffic or traffic jams. Both indicators are expressed in vehicle hours or simply hours. The performed vehicle hours and the lost vehicle hours for Flanders are presented in figure 7.1a. In the figure it is clear that the performed vehicle hours are increasing sharply, because of a growing amount of cars. This leads to more traffic jams, as well as a slight increase of the lost vehicle hours.

By dividing the vehicle loss hours by the performed vehicle hours, an average of the percentage for the extra travel time due to delayed traffic or traffic jams can be found. Using this percentage, the total travel time can be split into normal travel time and extra travel time. The percentage of the normal travel time can be inverted. This gives one the opportunity to calculate the total travel time, with the extra travel time included, and the extra travel time, if the normal travel time is known.



(a) Vehicle hours based on Flemish statistics



(b) Percentages travel times

In figure 7.1b it is clear that there will be a slight increase in the percentage of time lost in traffic jams or traffic delays. In 2011 10% of the travel times is lost in the traffic jams, in 2019 it increases with 2% to 12%.

7.2 Input parameters

The input parameters are the same as in the environment model. The model will calculate the benefits based on the traffic volume and the length of the trajectory. Using the same mindset as in the environment model, it is easy to calculate the normal travel time of 1 car, since one can just assume that the car will cover the entire trajectory. To calculate the benefits for a given traffic volume, the benefits for 1 car can just be multiplied by the given traffic volume. This because of the same reason that is already mentioned in the section of the environment model. The traffic volume is given in an amount per segment per day. One segment can be busier than the other but on average each segment of the trajectory will have the same number of cars. It can be simulated as the volume per segment per day that drive through the whole trajectory at a given speed.

If the normal travel time, without the time lost due traffic jams, is calculated, based on the volume, length and maximum speed, the extra time can be found. This extra time represents the average amount of traffic jams or delayed traffic per day.

Applying the percentages in figure 7.1b to the next input parameters, a trajectory of 1000 kilometers with an average traffic volume at maximum speed of 120 kilometers per hour, gives us a certain average of the total vehicle hours. Also the percentage of the vehicle hours that are lost due traffic jams will be calculated. Just like the other models, a distinction between busy and quiet days is made. But for the next examples, again there will be no difference between them.

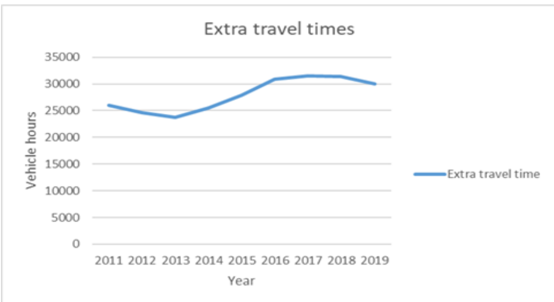
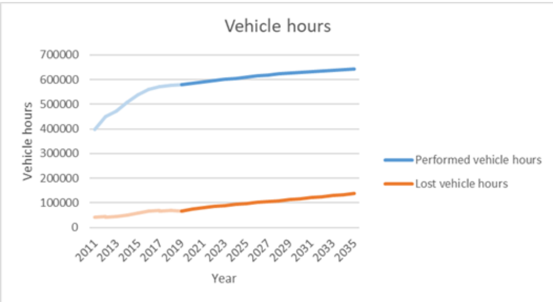


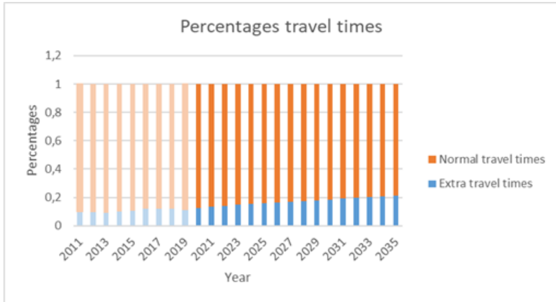
Figure 7.2: Extra travel times for 1000 kilometers

7.3 Forecasting

The results of the forecast of the data in figures 7.1a and 7.1b are shown in respectively figure 7.3a and figure 7.3b.



(a) Vehicle hours based on Flemish statistics



(b) Percentages travel times

Using this forecast, the extra travel times for each year can be found. The values from figure 7.3a can be applied to the input parameters and after the calculations are done, the results are presented in figure 7.4. This situation will be used as reference situation in a CBA.

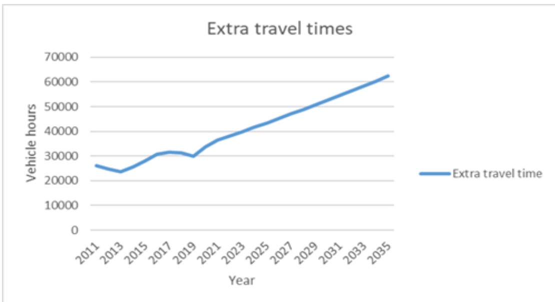


Figure 7.4: Extra travel times for 1000 kilometers

7.4 Reduction

The curve in figure 7.4 is increasing sharply. There will be more traffic jams, one reason is the growing amount of cars. A reduction is necessary. The services focus on the safety benefits but will cause a smoother traffic. This will generate a better traffic flow. In this section, a reduction of 1% is assumed. This parameter will be investigated in more detail in a later section.

Of course, again the benefits in the mobility model will depend on network effects, similarly to the other models. The more cars that own the services, the more benefits will become noticeable. Also here the sigmoid function, see 5.4, is implemented.

In figure 7.5, the services are implemented under the mandatory penetration rate. The hours are calculated for the same input parameters as in figure 7.4.

