# Municipal Strategies for Increasing Traffic Safety by Improving Road Infrastructures

*An identification of traffic safety strategies used by the Dutch G4 municipalities and a comparison on social costs and benefits*


Elze Kamerling

Delft University of Technology



SWOV WETENSCHAPPELIJK ONDERZOEK VERKEERSVEILIGHEID

TU Delft

# Municipal Strategies for Increasing Traffic Safety by Improving Road Infrastructures

*An identification of traffic safety strategies used by the Dutch G4 municipalities and a comparison on social costs and benefits*

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by

E. Kamerling
Student number: 4470931

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**Graduation committee**

| | |
|---|---|
| Chairman: | Prof. dr. G.P. van Wee, Section Transport and Logistics |
| First Supervisor: | Dr. J.A. Annema, Section Transport and Logistics |
| Second Supervisor: | Dr. W.W. Veeneman, Section Organisation and Management |
| External Supervisor: | Dr. G.J. Wijlhuizen, SWOV, Section Infrastructure and Traffic |

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SWOV WETENSCHAPPELIJK ONDERZOEK VERKEERSVEILIGHEID

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# Preface

After six months of hard work, I am happy to share the final deliverable of the master Complex Systems Engineering and Management: my master thesis. This graduation journey started almost one year ago when I had the first conversations with Jan Anne and Gert Jan about what the topic of this thesis should be. Eventually, the aim of this thesis is to increase the traffic safety by identifying what road infrastructure improvement strategies are currently used by the G4 municipalities, how they relate in terms of costs and benefits, the allocation thereof, and what complicating factors play a role in the road safety decision-making process. Although the master thesis is an individual project, I could not have done it without the help of numerous people.

First of all, many thanks to Jan Anne and Gert Jan, your guidance and help throughout this process as daily supervisors was limitless and very valuable. You did not only improve the quality of this research and report, but you also provided a listening ear when I needed it. Secondly, I want to thank Bert and Wijnand for sharing their constructive feedback during our meetings, and for participating in my graduation committee. Thirdly, thank you to all seven employees of the G4 municipalities and to Eric from CROW for taking the time out of your busy schedules to do an interview with me and to being open for answering follow-up questions. I would never have been able to conduct this research without your input. Fourthly, I am thankful for the pleasant and safe work environment that all collegeaus from SWOV were able to provide during my graduation internship. Fifthly, I want to thank Anne, Just, Linda, and Rens for their advice and sometimes much needed distraction during the writing of this thesis. Lastly, a big thank you to my parents who made me the person I am today, and who never stopped supporting me in the past seven years.

All good things must come to an end, including my student days in Delft. I am grateful to have been able to study and live in this city. It gave me friends for life, a valuable education, and so much more. I look forward to what the future has in store for me.

*Elze Kamerling*
*Amsterdam, July 2022*

# Summary

Many lives are lost in traffic every day. For young adults, traffic crashes are the primary cause of death worldwide. In an effort to change this, the EU set a target to reduce road traffic deaths and injuries with 50% by 2030 and to reach zero fatalities by 2050, as stated by the European Commission. This is known as the 'Vision Zero'. Despite a good start, the decline in the number of road deaths and injuries has leveled off in recent years. In the current scientific literature, there are many papers on how to increase traffic safety. Some of them concern effect studies that aim to discover what the effects on road safety are when a specific intervention in an infrastructure is made. Others focus on conducting a social costs and benefits analysis (SCBA) for a specific infrastructural project. And there are also numerous studies that investigate what characteristics make a road safe or unsafe for its road users. What many of these studies in the research field of traffic safety have in common is that they focus on a specific project or intervention. This implies that they do not look at multiple projects simultaneously.

This study distinguishes itself by researching multiple projects together which are part of a specific road safety strategy. Strategies are a long-range plan for achieving something or reaching a goal. In this study, this plan is a combination of projects that are selected based on a vision. So, specific safety projects within a strategy together aim to achieve the higher 'vision' and, thus, a strategy gives direction to selecting specific safety projects. In other words, a strategy is more than the sum of individual projects. This is due to possible synergy effects. Synergy can be defined as: "*The combined power of a group of things when they are working together that is greater than the total power achieved by each working separately.*" With this focus on strategies instead of individual projects, this study aims to offer insights into which policy safety vision can decrease traffic deaths and injuries against what social costs.

The second scientific contribution of this research is that the SCBA method is applied on traffic safety strategies to compare them. Normally, a SCBA is used to compare various individual projects or interventions on social costs and benefits because a SCBA is very suited to do so. However, in this research the method is used to compare the effects of multiple projects simultaneously, again, so called strategies. This is more complex than conducting an SCBA for individual projects, but it offers a great contribution to both science and the society because it makes it possible to compare different strategies based on costs and benefits. Consequently, this will change the current insights that we have on traffic safety strategies, and it helps public authorities to make better argued decisions about road safety. There are various benefits when including SCBAs in the political decision-making process even when the direct outcome is not adopted: The quality of the reflection and discussion on the usefulness, necessity, and design of a project (or strategy) increases, the information is more objective and independent, and the better insights are provided on the order of magnitude of welfare effects and the ratio between costs and benefits. Therefore, SCBA is a good method to use in this study.

This study focuses on road safety strategies that intervene in the infrastructure to increase traffic safety. The geographical scope of this research concerns the G4 municipalities (Amsterdam, Rotterdam, The Hague, and Utrecht). Considering the above, the main research question of this study is:

*What are infrastructure improvement strategies used by G4 municipalities to increase traffic safety and how do the societal costs and benefits of these strategies relate?*

## Methodology and Conceptualization

In this study, literature was used to gather information about infrastructure improvement strategies that increase traffic safety. First, international scientific literature was searched to figure out what is already known about this topic in the scientific landscape of traffic safety.

This literature served as the context in which the remainder of the research was conducted. It turned out that in the scientific literature only the hot/black spot strategy was mentioned. This strategy focuses on finding unsafe areas of road infrastructures, or hot spots, and changing the infrastructure of those road segments. Thereafter, the grey literature on a national and municipal level of the Netherlands was consulted. Again, this literature served as the context in which the remainder of the research was conducted. The Dutch national government has drawn up a Strategic Road Safety Plan (SPV) that states what traffic safety targets are desirable in 2030 and 2050, and how to reach those targets. The G4 municipalities based their own traffic safety implementation programs on the SPV. In these implementation programs some additional infrastructure improvement strategies are mentioned apart from the hot/black spot strategy. First, they aim to conduct a vulnerability strategy where vulnerable road users, such as cyclists, children, and elderly, are protected and prioritized above other road users. Finally, the G4 municipalities state that they want to conduct a risk-driven strategy. This strategy entails that you need to intervene in an infrastructure before a crash has occurred, instead of improving the infrastructure after crashes have happened. So, the abovementioned strategies give a first insight on the strategies that are used by the G4 municipalities.

Interviews were conducted with 7 employees of the G4 municipalities. The goal of the interviews was to figure out what infrastructure improvement strategies they used to increase their traffic safety. In addition, the traffic safety decision-making process of each of these municipalities was discussed. Including this second part of the interviews was necessary because it gave more insights on how the strategies were executed in practice rather than how they are in theory. Consequently, these insights increased the quality of the formulated policy recommendations at the end of the research. The interviewees were chosen based on their field of expertise (road infrastructures, road safety policies, mobility, or road safety strategies) and the fact that they worked for one of the G4 municipalities. They were kept anonymous in this study at their request. The interviews led to the identification of the infrastructure improvement strategies to increase traffic safety and the associated road safety decision-making process of the G4 municipalities. So, the interviews resulted in a complete list of infrastructure improvement strategies that the G4 municipalities use to increase their traffic safety, and what these strategies mean in practice.

After the strategies had been identified, they were compared using SCBAs. A SCBA is a method to estimate the effects of a project or strategy on the welfare of citizens. These effects on society were translated into a monetary unit, namely euros. First, a base alternative was created against which all strategies were compared. This base alternative outlines the situation if nothing changed in the road safety approach. Then, it was calculated per strategy what it would mean in terms of costs and benefits if the strategy would be executed from now on until 2040. The municipality of Amsterdam is used as a use case because it was expected that the outcomes for this municipality would be largely representative for the other G4 municipalities. The SCBA concludes with a sensitivity analysis. A sensitivity analysis can be defined as: "A tool that assesses how significantly an outcome changes in relation to the inputs". Various societal effects were increased or decreased with a fixed percentage to see what effect this has on the balance of the SCBA and the benefits/costs ratio. This says something about the comparative riskiness of different variables.

Finally, some policy recommendations were given to the G4 municipalities. These recommendations were verified by an expert in the field of both traffic safety and municipal decision-making processes. This expert consultation increased the value of the policy recommendations because it confirms the usability for the municipalities.

## Interview Results

The interviews showed that all G4 municipalities use roughly the same four infrastructure improvement strategies to increase their traffic safety namely, the frequency strategy, the combining projects strategy, the vulnerability strategy, and the subjective road safety strategy.