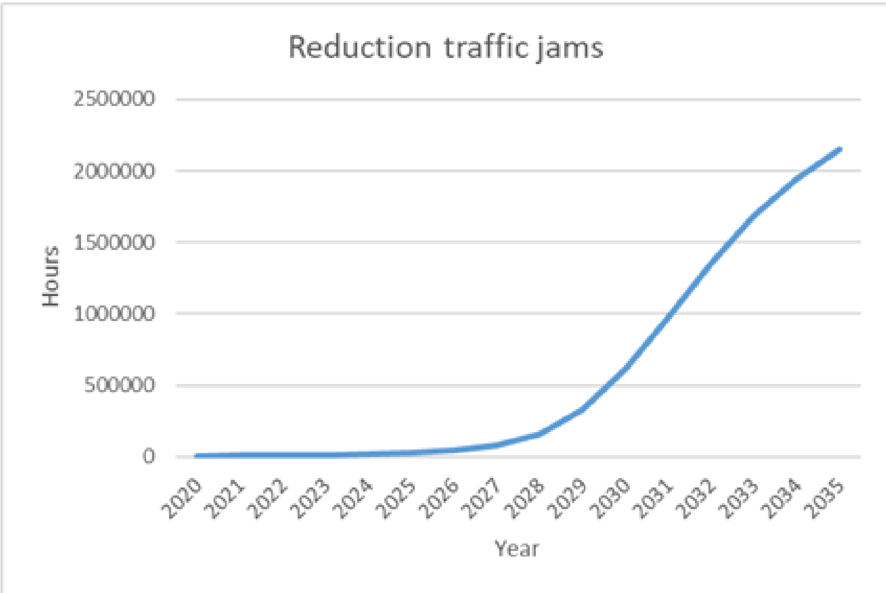


Figure 7.5: Reduction hours traffic jams for 1000 kilometers

7.5 Monetary

Being in a traffic jam costs the driver and society a lot of money. According to [38], the current cost of 1 hour is 10.58 euros for every passenger car in traffic jams or delayed traffic. That is the time you can not spend on your work or other activities.

The blue line is the benefit in euros for the mandatory penetration rate. To calculate the blue line, the monetary values are applied to figure 7.5.

Figure 7.6 shows also the monetary benefits for the reduction of the hours of traffic jams by implementing the services under other penetration rates. Table 7.1 gives the net present values for the different penetration rates over 15 years with a discount rate of 5%.

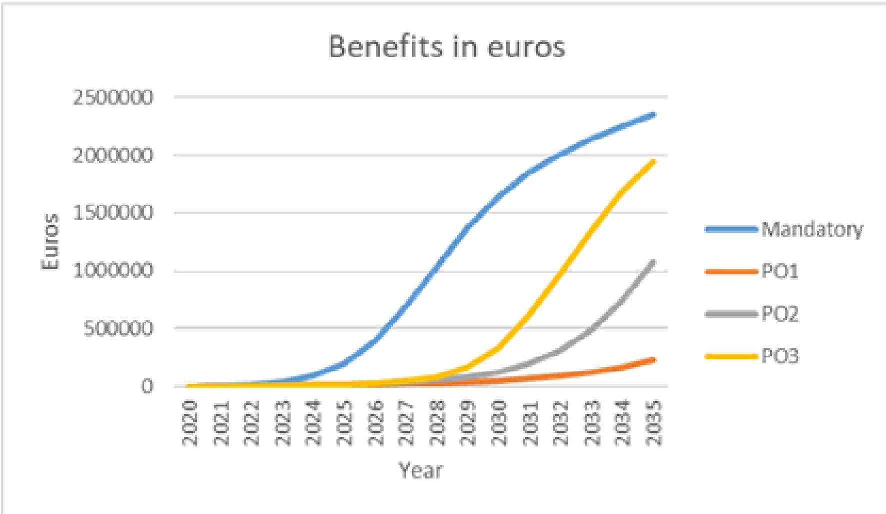


Figure 7.6: Monetary benefits

	NPV
Mandatory	€ 9.229.678
PO1	€ 497.271
PO2	€ 1.703.793
PO3	€ 5.081.093

Table 7.1: Net present values

Chapter 8

Umbrella model

The umbrella model involves the three different discussed top-down models together. The models and factors are based on [22], [39], [40] and [41]. If the services are implemented into the vehicles there will be less traffic jams, less CO_2 emissions and less fatalities and injuries.

But not all the benefits can be retrieved in this model. If the services will cause less accidents it is logic that there would be less traffic jams since some traffic jams occur because of accidents. Not only because some lanes are closed but traffic jams can also occur on the opposite lanes as so-called viewing traffic jams. The reduction of the number of avoided hours of delayed traffic caused by an accident is not taken into account in the model. It is very difficult to investigate the relation between an accident and the related traffic jam. It depends on to many factors, for example the time and place of the accident, are trucks involved, are there deaths or not,... There are to many uncertainties and unknown parameters to implement this into the model

For the environmental model, only the emission of CO_2 is taken into account. Day 1 V2V services focus on the safety benefits. The benefits of the environmental model and traffic efficiency are based on the behaviour of the drivers using those services. If a smoother traffic and a better traffic fluidity is assumed because of the services, this means that vehicles have to brake less and accelerate less or smoother. Because of the smoother traffic, CO_2 emissions will decrease a little bit. Vehicles will slow down earlier, because of the warning systems, but they will drive also longer over the same length, so the other emissions (CO, HC, NO_x, PM and PN) and fuel savings will be negligible.

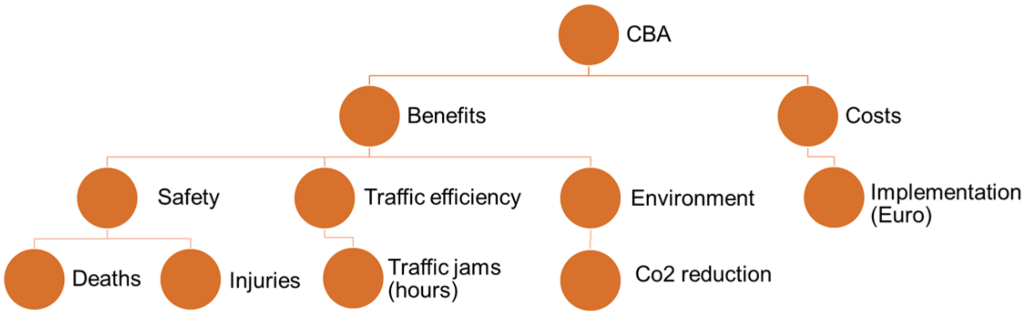


Figure 8.1: Umbrella model

Figure 8.1 presents how the different models fit into the overall model. Because the reduction of the traffic jams due the reduction of accidents is not taken into account the model as well as the benefits are mutually exclusive and collectively exhaustive (MECE). That means that a group is divided into subgroups that have no overlap and collectively represent the whole group.

8.1 Adoption rates

The adoption of the services are presented in the next table 8.1 and shown in figure 8.2.

Year	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
Mandatory	0,01	0,03	0,12	0,21	0,30	0,38	0,45	0,52	0,58	0,64	0,70	0,75	0,79	0,83	0,87
PO1	0,00	0,00	0,01	0,02	0,03	0,05	0,06	0,08	0,11	0,13	0,16	0,18	0,21	0,24	0,27
PO2	0,00	0,01	0,02	0,03	0,06	0,08	0,11	0,15	0,19	0,23	0,27	0,32	0,37	0,42	0,48
PO3	0,00	0,01	0,02	0,05	0,08	0,13	0,19	0,26	0,34	0,42	0,48	0,55	0,61	0,66	0,71

Table 8.1: Adoption rates

In the sections about the construction of the different models 4 penetration rates can be retrieved. The mandatory adoption rate is used to present some graphs to make the model build-up more clear. Besides the mandatory adoption rate 3 policies are used in the subsections about the monetary benefits. They are used to make the return more clear and to make a comparison between different policy options.