These strategies do not (fully) align with the strategies that were found in the literature. This confirms the expectation that research into infrastructure improvement strategies is not yet saturated. The frequency strategy is based on the number of road casualties. The roads with the highest number of road casualties are improved in this strategy. The hot/black spot strategy is also a part of this strategy. The combining projects strategy consists of combining infrastructural projects such as, maintenance, traffic safety, and greenery projects. Combining these projects brings various benefits; the costs for the traffic safety department are lower, there is less nuisance for citizens, and it has a greater impact on society. The vulnerability strategy bases its decisions on vulnerable road users. Cyclists and children are the vulnerable road users where the G4 municipalities focus on most. Consequently, this strategy leads to the improvement of school zones and bicycle paths. The subjective road safety strategy is based on the perception of road safety that citizens have, instead of the objective road safety of an infrastructure. This means that the road infrastructures are improved where people feel the most unsafe. The municipalities know where people feel unsafe through complaints they receive from citizens and through close contact with neighborhood organizations.

Each of the strategies can be labeled as proactive, reactive, or anything in between. A proactive strategy means that roads are improved before road crashes occur, and a reactive strategy means that roads are improved after road crashes have occurred. Figure 0.1 shows the extent to which each strategy is proactive or reactive.

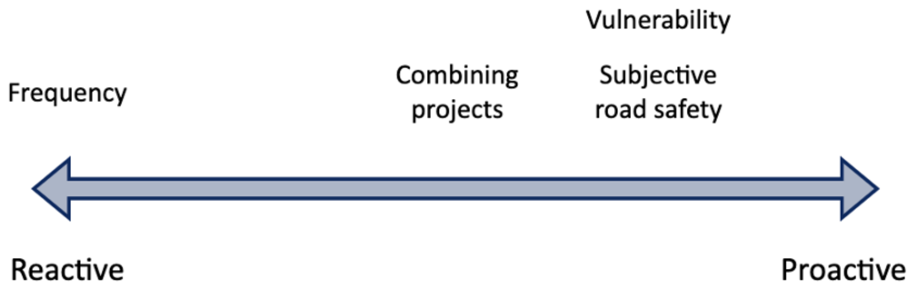


***Figure 0.1*** *The strategies of the G4 municipalities placed on the reactive-proactive spectrum*

The interviews also gave insights on the traffic safety decision-making process of the G4 municipalities. It turned out that there are many actors involved that have the power to make decisions at some point in the process. Moreover, decisions on road safety strategies are made at the start of the decision-making process. Consequently, this limits the possibilities for decision that are made later in the process, due to path dependency and the lock-in effect. In addition, there are also complicating factors that make it more difficult for the municipalities to stick to their road safety strategy. These complicating factors are limited budgets, political considerations, project execution time slots, multi-actor decision-making, and administrative capacity. All these complicating factors lead to a more reactive strategy, because the G4 municipalities are limited in their choice for a certain traffic safety approach.

## SCBA Results

The outcome of the SCBA showed that all four strategies have a positive balance, see table 0.1. This means that the execution of all these strategies leads to more social benefits than costs. However, every strategy has different implications for who will bear those costs and benefits, also see table 0.1.

In the frequency strategy the benefits are mostly allocated to car drivers and cyclists who use the roads with the highest number of traffic crashes. In municipal areas these are the roads with a speed limit of 50 km/h. In the combining projects strategy the benefits are partly allocated to the car drivers and cyclists who use the roads that are improved when executing this strategy, and partly allocated to the passers-by who enjoy, for example, the newly created greenery.

The infrastructures that are improved will mainly be roads that are dangerous in terms of road safety and roads that are scheduled for maintenance work. In the vulnerability strategy the benefits are allocated to two groups. The first group consists of all road users in school zones. These road users are mainly children, (grand)parents, and residents of the area. The second group concerns cyclists on bicycle paths. The benefits are allocated to these groups because the vulnerability strategy only improves school zones and bicycle paths. In the subjective road safety strategy the benefits are mostly allocated to the more vulnerable road users, such as cyclists and pedestrians. This strategy improves the infrastructures where people feel unsafe. Because it is expected that the more vulnerable road users feel unsafe more quickly, they also receive the largest share of benefits. In every strategy the costs for improving the infrastructure are at least partly borne by the municipality of Amsterdam, and more specifically, the department of traffic safety. In addition, the costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they, for example, experience noise disturbance, or they have to make a detour due to a broken-up road.

So, the allocation of costs is very similar for every strategy. However, who will bear the benefits varies greatly. If the goal of the G4 municipalities is to increase road safety on the locations with the lowest traffic safety, the frequency strategy would be fitting. If the goal is to execute road safety projects efficiently, the combining projects strategy would be fitting. If the goal is to protect vulnerable road users, the vulnerability strategy would be fitting. And lastly, if the goal is to make citizens feel safe and heard, the subjective road safety strategy would be fitting. In other words, depending on the goal(s) that the municipalities set themselves, increasing the use of one or more of these strategies is preferred.

***Table 0.1*** *Overview SCBAs of all strategies when conducted in the municipality of Amsterdam between 2022-2040 and the allocation of costs and benefits*

| **Strategy** | **Frequency strategy** | **Combining projects strategy** | **Vulnerability strategy** | **Subjective road safety strategy** |
|---|---|---|---|---|
| **Balance of SCBA** (€) x 1.000.000 | 294 | 163 | 380 | 115 |
| **Benefits/costs ratio** | 3.5 | 3.2 | 3.8 | 1.6 |
| **Non-monetary effect** | n/a | + | n/a | + |
| **Benefits allocation** | Car drivers and cyclists on risky roads | Car drivers and cyclists on improved roads and passers-by | Road users in school zones and cyclists on bicycle paths | Cyclists and pedestrians |
| **Costs allocation** | Municipality of Amsterdam, residents experiencing noise nuisance, and road users that have to make a detour | | | |

There is also a difference in the simplicity with which the strategies can be implemented. As discussed in section 6.3, there are various complicating factors that make the implementation of the strategies challenging. In table 0.2 it is shown per strategy to what extent every complicating factor is applicable. The combining projects strategy is the most challenging strategy to implement. Finding project execution time slots is difficult since combined projects are often large projects that cause many disruptions during the execution for road users. In addition, there are many parties involved in the decision-making process that have different interests. Consequently, reaching a consensus can take a lot of time. And lastly, extra administrative capacity is needed to steer these large projects in the right direction. The vulnerability strategy is the easiest strategy to implement. A limited budget and political considerations are the only complicating factors that play a significant role.

*__Table 0.2__ Overview complicating factors per road infrastructure improvement strategy*

| **Strategy →**<br>**Complicating factor ↓** | **Frequency strategy** | **Combining projects strategy** | **Vulnerability strategy** | **Subjective road safety strategy** |
|---|---|---|---|---|
| Limited budget | | | | |
| Political considerations | | | | |
| Project execution time slots | | | | |
| Multi-actor decision-making | | | | |
| Administrative capacity | | | | |

Not applicable ←→ Most applicable

From the sensitivity analysis it was derived that all factors that were included in the analysis were relatively insensitive to changes. The factors that were included in the analysis were the costs of traffic injuries, the expenses of traffic safety, the costs of negative effects, the costs of widening bicycle paths, and the effect of removing bicycle poles. These factors were chosen because they had the largest share of costs/benefits on the balance of the SCBA or because they had the highest uncertainty.

## Policy Recommendations

The results of the interviews and the SCBAs led to two policy recommendations addressed to the G4 municipalities. The first policy recommendation is about gaining insights on the effects of the infrastructure improvement strategies to increase traffic safety. In the interviews it turned out that the G4 municipalities are currently not aware that they use various strategies that can be identified individually. In addition, they do not have a clear overview of the effects of each strategy. In order to make argued choices about what strategies to use and to what extent, it is necessary to understand the pros and cons, as well as the costs and benefits of every strategy. Therefore, the first policy recommendation is: Keep track of the effects of each strategy, compare them, and use these insights to make argued traffic safety decisions.

The second policy recommendation is about using SCBAs in the traffic safety decision-making process. During the interviews the G4 municipalities stated that SCBAs, or other methods for expressing projects and strategies in monetary units, are rarely used. This is a missed opportunity as SCBAs can add a lot to the decision-making process. There are multiple benefits when using SCBAs in a decision-making process, even if the direct outcome of the SCBA is not adopted. First, when using a SCBA, it is possible to better reflect on the usefulness, necessity, and design of a project. Second, SCBA ensures better discussions, decision-making, and decisions about usefulness, necessity, and design of a project. Third, SCBA provides objective and independent information. And lastly, SCBA provides insight on the order of magnitude of welfare effects and the ratio between costs and benefits. Considering all these benefits, it is advised to the G4 municipalities that they make more use of SCBAs to improve their traffic safety decision-making process. A good time to include the use of SCBAs in the decision-making process could be during the traffic safety budget and program discussions of the coalition and the city council. These are the moments where the biggest decisions about the infrastructure improvement strategies to increase traffic safety are made.

## Recommendations for Future Research

The recommendations for future research are aimed to either improve the reliability of this study or to extend this study. The first recommendation for future research is investigating the uncertain factors of the SCBAs in this study. It is inherent that when a SCBA is conducted, estimations must be made which brings uncertainty. Investigating the effects of these uncertain factors, and therewith making them less uncertain, could lead to more reliable SCBAs.

In addition, it is recommended to redo the study with a larger number of interviewees per municipality. Furthermore, this study focused on the G4 municipalities and their traffic safety strategies. It would be interesting if future research focuses on medium and small sized municipalities to see if the results are similar to those of the G4 municipalities or not. That way the smaller municipalities can also gain insights on their infrastructure improvements and increase their traffic safety. Also, the G4 municipalities stated in the interviews that they want to be more proactive by increasing the use of a data-driven strategy. Unfortunately, this is not yet possible due to a lack of (reliable) data. So, a recommendation for future research is to investigate what must be changed in the data collection of the G4 municipalities to successfully conduct a data-driven strategy. Fifth, it is recommended to extend the current research by including synergy effects in the SCBA. This will increase the accuracy of the SCBA. Sixth, it is recommended to conduct research on municipal strategies on human and vehicle factors that contribute to road crashes. In the current study only the infrastructure factors were considered. Seventh, it is recommended to be investigated what current ratios of sub strategies are used in the main strategies of the G4 municipalities by tracking down the costs and benefits of each strategy. Gaining insights in the ratios in combination with the social costs and benefits of each road safety strategy can give the municipalities more insights on the current cost effectiveness of the combination of strategies they use. Finally, it is recommended to conduct studies on the effects of the individual projects that are executed within the strategies. Some of the individual projects that are included in a strategy might not contribute to the goal that is set by that strategy. To find out whether this is the case, the effects of each individual project on social costs and benefits and the distribution over actor groups must be researched.

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# List of Abbreviations

| | |
|---|---|
| **BRON** | Bestand Geregistreerde Ongevallen in Nederland (File Registered Accidents in the Netherlands) |
| **CBS** | Centraal Bureau voor de Statistiek (Central Bureau for Statistics) |
| **CROW** | Centrum voor Regelgeving en Onderzoek in de Grond-, Water-, en Wegenbouw en de Verkeerstechniek (Center for Regulations and Research in Ground, Water, and Road Construction, and Traffic Engineering) |
| **FTE** | Full-Time Equivalent |
| **G4** | The four largest municipalities in the Netherlands: Amsterdam, Rotterdam, The Hague, and Utrecht |
| **LBZ** | Landelijke Basisregistratie Ziekenhuiszorg (National Basic Register Hospital Care) |
| **MAIS** | Maximum Abbreviated Injury Scale |
| **NVP** | Net Present Value |
| **SCBA** | Social Cost and Benefit Analysis |
| **SPV** | Strategisch Plan Verkeersveiligheid (Strategic Plan Traffic Safety) |
| **SWOV** | Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Institute for Road Safety Research) |
| **VSL** | Value of Statistical Life |

# 1 Introduction

Many lives are lost in traffic every day. For young adults, traffic crashes are the primary cause of death worldwide (AD, 2018). In an effort to change this, the EU set a target to reduce road traffic deaths and injuries with 50% by 2030 and to reach zero fatalities by 2050, as stated by the European Commission (2019). This is known as the 'Vision Zero'. Despite a good start, the decline in the number of road deaths and injuries has leveled off in recent years (European Commission, 2019). To get back on track and decrease the number of road deaths and injuries, knowledge is needed in the field of road safety. Most of the research in the field of traffic safety is on individual projects or interventions and not on various projects combined, in other words, strategies. Strategies are a combination of projects with a vision behind it and the possibility of synergy effects, see section 1.3. So, projects in a strategy together achieve a higher goal and thus the strategy gives direction to the projects. Therefore, this study aims to research these strategies instead of individual projects.

Based on the EU 'Vision Zero', the Netherlands has drawn up the Strategic Road Safety Plan (SPV) (Ministerie van Infrastructuur en Waterstaat, 2018). The targets in this strategic plan are to reach zero road casualties in the long run (SWOV, n.d.-a). Similar to the EU figures, there has been no downward trend in the number of road deaths and injuries in the Netherlands over the past 10 years (SWOV, 2021a). For a more detailed description of the traffic safety situation in the Netherlands, see appendix A. So, more knowledge about traffic safety is needed in the Netherlands as well to get back on track and meet the set targets. In the Dutch grey literature and policy documents little information can be found on traffic safety strategies. Again, the focus lies on individual projects and interventions. Therefore, doing research on these strategies on a national level also adds value because it can help the Dutch road authorities making better argued decisions about traffic safety.

## 1.1 Relevance to Science

In the current scientific literature, there are many papers on how to increase traffic safety. Some of them concern effect studies that aim to discover what the effects on road safety are when a specific intervention in an infrastructure is made. Others focus on conducting a social costs and benefits analysis (SCBA) for a specific infrastructural project. And there are also numerous studies that investigate what characteristics make a road safe or unsafe for its road users. What many of these studies in the research field of traffic safety have in common is that they focus on a specific project or intervention. This implies that they do not look at multiple projects simultaneously. This study distinguishes itself by researching multiple projects together which are part of a specific road safety strategy. Strategies are a long-range plan for achieving something or reaching a goal (Cambridge Dictionary, 2022b). In this study, this plan is a combination of projects that are selected based on a vision. So, specific safety projects within a strategy together aim to achieve the higher 'vision' and, thus, a strategy gives direction to selecting specific safety projects. In other words, a strategy is more than the sum of individual projects. This is due to possible synergy effects. As defined by the Cambridge Dictionary (2022a) synergy is: "*The combined power of a group of things when they are working together that is greater than the total power achieved by each working separately.*" With this focus on strategies instead of individual projects, this study aims to offer insights into which policy safety vision can decrease traffic deaths and injuries against what social costs.

The second scientific contribution of this research is that the SCBA method is applied on traffic safety strategies to compare them. Normally, a SCBA is used to compare various individual projects or interventions on social costs and benefits because a SCBA is very suited to do so (Wijnen, Wesemann, & de Blaeij, 2009). However, in this research the method is used to compare the effects of multiple projects simultaneously, again, so called strategies.

This is more complex than conducting an SCBA for individual projects, but it offers a great contribution to both science because it makes it possible to compare different strategies based on costs and benefits and this cannot often be found in the current literature. Consequently, this will change the current insights that we have on traffic safety strategies, and it helps public authorities to make better argued decisions about road safety.

## 1.2 Research Objective and Research Questions

This study aims to increase the traffic safety by closing the above-mentioned scientific knowledge gap that is currently existing. This is done by identifying what road infrastructure improvement strategies are currently used to increase traffic safety, and how they relate in terms of costs and benefits. It is important to gain insights on the costs and benefits of these strategies because road authorities can then make more argued decisions about their traffic safety approach. Even if the direct outcomes of the SCBAs in this study are not adopted directly, it can still be a useful tool during the decision-making process. For example, it provides more objective information, and it ensures better discussions (Mouter, Annema, & van Wee, 2012). This study focuses on road safety strategies that intervene in the infrastructure to increase traffic safety. The geographical scope of this research concerns the G4 municipalities (Amsterdam, Rotterdam, The Hague, and Utrecht). Considering the above, the main research question of this study is:

*What are infrastructure improvement strategies used by G4 municipalities to increase traffic safety and how do the societal costs and benefits of these strategies relate?*

The main research question is divided into five sub research questions. The first sub question gives an overview of what is already known about infrastructure improvement strategies that are used by Dutch government authorities. The second sub question aims to identify the infrastructure improvement strategies of the G4 municipalities by conducting interviews. The third sub question examines the infrastructure improvement decision-making process of the G4 municipalities. The fourth sub question analyzes the costs and benefits of each strategy by conducting a social cost and benefits analysis (from now on SCBA). The fifth sub question formulates a policy recommendation for the G4 municipalities about what infrastructure improvement strategies would be advised.

1. *What is already known about infrastructure improvement strategies that are used by Dutch government authorities to increase traffic safety?*
2. *What G4 municipal infrastructure improvement strategies to increase traffic safety can be distinguished?*
3. *How is the decision-making process of the G4 municipalities structured when it comes to making decisions about what infrastructures to improve to increase traffic safety?*
4. *What are the costs and benefits for the society of each of the G4 municipal infrastructure improvement strategies to increase traffic safety?*
5. *What would be advised to the G4 municipalities regarding their infrastructure improvement strategies and their traffic safety decision-making processes?*

## 1.3 Scope

To discuss the scope of this study, first some definitions of traffic safety, traffic fatalities, and serious traffic injuries must be given. In this research, traffic safety refers to road traffic safety. According to Botha (2005, p. 515), road traffic safety is: "*A measure of the number of road traffic crashes and casualties resulting from crashes per time period*". The number of crashes and casualties can be expressed in rates, such as the number of crashes per 100,000 citizens or fatalities per travelled kilometers (Botha, 2005). Traffic fatalities are defined as road users who die because of a sudden occurrence on a public road related to traffic within 30 days. In addition, at least one moving vehicle must be involved.