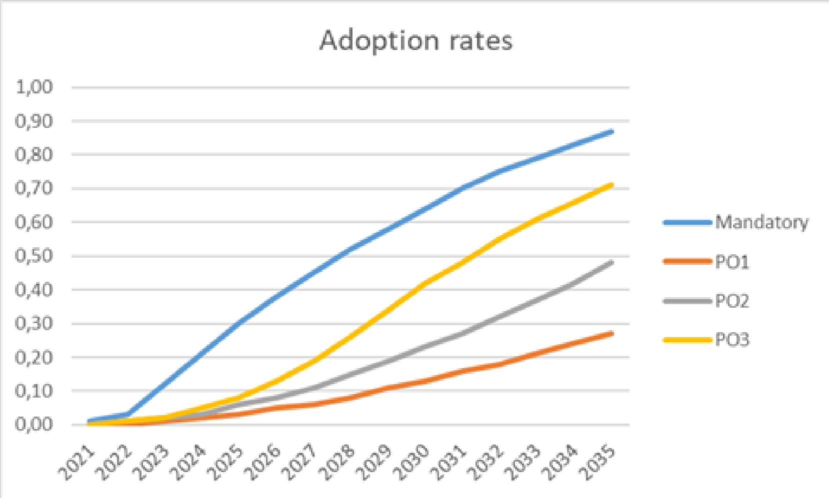


Figure 8.2: Adoption rates

The policies are based on [42]. A policy is a statement of intent, and is implemented as a procedure or protocol. Policies are generally adopted by the European Union and will have an influence on the decisions of the government of the different Member States. The adoption rate will then represent the rate of the implementation for the whole European Union. The policies can also be interpreted as the policy of the government who has to make the decision, for example the Belgian or Flemish government and then the adoption rate will present the penetration of the services in the respectively Belgian or Flemish vehicle fleet.

The first policy involves a light intervention based on non-legislative measures, including non-binding guidelines on the interoperability of day 1 services, secure communication, data protection and compliance assessment. The adoption rate will increase very slightly over the years.

The second policy involves a moderate intervention based on specifications under the ITS Directive. This would include elements similar to those in PO1, but make them legally binding through a Delegated Regulation. Nevertheless, Member States and/or industry remain free to decide whether or not to deploy C-ITS.

The third policy involves a strong intervention based on a vehicle-to-vehicle (V2V) mandate and the setting up of governance bodies. This option builds further on the legally binding specifications in a stepwise approach, by ensuring that all new vehicles are equipped with C-ITS stations, drastically increasing the uptake rate and thus meeting the threshold for effective service delivery (related to the network effect) much quicker. PO3 includes additional measures that support the deployment of C-ITS and cannot be introduced through a delegated act alone. This means that the third policy will involves a set of rules that the car manufacturers or car users have to follow. This will lead to a more steeper curve than the other policies.

The mandatory policy involves that all the new cars must have the services. All the new sold cars will have the services. The penetration rate is based on the remove rate and the new inscriptions of cars.

8.2 Input parameters

The input parameters must be the same for all 3 models, such that a nice coherence is assured. For the different models there are 2 main parameters and are already discussed for each model. The traffic volume in cars per segment per day and the length of the trajectory in kilometers. Based on those parameters, the model will calculate the benefits. The correlation between the input parameters and the model is already discussed in the section of the model concerned.

Also the benefits must be calculated over the years. If a model returns the benefits in days, 365 days a year are assumed, so the benefits can be added together.

Part IV

Results and discussions

Chapter 9

Sensitivity analysis

Sensitivity analysis is a method that can be traced back to the economic sciences to estimate the extent to which key factors react to changes in input parameters.

The overall model consists of 3 sub-models. Based on the literature study, the most important model would be the safety model. If the net present values are compared for the different models this assumption can be checked. For a trajectory of 1000 kilometer, a maximum speed of 120 kilometers per hour and an average traffic volume per segment per day the net present values can be found in table 9.1. To make it more visual and clear, the shares of the net present values are shown in figure 9.1. Both, the table and the figure, show that the safety model is the most important benefit. It is therefore advisable to first examine the safety model.

	NPV
Safety model	€ 74.446.110
Environmental model	€ 2.112.277
Mobility model	€ 9.229.678

Table 9.1: Net present values

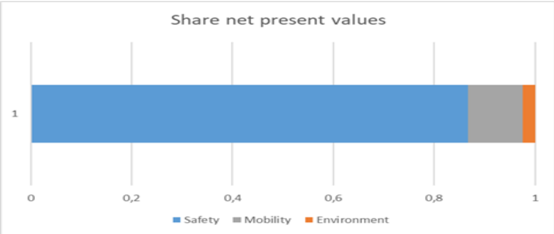


Figure 9.1: Share NPV of the models

9.1 Safety model

Service	***Collision Type***	***Avoided victims***	***Percentages***
EBL	Rear-end	82,2	0,3084
	Frontal	0,0	0,0000
	Side-by-side	2,8	0,0105
	With a pedestrian	0,0	0,0000
	Obstacle (within roadside)	0,2	0,0008
	Obstacle (outside roadside)	3,5	0,0131
	1 driver, no obstacle	1,0	0,0038
EVA	Total	6,1	0,0230
SSV	Total	23,1	0,0865
TJAW	Rear-end	61,6	0,2309
	Frontal	0,0	0,0000
	Side-by-side	2,2	0,0082
	With a pedestrian	0,0	0,0001
	Obstacle (within roadside)	0,1	0,0005
	Obstacle (outside roadside)	2,7	0,0103
	1 driver, no obstacle	0,8	0,0031
HLN	Rear-end	43,9	0,1646
	Frontal	0,5	0,0019
	Side-by-side	10,9	0,0409
	With a pedestrian	0,0	0,0002
	Obstacle (within roadside)	1,0	0,0039
	Obstacle (outside roadside)	21,0	0,0788
	1 driver, no obstacle	2,8	0,0106

Table 9.2: Shares services

Based on table 9.2 the safety benefits are mostly determined by avoiding rear-end collisions. Especially the services traffic jam ahead warning, emergency brake light and hazardous location notification have a large share in this. They represent together around 70 % of the avoided accidents. So those three will be examined.

The reduction factors for the safety model that are shown in the tables 5.1, 5.2, 5.3, 5.4 and 5.5 for the avoided accidents, are for an average impact of the services. In table 9.3 the factors that will be examined in the sensitivity analysis. The extreme points will be examined, the point where there is no reduction and the point where there is a doubling of the reduction.

Service	***Severity***	***-100%***	***Average impact***	***+100%***
EBL	Fatality	0,00 %	12,30 %	24,60 %
	Injury	0,00 %	10,00 %	20,00 %
TJAW	Fatality	0,00 %	7,30 %	14,60 %
	Injury	0,00 %	9,40 %	18,80 %
HLN	Fatality	0,00 %	7,00 %	14,00 %
	Injury	0,00 %	4,90 %	9,80 %

Table 9.3: Reduction factors depending on impact

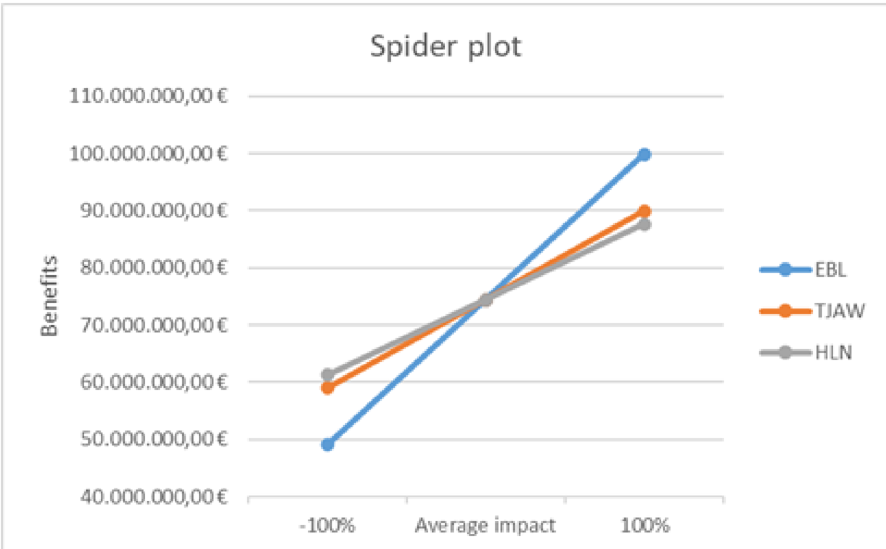


Figure 9.2: Spider plot NPV different reduction factors

Service	*Severity*	*-100%*	*Average impact*	*+100%*
EBL	Fatality	0,00%	12,30%	24,60%
	Injury	0,00%	10,00%	20,00%
	Benefits	€ 49.028.963,90	€ 74.446.110,43	€ 99.863.256,96
		-34,14%	0,00%	34,14%
TJAW	Fatality	0,00%	7,30%	14,00%
	Injury	0,00%	9,40%	18,80%
	Benefits	€ 59.022.608,57	€ 74.446.110,43	€ 89.869.612,29
		-20,72%	0,00%	20,72%
HLN	Fatality	0,00%	7,00%	14,00%
	Injury	0,00%	4,90%	9,80%
	Benefits	€ 61.232.063,51	€ 74.446.110,43	€ 87.660.157,35
		-17,75%	0,00%	17,75%

Table 9.4: Sensitivity: Net present values

Change in total benefits	*-100%*	*Average impact*	*+100%*
EBL	-29,63%	0,00%	29,63%
TJAW	-17,98%	0,00%	17,98%
HLN	-15,40%	0,00%	15,40%

Table 9.5: Change in total benefits

Table 9.4 and figure 9.2 show that the reduction factors for the rear-end collisions avoided by the service hazardous location notification and the traffic jam ahead warning are least sensitive. The reduction factor for the services emergency brake light is, unlike the factors for the other services, more sensitive. This is also because the service has a bigger share of the avoided victims.

In table 9.5 the sensitivity of the total benefits are calculated for the different safety reduction factors. The safety benefits are the biggest share of the total benefits so if a factor is sensitive for the safety model, it will also be sensitive for the umbrella model.

9.2 Mobility model

Given the limited analysis of the mobility benefits for the Day 1 V2V services, no reduction factors are estimated. Nevertheless, an increase in feeling of safety indicates positive implications for mobility. Because of the smoother traffic lanes will have a bigger maximum capacity per hour. Traffic jams and delayed traffic will occur less or later. Cars will execute less emergency brakes because of the services. Due to shock reactions those emergency brakes could also cause traffic jams. Based on a V2I service that has the same impact a reduction factor of 1% is assumed.

Despite the small share in the total benefits, a sensitivity analysis will be executed due to the high uncertainty of the reduction factor.

Traffic jams	***-100%***	***Average impact***	***+100%***
Reduction factor	0%	1%	2%
Mobility benefits	0,00	9.229.678,33	18.459.356,66
Change in mobility benefits	-100,00%	0,00%	100,00%
Change in total benefits	-10,76%	0,00%	10,76%

Table 9.6: Sensitivity: Net present values

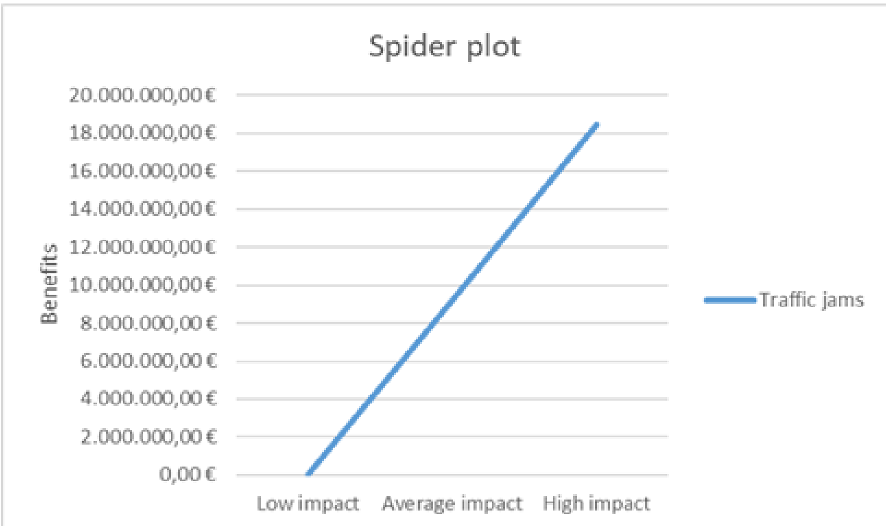


Figure 9.3: Spider plot NPV reduction factor

9.3 Environment model

As already mentioned, the services will also contribute to the environment. The services will cause a reduction in the CO_2 emissions. This because of the same reason mentioned in section 9.2, namely smoother traffic. To make an assumption about the reduction factor, also here the comparison with a V2I service is made. A reduction factor of 3% is assumed for the CO_2 emission.