The definition of a serious road injury is: "*A casualty with moderate to serious injuries who has been admitted to a hospital as a result of a road crash and who has not died within thirty days*." (SWOV, 2021b). For more detailed definitions, see appendix A.

In this study some choices were made regarding the scope of the research. The first scoping decision is about the extent to which the synergy effects are included in the research. As discussed in section 1.1, the effects of strategies are more than the sum of the individual projects due to possible synergy effects. In the identification of the strategies and the road safety decision-making process of the G4 municipalities these synergy effects are considered. However, when conducting the SCBA these synergy effects are not included. Including these synergy effects makes conducting the analysis more complicated and less reliable. Therefore, it is not achievable within the time constraints of this research to include the synergy effects in the SCBA.

The second decision that was made was to focus on the traffic safety strategies of municipalities as road authorities, and more specifically the G4 municipalities. The G4 exists of the municipalities of Amsterdam, Rotterdam, The Hague, and Utrecht. As mentioned earlier, most fatal traffic crashes happen on municipal roads (SWOV, 2022) and the G4 municipalities are the areas with the largest absolute number of fatal traffic crashes per 100 km of total road length (Verkeersveiligheidsvergelijker, n.d.), see figure 1.1. Consequently, there is a large potential for gaining traffic safety benefits on municipal roads of the G4 municipalities.

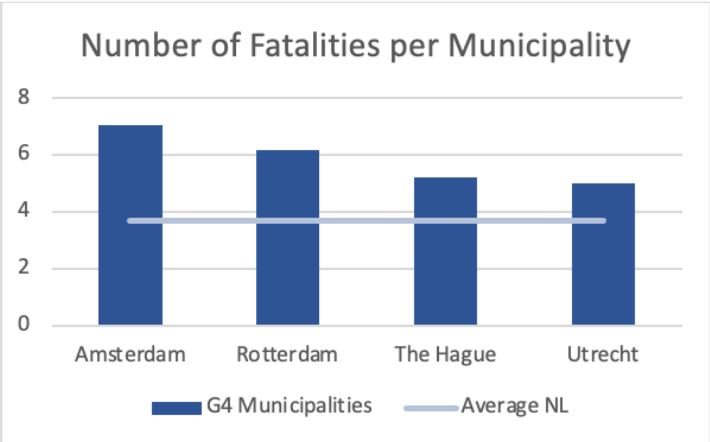



***Figure 1.1*** *Number of registered road deaths per 100 km of total road length 2011-2020 (Verkeers-veiligheidsvergelijker, n.d.).*

The third scoping choice is about traffic safety interventions. There are many factors that have an influence on traffic safety varying from human factors to vehicle safety and environmental factors. As stated by Treat (1977), the environmental, or road infrastructure, factors play a role in 44.2% of all traffic crashes. In addition, infrastructure improvements have high costs but are also highly effective when it comes to increasing road safety compared to non-infrastructure improvements (Turner, Job, & Mitra, 2021). So, because infrastructure plays a big role in traffic safety and because the impact on the municipal budget and the society is big, this study only focuses on infrastructure measures to increase traffic safety.

## 1.4 Relevance to Society and Master Program

In the Netherlands in 2020, 610 people lost their lives in a traffic crash and the long-term decline in road deaths from the mid-seventies has stagnated (CBS, 2021; SWOV, 2021). Although these numbers are not that positive, over the past years large investments already have been made by the Dutch government to improve traffic safety. In 2019 half a billion euros was made available for tackling unsafe roads and traffic situations (Vissers, 2019).

Research from SWOV (2022) shows that most fatal traffic crashes happen on municipal roads. Therefore, more investments in municipal roads are needed to improve traffic safety. However, municipalities do not always possess the required knowledge to improve the infrastructural situation (Bax et al., 2020). Moreover, municipalities struggle with determining the strategy of which roads need to be improved because the SPV does not clearly state how to make these practical decisions. This study aims to help the G4 municipalities with increasing their traffic safety by providing policy recommendations on their infrastructure improvement strategies and traffic safety decision-making process.

The master Complex Systems Engineering and Management with the Transport and Logistics track distinguishes itself by analyzing and designing complex socio-technical transport systems in a multidisciplinary way. The traffic safety aspect of the G4 municipalities is central in this study. The analysis component of this research consists of gaining insights on the infrastructure improvement strategies of the G4 municipalities to increase traffic safety and the associated social costs and benefits. The designing component of this study is reflected in the policy recommendations where the acquired knowledge is used to give advice on how to improve the infrastructure improvement strategies of the G4 municipalities.

## 1.5 Report Structure

In chapter 1, the problem that is central in this study is introduced, the scope is explained, and the main and sub research questions are formulated. In chapter 2, the methodology to answer the research questions is discussed. The available literature on road safety strategies is considered in chapter 3 and 4. In addition, chapter 3 gives a conceptualization. In chapter 5, the results of the interviews are explained. Chapter 6 elaborates on the road safety decision-making process of the G4 municipalities and the role the strategies play in this process. The results of the SCBAs are considered in chapter 7. In chapter 8, the policy recommendations are discussed. The research concludes with the conclusion of this study, a discussion about the research methods and scope, and recommendations for future research in chapter 9. This structure is also visualized in figure 1.2.

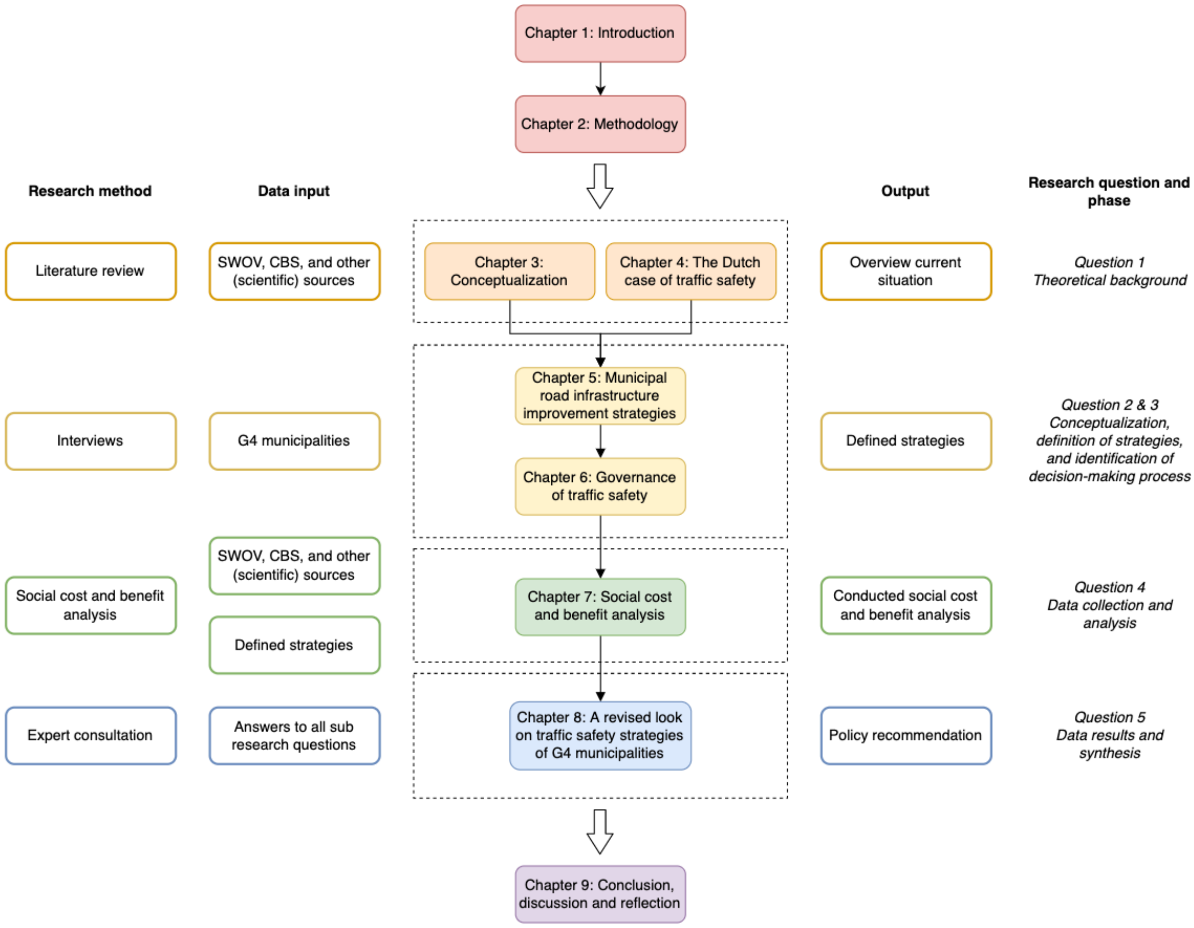



***Figure 1.2*** *Research flow diagram of this study*

# 2 Methodology

In this chapter the research methods that are used to answer the research questions are shortly discussed. Since this is only a brief overview, the methods are explained in more detail in the corresponding substantive chapter. First, a literature review is conducted to gather the state-of-the-art knowledge of Dutch infrastructure improvement strategies. Second, interviews are held with all the G4 municipalities to find out what infrastructure improvement strategies they use. Third, a social cost and benefit analysis is conducted to be able to compare all different infrastructure improvement strategies. And lastly, an expert is consulted to check if the drafted policy advice is useful and realistic for G4 municipalities.