Despite the small share in the total benefits, a sensitivity analysis will be executed due to the high uncertainty of the reduction factor..

CO2 emission	***-100%***	***Average impact***	***+100%***
Reduction factor	0%	3%	6%
Environment benefits	0,00	2.112.276,56	4.224.553,11
Change in environment benefits	-100,00%	0,00%	100,00%
Change in total benefits	-2,46%	0,00%	2,46%

Table 9.7: Sensitivity: Net present values

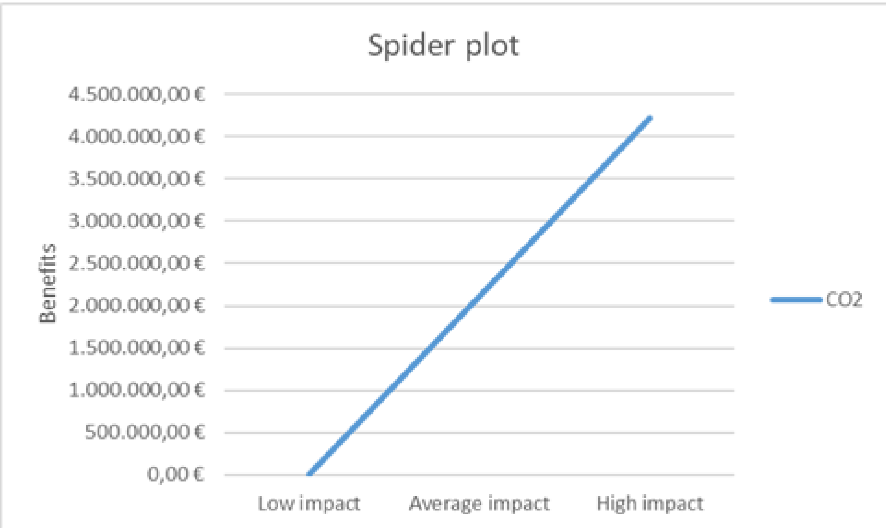


Figure 9.4: Spider plot NPV reduction factor

9.4 Total model

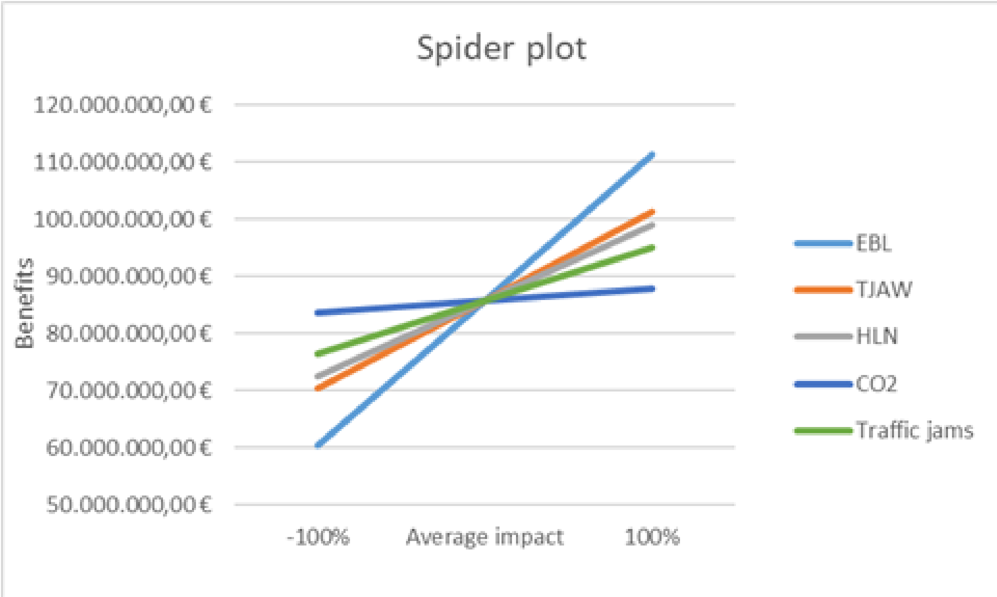


Figure 9.5: Spider plot NPV reduction factors

The change of the benefits of each model is now evaluated in the overall model. As expected, the most sensitive factors are the safety factors. But also the reduction factor for the mobility model is quite sensitive. That was already clear in table 9.6, where the difference in percentages is represented. The environmental model is not sensitive. The benefits of the model are too small in comparison with the other benefits.

In drawing up a cost-benefit analysis, especially the mobility reduction factor and the safety factors for the rear-end collisions avoided by the services EBL, TJAW and HLN are very important and significant. The environmental model is not very important for the total monetary benefits.

Chapter 10

CBA: Flanders

The created model can be used to evaluated trajectories if the length and the volume is known. In this section an evaluation of Flanders will be made.

Volume (Busy days)	27580	Cars/segment/day
Volume (Quiet days)	19000	Cars/segment/day
Length	916	Kilometers
Max. speed	120	Kilometers/hour

Table 10.1: Input parameters Flanders

The input parameters are shown in table 10.1. The traffic volume on respectively busy and quiet days are 27580 and 19000 cars per day per segment. The length of the motorways in Flanders is 916 kilometer nowadays and an average maximum speed of 120 kilometers per hour is taken. To start, all the factors are set on the factors that have an average impact. The volume parameters are chosen using Flemish statistics [25] but with a pessimistic mindset. Different policy options for Flanders will be investigated.

The different policies will be evaluated and compared with the reference situation. In this case the reference situation is the situation if no services would be implemented.

10.1 Mandatory policy

The first possibility is that Day 1 V2V services are obligated in new cars. That means that all the newly sold cars must include those services. The cost will be for the car manufacturers, but they can include the cost in the selling price. Based on the remove rate and the new inscriptions, the adoption rate of the mandatory policy can be calculated. The rate is presented in table 10.2.

Year	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***	***2031***	***2032***	***2033***	***2034***	***2035***
Mandatory	0,01	0,03	0,12	0,21	0,30	0,38	0,45	0,52	0,58	0,64	0,70	0,75	0,79	0,83	0,87

Table 10.2: Adoption rate: Mandatory

This adoption rate is the fastest way of the 4 discussed options to implement the C-ITS services. This policy involves also the highest net present value of the benefits received in 15 years. No costs must be made because the cost is redirected to the car manufacturer. The car manufacturer process this cost in the selling price of the car, causing the cost to end up with the user.

The benefits for the mandatory adoption rate is shown in table 10.3 and plotted in figure 10.1.