## 2.1 Literature Review

Before this research can be conducted, the status quo of the current literature must be known. In this study, literature is used to gather information and with that outline the context of this study. In the third chapter, an overview is given of the available international literature on infrastructure improvement strategies to increase traffic safety. The goal of this first literature review is to identify a scientific knowledge gap and therefore, to prove the scientific relevance of the research. For the exact steps that were taken during the literature search, see chapter 3. In the fourth chapter, the first research question is answered using literature: *What is already known about infrastructure improvement strategies that are used by Dutch government authorities to increase traffic safety?* The information that is gathered is used as input for drafting interview questions. Most of the literature used in this chapter is grey literature, such as policy literature and government documents. This is useful because the G4 municipalities share some information about their infrastructure improvement strategies via grey literature and not via scientific literature. So, to gain full insight on how G4 municipalities operate, grey literature must also be considered. Together, chapter 3 and 4 give a good conceptualization of what is already known on the subject of municipal infrastructure improvement strategies to increase traffic safety.

## 2.2 Interviews with the G4 Municipalities

Little is known about the G4 municipal infrastructure improvement strategies in the literature. So, another method for data collection is used, namely interviews. The interview approach is used to answer the second research question: *What G4 municipal infrastructure improvement strategies to increase traffic safety can be distinguished?* In addition, some data is gathered during the interviews that will later be used as an input for the SCBA. In total, 7 interviews are conducted to gather the needed information. In the following paragraphs, the process of selecting candidates for the interviews and conducting the interviews is discussed.

### 2.2.1 Process of Candidate Selection

To find candidates who wanted to participate in the interviews, two approaches were used. First, the network of SWOV was used to find employees of the G4 municipalities that have knowledge about infrastructure improvement strategies. Second, the G4 municipalities were reached out to via email to see if someone was willing to participate. Both approaches resulted in interview candidates. The found interviewees are all employees at one of the G4 municipalities (Amsterdam, Rotterdam, The Hague, and Utrecht). They have different backgrounds and expertise, varying from road safety policies to road safety strategies, and road infrastructures, see table 2.1 and 2.2. These different perspectives on the topic, give a more complete picture of the situation. From three municipalities, two employees are interviewed, and from one municipality, one employee is interviewed. The decision to speak to two employees per municipality, where possible, was made to rule out biases as much as possible.

***Table 2.1*** *Overview of the interviewees*

| Municipality | Interviewee | Field of expertise |
|---|---|---|
| Municipality 1 | Employee 5 | Road infrastructures |
| | Employee 6 | Road safety policies |
| Municipality 2 | Employee 2 | Mobility |
| | Employee 3 | Road safety strategies |
| Municipality 3 | Employee 4 | Road safety strategies |
| Municipality 4 | Employee 1 | Road safety policies |
| | Employee 7 | Road infrastructures |

The employees can be divided in four fields of expertise:

***Table 2.2*** *Fields of expertise of the interviewees*

| | |
|---|---|
| ***Policy experts*** Employees 1 and 6 make new policies on road safety for their municipality. This gives them a lot of knowledge about what it entails to increase traffic safety in a municipality and which infrastructure improvements are mostly used. | ***Infrastructure experts*** Employees 5 and 7 are very knowledgeable on road infrastructures. One is an expert on road management and the other has a background in traffic engineering. |
| ***Mobility expert*** Employee 2 has some broader knowledge about mobility, traffic safety including. | ***Strategy experts*** Employees 3 and 4 are responsible for the content of the traffic safety strategies for their municipality. So, their expertise is devising and changing strategies concerning road safety. |

### 2.2.2 Process of Conducting the Interviews

The process of conducting interviews starts with deciding who you want to interview, see previous paragraph, and what you want to know. Depending on the kind of information you need, interview questions can be structured, semi-structured, or unstructured. Since not much has been written on the topic of this study, the interviews had a more explorative nature. Therefore, semi-structured and unstructured interviews were more appropriate than structured (Wethington & McDarby, 2015). In the end, a semi-structured interview form was chosen because you can easily compare semi-structured interviews whilst also keeping the explorative nature. A semi-structured interview has standardized question that are asked to every interviewee and individual questions to gain more information about an individual experience (Wethington & McDarby, 2015). A downside to this approach is that these open-ended questions lead to a lot of data that needs to be processed. Consequently, this interview approach is very time consuming (Wethington & McDarby, 2015). In the process before conducting the interviews, most of the interview questions were shared via email with the participants so they could prepare the interview. In addition, a document of informed consent was sent to them. "*Informed consent is an ethical and legal requirement for research involving human participants. It is the process where a participant is informed about all aspects of the trial, which are important for the participant to make a decision*" according to Musmade et al. (2013). In this study the informed consent document stated that audio records would be made during the interviews and that all participants would stay anonymous. The anonymous processing of interview data was at the request of the participants themselves. Therefore, instead of the names, the terms 'employee 1, 2, …' and municipality 1, 2, …' are used. In addition, no statements will be connected to an employee or a municipality if this can be traced back to which person or municipality it concerns. For the full informed consent document, see appendix C. Before the interviews were held, the Ethics Committee of SWOV needed to approve them.

They did this by checking what the goal of the research was and what was asked of the participants. When everything was approved, by both the Ethics Committee and the interviewees, the interviews were conducted. Because of the COVID restrictions this happened via an online Microsoft Teams meeting. After the interviews were conducted, summaries of the interviews were made and sent to every participant via email. This way, they could correct statements that they disagreed with and check if the researcher understood them well. So, this gave the interviewees the chance to check the outcomes of the interview without having the power to change the ultimate conclusions of the research. For the list of interview questions, see appendix D. Figure 2.1 gives an overview of all the steps that are taken during the process of conducting interviews.

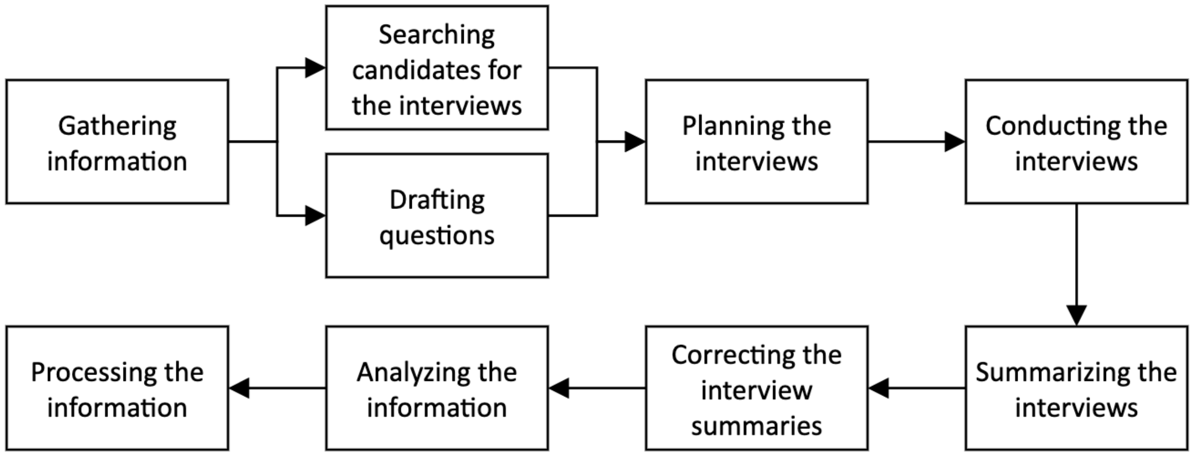



***Figure 2.1*** *Process of conducting interviews*

## 2.3 Social Cost and Benefit Analysis

To answer the fourth research question: *What are the effects on the society of each of the G4 municipal infrastructure improvement strategies to increase traffic safety?* a SCBA is conducted. A SCBA is a method to estimate the effects of a project or strategy on the welfare of citizens (MKBA informatie, n.d.-a). The outcomes of these positive and negative effects can be used to compare the different municipal infrastructure improvement strategies. A comparison of these strategies can be helpful for the G4 municipalities to offer them insights on their current approach and, if desired, it can help them with initiating a new approach. According to Mouter (2012) SCBA's can give good insights on the order of magnitude of the various effects because the welfare effects of a project (or strategy) are converted into one quantitative unit, namely money.

In this study, the SCBAs are made for the municipality of Amsterdam. This municipality is used as a use case because it is expected that the outcomes of the SCBAs are largely representative for the other G4 municipalities. In addition, the municipality of Amsterdam has a lot of data available for conducting such an analysis. The first step of conducting a SCBA is estimating the number of road deaths, road injuries, and material damage until 2040 in Amsterdam. This timeframe is chosen because it is long enough to give a good overview of what the strategies mean in terms of social costs and benefits in the long run, but it is short enough to limit the uncertainty of the road safety numbers. BRON data and data of the municipality of Amsterdam are used to analyze the initial road safety numbers. A road safety prognosis of the Netherlands from SWOV is used to estimate the future road safety numbers in Amsterdam. With these numbers, a base alternative is drafted. This base alternative captures the most likely developments without a new project or strategy. It is compared with the alternatives in which the most likely developments with a new project or strategy are captured (MKBA informatie, n.d.-b). After the base alternative is made, the strategy alternatives are drafted. Therefore, the costs and benefits of each individual strategy need to be known and monetized. This is done in three ways: First, numbers given by SWOV, the municipality of Amsterdam, and during the interviews can be copied.

Second, estimations are made using the before-mentioned sources or other internet sources. And third, if no there are no numbers available on the effects that need to be monetized, an estimated guess is made using common sense and basic calculations. All the mentioned steps in this paragraph of conducting a SCBA are based on the 8 research steps of Romijn & Renes (2013). After the SCBAs are finalized, a sensitivity analysis is conducted. A sensitivity analysis is 'a tool that assesses how significantly an outcome changes in relation to the inputs' according to USAID (2012). Various societal effects are increased or decreased with a fixed percentage to see what effect this has on the balance of the SCBA and the benefits/costs ratio. This says something about the comparative riskiness of different variables (USAID, 2012). Attached to this report is an Excel file with all the calculations of the SCBAs and the sensitivity analysis, and the sources that were used to make the calculations.

The decision-making authorities, in this case the G4 municipalities, do not always adopt the direct outcome of a SCBA. However, it can still be a useful tool during the decision-making process. A study by Mouter, Annema, & van Wee (2012) revealed four benefits of SCBA's:

1. Using a SCBA, it is possible to better reflect on the usefulness, necessity, and design of a project.
2. SCBA ensures better discussions, decision-making, and decisions about usefulness, necessity, and design of a project.
3. SCBA provides objective and independent information.
4. SCBA provides insight into the order of magnitude of welfare effects and the ratio between costs and benefits.

So, based on these benefits it is concluded that SCBA is the preferred method to use during this study.

## 2.4 Expert Consultation

After the strategies are identified and compared using interviews and SCBA, policy recommendations for the G4 municipalities can be drafted. These policy recommendations answer the fifth research question: *What would be advised to the G4 municipalities regarding their infrastructure improvement strategies and their traffic safety decision-making processes?* The policy recommendations are based on the interviews and insights on how the G4 municipalities operate when making road safety decisions. After the initial draft, an expert in the field of traffic safety is consulted to verify that the policy recommendations are useful and realistic. By that, the value of the policy recommendations is increased. It is important that this expert is familiar with the road safety decision-making process of the G4 municipalities specifically. Because the processes of these municipalities can differ from the processes of smaller municipalities. Consequently, the policy recommendations can also differ. Using the advice and suggestions of the expert, the final policy recommendations are made.

## 2.5 Conclusion

In this chapter, the methodology used to answer the sub and main research questions is discussed. The first sub research question is answered by in a literature review of both scientific and grey literature. The second sub research question is answered by conducting interviews with the G4 municipalities. The third sub research question is answered by conducting a SCBA for every infrastructure improvement strategy. Finally, the last sub question is answered with the help of an expert in the field of municipal policy recommendations.

# 3 Conceptualization

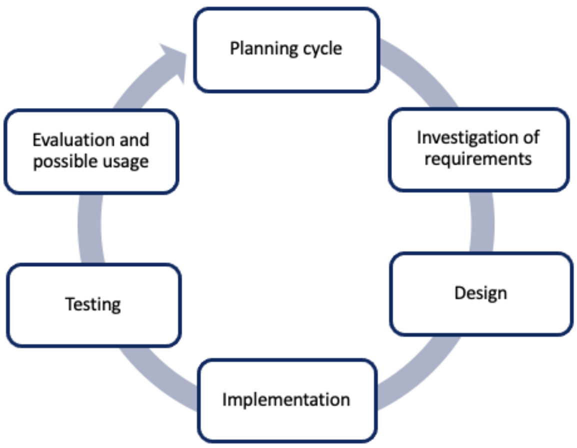
In this chapter, the international scientific literature that is currently available on infrastructure improvement strategies is discussed. The goal is to identify a scientific knowledge gap by investigating what literature is already available, and therefore, what literature is still missing. This chapter is structured as follows: the identification of the municipal project management process, the literature review process, the relevant literature, the knowledge gap identification, and the expectations of municipal strategies are discussed.

## 3.1 Life Cycle Process of Municipal Project Management

The decision-making process of municipal traffic safety projects is expected to be, like most of the project management processes, a cyclical process (Weick, 1969; Witte, 1972). The general model for a project management life cycle is shown in figure 3.1. First, a problem occurs, and a planning is made to tackle it (planning cycle). After that, it is investigated what is needed to solve the problem (investigation of requirements). Then, a design is drawn up that explains how to tackle the problem (design). Thereafter, the design is implemented (implementation). Lastly, it is tested and evaluated if the problem is solved or not (testing, and evaluation and possible usage), and the cycle starts over.

This cyclical process also applies to the process of the G4 municipalities when they decide what road infrastructures to improve and the implementation of that decision, see figure 3.2. Various steps are taken by the G4 municipalities to achieve increased road safety. But first, some form of traffic unsafety must occur, and it must be signaled by the municipalities. This lack of traffic safety is caused by risk factors. The municipality can choose to intervene with infrastructure measures. What road infrastructure measures are implemented is influenced by the traffic safety strategy that is used by the municipalities. After the implementation of the road infrastructure measure, the traffic safety on that road segment can increase, decrease, or stays the same. This depends on the effect that the measure has on that specific part of the road. Then, the cycle starts again. So, this municipal project management process is very similar to the generic project management process.

In exploratory conversations with experts from Delft University of Technology and SWOV, it appeared that there is expected to be a knowledge gap about the strategies that municipalities use to improve their road infrastructures. This expected knowledge gap is marked yellow in figure 3.2. The literature review examines whether this is indeed the case and what scientific papers are available on this topic.



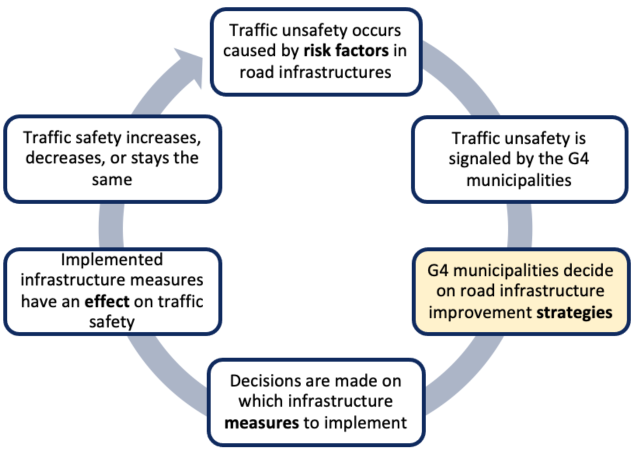




***Figure 3.1*** *Cyclical process of project management (Nagaraj, Ramachandra, & Kumar, 2010) (left)*

***Figure 3.2*** *Cyclical process of municipal project management (right)*

## 3.2 Literature Review Process

In the literature review, every subtopic of figure 3.2 is researched. But the focus is on the strategies that exist to decide what infrastructure is going to be improved. The question is asked: What literature is available on every subtopic? To find out, the search strings summed up in table 3.1 are used. The search strings have been used to find literature on the databases: Google Scholar, Scopus, ScienceDirect, SpringerLink, and Elsevier. This resulted in 150 scientific papers.

***Table 3.1*** *Search strings used in the literature review*

| **Search strings** | |
|---|---|
| Traffic safety problems | Factors of unsafe roads |
| Road infrastructure AND traffic safety AND factors | Traffic safety AND infrastructure |
| Infrastructure investment AND strategies AND traffic safety | Municipality AND infrastructure investment AND traffic safety |
| Municipality AND infrastructure investment AND strategies AND traffic safety | Sustainable safety AND infrastructure investment AND strategies |
| Government investments AND infrastructure AND traffic safety | effects of road infrastructure measures AND traffic safety |
| Infrastructural measures AND traffic safety | |

Not all found scientific papers are relevant for the literature review. Therefore, a literature selection process is carried out, see figure 3.3. First, the search strings are entered in the databases. Then, the literature is screened on the abstract. The abstract gives a good indication if the paper is relevant or not. The irrelevant literature is excluded from the review. The full text of the remaining literature is read, and it is decided if the paper is included in the literature review or not. In addition, the backward snowballing method is used on the included literature to find new scientific papers. A total of 33 scientific papers was used in the end. In the next paragraph, the knowledge gap identification is discussed.