Safety	€ 68.192.637,15
Environment	€ 1.761.690,06
Traffic efficiency	€ 7.697.776,36
Total	€ 77.652.103,57

Table 10.3: Net present values: Mandatory

The table shows that if the services were adopted according to the adoption rate in 10.2, there would be a net present value of the total benefits for the society of €77.652.104. A discount rate of 5% is used. This amount can be used to subsidize the penetration of the C-ITS services. It can be done by subsidizing the car manufacturers or the buyers of the new C-ITS cars.

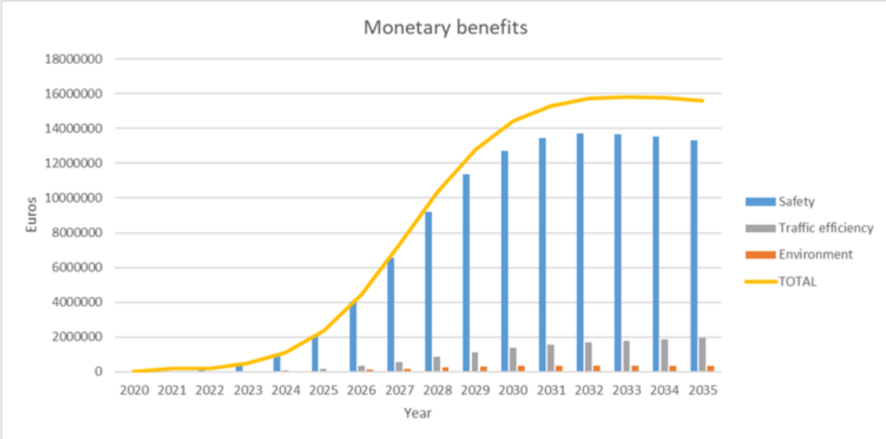


Figure 10.1: Benefits Flanders: Mandatory

10.2 Policy option 1

The first policy option is the option where the government does not interfere in the implementation. The car manufacturers choose if they implement it in their cars or not. Users can choose if they want to buy a car with or without the services. The adoption rate will be not as fast as a mandatory implementation so there will be less benefits over 15 years. The adoption rate is shown in table 10.4.

Year	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
PO1	0,00	0,00	0,01	0,02	0,03	0,05	0,06	0,08	0,11	0,13	0,16	0,18	0,21	0,24	0,27

Table 10.4: Adoption rates: PO 1

As already mentioned the benefits will be less because the end-users must choose for themselves if they want to pay more to have the services. The benefits are presented in table 10.5 and shown in figure 10.2.

Safety	3.699.312,58
Environment	96.739,51
Traffic efficiency	414.736,35
Total	4.210.788,44

Table 10.5: Net present values: PO 1

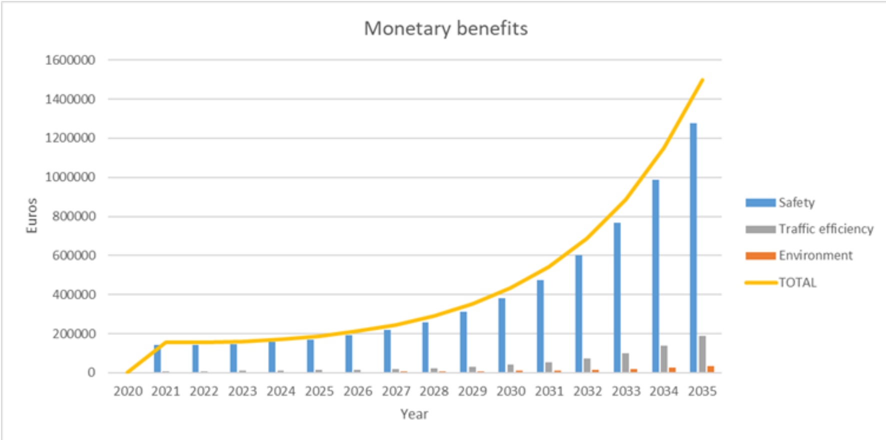


Figure 10.2: Benefits Flanders: PO 1

10.3 Policy option 2

The second policy will cause a little faster implementation of the services. The government let the users still choose to implement C-ITS or not, but the government encourages it. This ensures a faster implementation of the services. Because of the faster adoption it involves also higher benefits in 15 years than policy option 1. The adoption rate can be found in table 10.6.

Year	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
PO2	0,00	0,01	0,02	0,03	0,06	0,08	0,11	0,15	0,19	0,23	0,27	0,32	0,37	0,42	0,48

Table 10.6: Adoption rate: PO 2

The benefits can be found in table 10.7 and they are plotted in figure 10.3. It is clear that there is a higher monetary benefit in 15 years than if policy 1 is used, because of the higher adoption rate.

Safety	11.378.927,44
Environment	296.154,57
Traffic efficiency	1.421.004,91
Total	13.096.086,92

Table 10.7: Net present values: PO 2

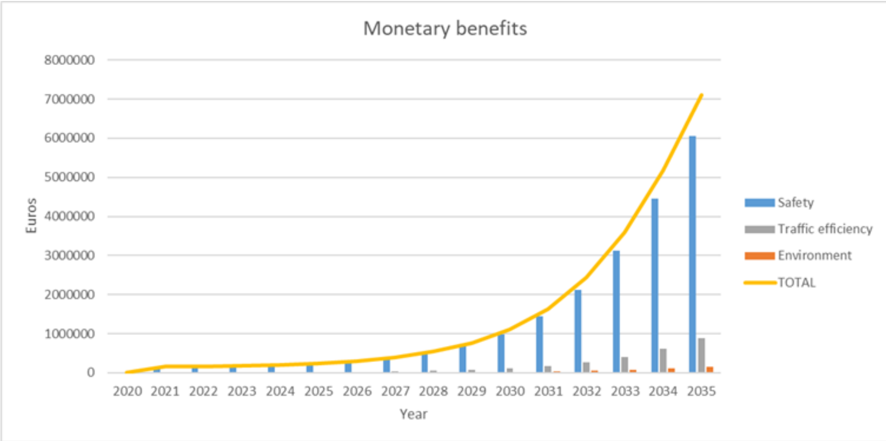


Figure 10.3: Benefits Flanders: PO 2

10.4 Policy option 3

The third policy involves the fastest implementation of the 3 policies without the mandatory implementation. It is a policy where the government will set very strict rules. This will ensure the highest benefits. Higher benefits can cause higher subsidizing. If the government operates according to policy 3, the adoption rate for the services that is estimated is shown in table 10.8. This adoption rate will ensure the benefits that are presented in table 10.9 and in figure 10.4. That is the amount that could be used to subsidize the services and implement them even faster.