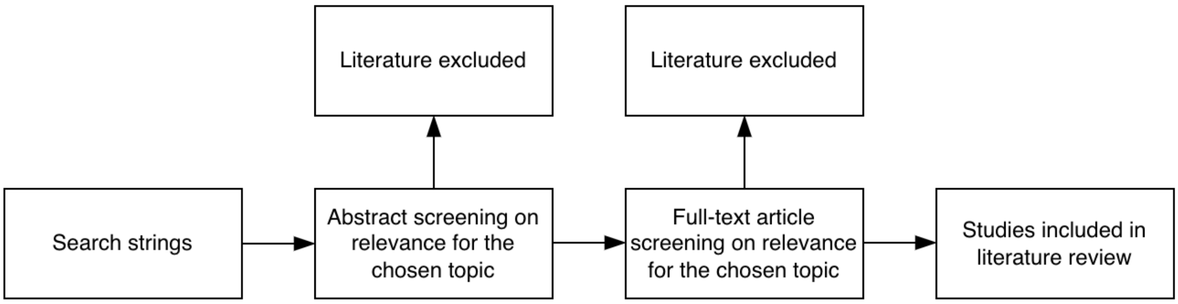



***Figure 3.3*** *Literature selection process*

Ultimately, the decision is made to only include the scientific papers that are relevant for the topic of this study in the literature review i.e., strategies for deciding what infrastructures to improve to increase traffic safety. It is explored what literature there is available on the other subtopics but no written text in the research is devoted to this. The found literature on all subtopics can be found in appendix E. This literature serves as background knowledge.

## 3.3 Literature on Road Infrastructure Improvement Strategies

In this paragraph, the papers on strategies for deciding what road infrastructure to improve are discussed. First, some generic statements on the decision-making of governments are considered. Thereafter, two strategies are explained that were found in the literature: the hot/black spot strategy (Farnsworth, 2013) and the Sustainable Safety strategy (SWOV, 2018b).

Governments, such as national governments, provinces, and municipalities, can adopt different strategies to increase the traffic safety on the roads where they are responsible for. To implement these strategies, they are translated into policies. One of the aspects that road safety policies are mostly focused on is providing new or better infrastructure (Alblate, Férnandez, & Yarygina, 2013). According to Shah & Ahmed (2019) there are four decision-making authority levels that deal with traffic safety on roads: international, national, provincial, and municipal. For a more detailed description of the decision-making authorities in the Netherlands, see appendix A. Most of the decisions that these authorities make about what road safety measures to take, are based on technical, economical, and social criteria according to Yannis et al. (2015). However, research from Wiethoff et al. (2012) shows that public authorities prefer safety measures that require minimal infrastructural investments. That makes sense since governments are often on a tight budget and infrastructural investments can be costly.

But what strategies for making decisions about what road infrastructure to improve are given in the scientific literature? One of the strategies that is mentioned, is the hot, or black, spot strategy. This strategy focuses on finding unsafe areas of road infrastructures, or hot spots, and changing the infrastructure of those road segments (Farnsworth, 2013). According to Geurts & Wets (2003), the international literature does not provide a generally accepted definition for a hot spot, but it is commonly referred to as a location with an increased risk of a road crash. The seven steps to identify hot spots as defined by Farnsworth (2013) are shown in figure 3.4. First, it is identified for what road segments there is a safety concern. This is based on the number of crashes that have occurred during a certain period. After that, it is identified within the segment what the problem spot is. Again, the number of crashes is considered, but this time also the severity of those crashes. Third, a micro analysis is conducted to track down the cause of the problem and factors that are contributing to the problem. This leads to step 4 and 5, a definition of both the problem segment and the problem itself. What is the exact location of the problem, and what is the exact definition of the problem? When this is clear, a list of possible countermeasures can be drafted. Most of the time, the goal is to find a measure that is effective, quick, executable, and inexpensive. Lastly, a feasible countermeasure is chosen. This can be one countermeasure, or a combination of different countermeasures (Farnsworth, 2013). Often, this hot spot strategy is used to identify hot spots on highways. However, it can also be used for road segments under municipal jurisdiction (Wang et al., 2018).

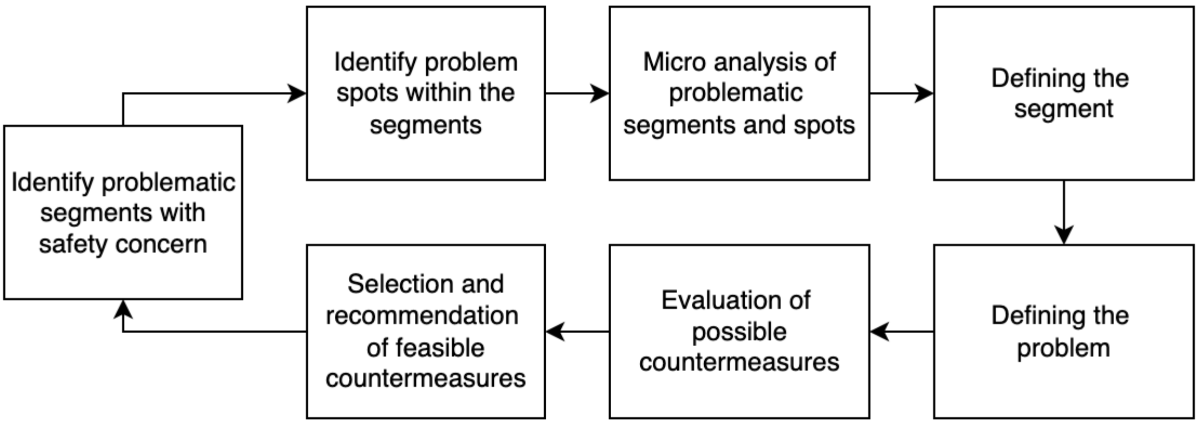



***Figure 3.4*** *The seven steps of the hot spot strategy as a continuous process*

The second strategy is not so much a strategy as it is a way of thinking to increase road safety. It is based on the approach discussed in the book *Sustainable Safety 3rd Edition* and determines road safety risks and suggests measures accordingly following the sustainable safety principles. These principles are described in the book *Sustainable Safety 3rd Edition* written by SWOV Institute for Road Safety Research (2018b). SWOV (2018b) states that: "*The Sustainable Safety vision is an optimal approach for improving road safety.*

*A sustainably safe road traffic system prevents road deaths, serious road injuries and permanent injury by systematically reducing the underlying risk of the entire traffic system*." The vision of Sustainable Safety is based on three design principles for infrastructures. These design principles are discussed below.

*Functionality of roads*
The first design principle of Sustainable Safety is the functionality of roads. In the perfect scenario every road has only one functionality, this is also known as mono-functionality. In addition, it is desirable that the road network is structured hierarchically. This can be done by dividing roads in three categories: Through roads, distributor roads, and access roads. Figure 3.5 shows what these road categories look like (SWOV, 2018b).

*(Bio)mechanics*
The (bio)mechanics design principle focuses on the different characteristics of road users. Some road users are more vulnerable, some have a higher speed, or a larger mass. When mixing these various groups of road users, dangerous situations can occur. Therefore, the (bio)mechanics principle says that it would be best if all transport modes with different speed, direction, mass, and size are separated. In addition, vulnerable road users, such as pedestrians and cyclists, should be protected. This also entails that the road environment should be forgiving, in other words, that the road is built in such a way that fatalities and serious injuries are prevented as much as possible in case of a crash (SWOV, 2018b). See appendix F.1 for the corresponding road design requirements.

*Psychologics*
The third and last design principle of Sustainable Safety is psychologics. The focus of this principle is that the road design matches the road user competences. As stated by SWOV (2018b, p. 21): "*This means that … the information from the traffic system is perceivable, understandable (self-explaining), credible, relevant, and feasible*." It is important that road users, both motorized and non-motorized, can carry out their task when participating in traffic. This includes adjusting their behaviour in constantly changing situations (SWOV, 2018b).