Year	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
PO3	0,00	0,01	0,02	0,05	0,08	0,13	0,19	0,26	0,34	0,42	0,48	0,55	0,61	0,66	0,71

Table 10.8: Adoption rate: PO 3

Safety	34.097.561,35
Environment	883.070,66
Traffic efficiency	4.237.755,44
Total	39.218.387,45

Table 10.9: Net present values: PO 3

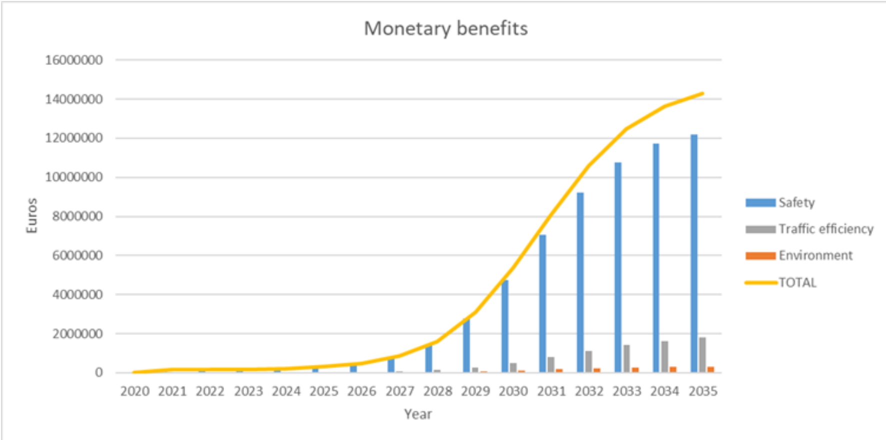


Figure 10.4: Benefits Flanders: PO 3

10.5 Traffic Volume

It is quite logic that the input parameter 'length' will have a direct linear influence on the monetary benefits. If a trajectory is twice as long as another trajectory, the benefits will be doubled. Also the input parameter 'traffic volume' will have an influence on the benefits, that is shown in table 10.10. Even though the A11 is three times as long as the R1, the monetary benefits for the R1 are a lot more due to the traffic volume. But unlike the parameter 'length', the parameter 'traffic volume' will not have a linear relation with the monetary benefits. That is because of the s-shaped relation, that is shown in figure 5.5, between the amount of accidents and the traffic volume in the safety model.

	A11	***R1***	***Unit***
Length	51	17	kilometers
Volume (Busy)	17000	80000	Cars/day/segment
Volume (Quiet)	12500	71000	Cars/day/segment
Benefits	1.696.173	4.548.969	Euros

Table 10.10: Comparison: A11 and R1

Specifically for Flanders, this means that the fact that the traffic volumes, listed in table 10.1, may vary, must be taken into account. The parameters are chosen at their worst. For example the parameter 'length' can only increase, it is very unlikely that the government decides to remove a part of the highway. But if the government decides to create an extra section of highway, this will only increase the benefits of the services. The amounts for the parameter 'traffic volume' has been chosen based on the average of the past years. Due to the increasing trend in traffic volume, these benefits are also likely to increase only in the future.

Still, this is not a certainty. Due to the COVID-19 pandemic outbreak, there was almost no traffic on the Flemish motorways in March and April 2020. As reported by [43], in those 2 months, on average, there was around 55 % less non-freight traffic during the week and around 70 % less non-freight traffic in the weekend.

If the services where already implemented during the COVID-19 outbreak, the benefits would be less because of the lower traffic volume during those two months. In table 10.12 the monetary benefits for 2020 are presented for different adoptions, if the services would be implemented and there was no COVID pandemic.

Adoption	***0,00***	***0,01***	***0,10***	***0,20***	***0,30***	***0,40***	***0,50***	***0,60***	***0,70***	***0,80***	***0,90***	***1,00***
Safety	0	163.758	394.832	1.034.210	2.583.138	5.793.286	10.709.670	15.574.818	18.669.428	20.093.328	20.619.424	20.765.900
Environment	0	4.490	10.322	25.806	61.623	132.298	234.460	327.188	380.028	398.052	390.400	391.260
Mobility	0	8.631	22.093	60.886	159.742	375.743	727.452	1.106.401	1.385.205	1.555.222	1.662.908	1.743.071

Table 10.11: Monetary benefits for different adoptions (2020 without COVID-19)

Table 10.11 shows the benefits with the COVID-19 outbreak in 2020. The traffic volumes in March and April are less than normal.

Adoption	***0,00***	***0,01***	***0,10***	***0,20***	***0,30***	***0,40***	***0,50***	***0,60***	***0,70***	***0,80***	***0,90***	***1,00***
Safety	0	141.174	340.544	892.211	2.228.948	4.999.957	9.244.904	13.447.154	16.121.882	17.354.428	17.811.693	17.940.989
Environment	0	4.054	9.320	23.300	55.639	119.451	211.692	295.415	343.124	359.398	352.489	353.266
Mobility	0	7.793	19.948	54.973	144.229	339.256	656.810	998.960	1.250.691	1.404.198	1.501.426	1.573.805

Table 10.12: Monetary benefits for different adoptions (2020 with COVID-19)

Table 10.13 shows the loss of monetary benefits due to the COVID-19 outbreak. The reduction of traffic volumes in 2 months of 2020 would be responsible for €3 million loss of benefits if the services are 100% implemented. The biggest part of the benefits are safety benefits. Less traffic volume will cause less accidents. The fewer accidents would occur, the fewer accidents that can be avoided because of the services.

Adoption	***0,00***	***0,01***	***0,10***	***0,20***	***0,30***	***0,40***	***0,50***	***0,60***	***0,70***	***0,80***	***0,90***	***1,00***
Safety	0	22.584	54.288	141.999	354.191	793.329	1.464.766	2.127.664	2.547.546	2.738.900	2.807.730	2.824.911
Environment	0	436	1.002	2.506	5.984	12.847	22.768	31.773	36.904	38.654	37.911	37.995
Mobility	0	838	2.145	5.912	15.512	36.488	70.641	107.440	134.515	151.025	161.482	169.266

Table 10.13: Difference between the benefits because of COVID-19

So it is important to take in mind that the traffic volume on the segments of the trajectory is just like the length of the trajectory a sensitive and important parameter. The difference between both is that the length of the trajectory is a fixed parameter. Traffic volume is an uncertain parameter. The increasing trend of the traffic volume is no assurance. The COVID-19 outbreak is a good example to show that also unexpected incidents can have an influence on the traffic volume.

10.6 Recommendations

Of course the mandatory policy gives the highest net present benefits in 15 years. The fast implementation of the services will ensure, due to network effects, high benefits. However, this implementation is highly encouraged, it is impossible for the car manufacturers to change their factories in one year, and make from than on only cars that are equipped with the services.

That is why policy 3 is recommended. The car manufacturers have time to implement the services in their cars. They can wait until they have a new version of a specific car to implement the communication services in that specific model.

But it is still recommended to have a fast implementation. The government can choose to use the €40 million to subsidize the end-users. They can pay grants to the consumers that choose a C-ITS car above a car that is not equipped with the V2V services. Policy 3 assumes that after eight years all the newly sold cars will own the services. After six years already more than 70% will own the services. During those six years the grants can ensure a faster implementation because the consumers will choose a C-ITS car. It is actually better to get to 70% faster than slower. Specifically for Flanders, using the €40 million, considering the discount rate, the government can lower the commissioning tax with €60 for each newly sold C-ITS car during those six years. If you know that the cost of a commissioning tax is between the €500 and €1000 and a C-ITS is safer to drive, then that is an attractive offer.

Part V

Conclusions and future work

Chapter 11

Conclusions

Nazareth 1996, 10 deaths, 56 seriously injuries and 30 slightly injuries. More than 200 cars collided in a sudden fog bank on the E17 in Nazareth, on the busy Ghent - Kortrijk traffic axis. The increasing road transport volumes cause a lot of problems, for example extra accidents.

The climate battle has not ended yet. The modern man is barely 200,000 years old and has therefore never known such CO_2 concentrations. This is, of course, cause for great concern about our climate and shows, once again, that urgent action is needed to reduce our greenhouse gas emissions. To reduce the emissions, the European Union has set some goals that Member States must achieve.

Nobody likes to spend their free time on traffic jams. However, the number traffic jams are still increasing because of the growing road volume. In Flanders alone, there is an average of 150 kilometers of traffic jams per day.

In order to reduce the traffic deaths, to achieve the goals of the European Union and to decrease the number of traffic jams a solution must be found. Cooperative Intelligent Transport Systems or C-ITS has the potential to play a significant role in achieving the goals to tackle the increasing problems of congestion, transport energy consumption, road safety and emissions. By implementing these new technologies; efficiency, safety and environmental performance of road transport is expected to increase.

In this research the benefits of the services are modeled for a given trajectory, specified by the traffic volume and length of the trajectory. Three big socio-economic benefits will be evaluated: traffic efficiency, CO_2 emission and road safety. The situation in which the Day 1 vehicle-to-vehicle (V2V) communication services are implemented is compared to a situation without the services, the reference situation. This reference situation is forecast by using Belgian and Flemish statistics. The benefits; presented in number of deaths, injuries, gram CO_2 or vehicle loss hours, are calculated for a requested trajectory. To have an idea of the combined impact and to compare the benefits with each other, they are translated into monetary values.

In the dissertation three policies and a mandatory policy are assumed. Policy 1 represents the policy of the government where they apply the lightest intervention and policy 3 where the government will intervene significantly. Of course, the mandatory policy, where all the newly sold cars must own the services, will have the fastest adoption rate. Policy 3 will have the second fastest.

It is estimated that The Day 1 V2V services can generate €34 million in safety benefits if policy 3 is imposed. It is estimated that the services will save 12 lives, prevent 62 seriously injuries and more than 800 slightly injuries. In total this is around 1000 accidents that will be avoided. For a mandatory policy the numbers are even doubled.

The services can reduce the lost vehicle hours with 2 million hours per year. If a person spends 1 hour per day in traffic jams or traffic delay and that for 260 days a year, the person will waste 160 minutes a year less in traffic jams or delayed traffic. This is a welcome perk for the person in question, but it has also a monetary benefit with a net present value of €4.3 million over 15 years if policy 3 is obliged.

The Day 1 V2V services can help achieving the goals of the European Union. The monetary benefits can not be the only reason to reduce the emission of CO_2. The environment must be saved and every little bit counts. But also here monetary benefits can be shown. The reduction of CO_2 emissions is good for a net present value of the benefits of €0.9 million. This is again if policy 3 is obliged.

In short, doubting whether or not to implement C-ITS services, is not up to scratch. Implementing the services will yield a net present benefit of €40 million for the next 15 years. The policy recommendations are somewhat harder to decide.

However, the net present benefit of a mandatory policy is almost twice as much as the net present benefit when policy 3 is used, it is not necessary to make the services mandatory. But a fast adoption rate is suggested. That is the reason why the benefits of policy 3 are used in this chapter. In this way car manufacturers have time to change their production lines or wait until a new model will be made to implement the services.

If they implement the services according to the adoption rate due to policy 3, there will be an amount of €40 million to invest in the services. This will help increase the penetration rate of the services. The investment can be done by subsidizing the car manufacturers or subsidize the users. Policy 3 assumes that more than 70% of the newly sold cars will be equipped with the V2V services after six years. It is recommended to subsidize the consumers during those first six years of the C-ITS implementation to ensure a fast adoption. This will encourage the buyers of new cars to choose a car with services instead of a car without the services.

The faster the services are implemented, the earlier CO_2 can be reduced, traffic jams can be decreased and lives can be saved. Lives that would be lost without a fast adoption. If the adoption rate is more rapidly there will be higher net present value of the benefits in 15 years. This means that it is recommended to implement the Day 1 V2V services as fast as possible.

Chapter 12

Shortcomings and future work

This research has some assumptions and restrictions. The two biggest assumptions are that the dissertation only focuses on the highways and that only passenger cars will be taken into account. This implies that only the services that will have an influence on the highways would be investigated.

Future work

It can be vary valuable to also examine the V2V services that could prevent accidents on urban roads. For example, one of the investigated services, emergency vehicle approaching, can avoid an enormous amount of accidents intersections. This services is not the only one that would prevent accidents on intersections.

The other mentioned assumption is that only passenger cars are taken into account. This limitation can has a big influence on the benefits since there is a lot of freight traffic on the Belgian roads. It will be valuable to investigate the services considering the freight transport.

Shortcomings

Victims and accidents are used interchangeably. In this dissertation it is assumed that every accident includes only one victim. In reality an accident can involve more than one car and every car can include more than one person. This shortcoming could also be further investigated.

The goal of implementing the services is to avoid a lot of accidents, the more accidents that will be prevented, the better. An accident causes often a traffic jam. The reduction in accidents will have a direct influence on the traffic efficiency on the roads, but is not implemented in the model. There are too many uncertain factors, so it would be impossible to implement this relation. So the relation between an accident and the traffic jam is also a shortcoming of this dissertation.

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