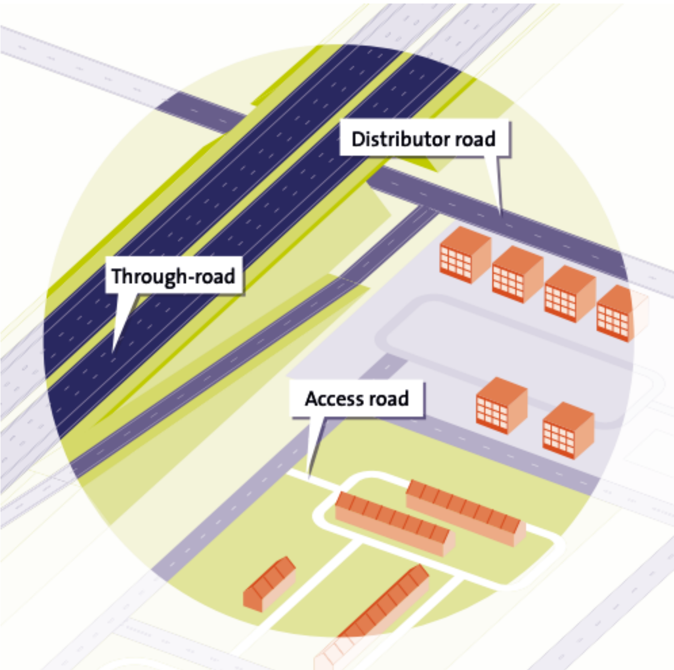



***Figure 3.5*** *Hierarchical classification of roads (SWOV, 2018b, p. 15)*

## 3.4 Knowledge Gap Identification

In the current scientific literature, there are many papers on how to increase traffic safety. Some of them concern effect studies that aim to discover what the effects on road safety are when a specific intervention in an infrastructure is made. Others focus on conducting a social costs and benefits analysis (SCBA) for a specific infrastructural project. And there are also numerous studies that investigate what characteristics make a road safe or unsafe for its road users. What many of these studies in the research field of traffic safety have in common is that they focus on a specific project or intervention. This implies that they do not look at multiple projects simultaneously. This study distinguishes itself by researching multiple projects together which are part of a specific road safety strategy. Strategies are a long-range plan for achieving something or reaching a goal (Cambridge Dictionary, 2022b). In this study, this plan is a combination of projects that are selected based on a vision. So, specific safety projects within a strategy together aim to achieve the higher 'vision' and, thus, a strategy gives direction to selecting specific safety projects. In other words, a strategy is more than the sum of individual projects. This is due to possible synergy effects. As defined by the Cambridge Dictionary (2022a) synergy is: *"The combined power of a group of things when they are working together that is greater than the total power achieved by each working separately."* To visualize this, two conceptual models are made, one for the strategy approach and one for the individual projects approach, see figures 3.6 and 3.7. In figure 3.6, the road infrastructure measures are executed simultaneously. This could lead to synergy effects because the effects of the measures can interact.

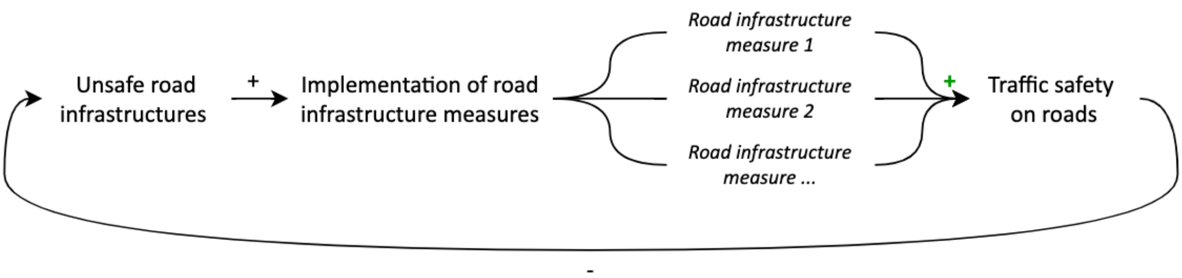



***Figure 3.6** Strategy approach with possible synergy effects*

In figure 3.7, the road infrastructure measures are executed separately. Consequently, this approach does not allow for any synergy effects to occur. With this focus on strategies instead of individual projects, this study aims to offer insights into which policy safety vision can decrease traffic deaths and injuries against what social costs.

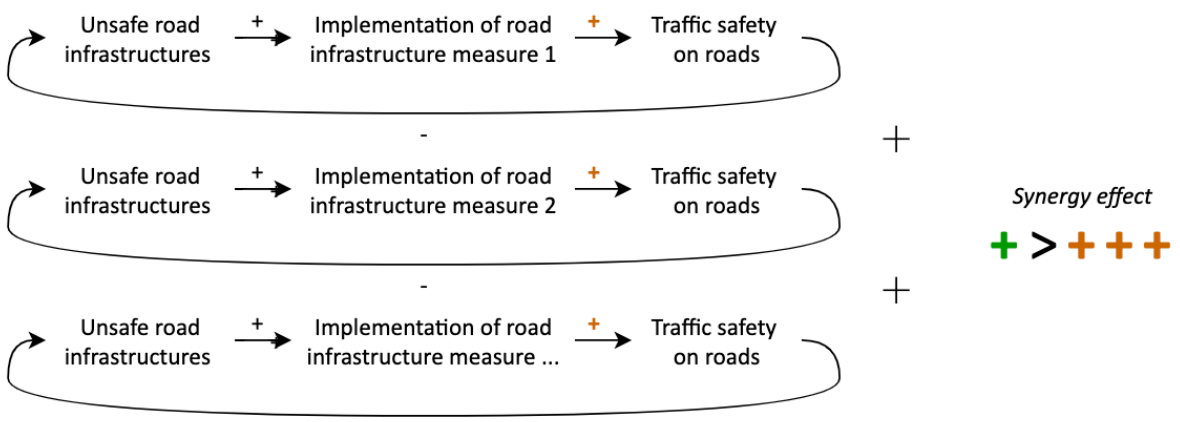



***Figure 3.7** Individual projects approach without synergy effects*

For a detailed example of synergy effects in a strategy, see section 3.6.

In the current literature two strategies are mentioned: the hot/black spot strategy and the Sustainable Safety strategy. However, it is expected that there are more road safety strategies that are currently used by road authorities. So, there is most likely a gap in the scientific literature when it comes to the identification of these road safety strategies. This goes for road safety strategies in general, but also for municipalities and their road safety strategies.

The second knowledge gap is about the use of the SCBA method for researching how traffic safety strategies compare to each other. Normally, a SCBA is used to compare various individual projects or interventions on social costs and benefits because a SCBA is very suited to do so (Wijnen, Wesemann, & de Blaeij, 2009). But research on the use of SCBA when comparing road safety strategies is largely missing in the literature. So, this can be considered the second knowledge gap. In this research a SCBA is used to compare the effects of multiple projects simultaneously, again, so called strategies. This is more complex than conducting an SCBA for individual projects, but it offers a great contribution to both science and the society because it makes it possible to compare different strategies based on costs and benefits. Consequently, this will change the current insights that we have on traffic safety strategies, and it helps public authorities to make better argued decisions about road safety.

Combining these knowledge gaps and the scope, results in the main research question that is stated in chapter 1, and the following research goal: To find what possible road infrastructure improvement strategies there are for the Dutch G4 municipalities to increase their traffic safety, and how they relate in terms of costs and benefits.

## 3.5 Municipal Strategy Expectations

This paragraph gives an overview of the infrastructure improvement strategies found so far in the literature and the expectations for the not yet identified strategies. This overview is visualized in figure 3.8.

As discussed before, in the literature only two strategies can be found: the hot/black spot strategy and the Sustainable Safety strategy. The first one, is a strategy that suggests that the road infrastructure with the largest number of road casualties should be improved. The second one, is not really a strategy. It is a way of thinking and a context in which all road infrastructure measures are conducted. It is expected that the infrastructure measures implemented by the G4 municipalities will adhere to the Sustainable Safety principles as much as possible, but that does not make it a strategy. It does not suggest how to make decisions on what infrastructures to improve. It mainly says something about how infrastructures can and should be improved. Therefore, the Sustainable Safety principles are shown as the border of figure 3.8.

The remaining part of figure 3.8 shows how the strategies, infrastructure measures, and costs and benefits are related. A municipal road safety strategy is based on one or more considerations. These strategies lead to the implementation of one or more road infrastructure measures. And lastly, these measures have an impact on society in the form of costs and benefits. Each measure has an effect on traffic safety and possibly also on other areas. In addition, the implementation of the measure and the changes to the environment, can lead to costs. These costs and benefits vary per road infrastructure measure, and therefore, per strategy. In figure 3.8, the green and red arrows are not representative of the size of the social costs and benefits. They only illustrate that the costs and benefits can differ.

The ‘other strategies’ box is researched in the first part of this study. What are other strategies that the G4 municipalities use? According to Yannis et al. (2015), government authorities often make their decisions based on technical, economical, and social criteria. So, it is expected that these considerations play a role in the strategies that are not yet defined in the scientific literature.

For each of the three criteria mentioned by Yannis et al. (2015), it is discussed why it makes sense to include them in the strategies. First, it is expected that economic considerations play a role. Every municipality wants to increase their traffic safety, but their budget is limited. Second, technological considerations could be included. Instead of looking at the number of road casualties, municipalities could look at the road infrastructures as a technical system with characteristics. Some of these characteristics lead to an increase or decrease of traffic safety. Focusing on these technological criteria could be a municipal strategy. Third, municipalities could consider social criteria. Some road users are more vulnerable than others and the strategies might put more emphasis on protecting these more vulnerable groups. Also, it could be that municipalities alter their strategies to the wishes of their citizens. After all, the job of a municipality is to represent their citizens, and therefore, keep them content with the (traffic safety) decisions that are made. In the second part of the study, it is researched which strategies lead to the implementation of what road infrastructure measures and what social costs and benefits are associated with this. In this way, the different strategies can easily be compared.

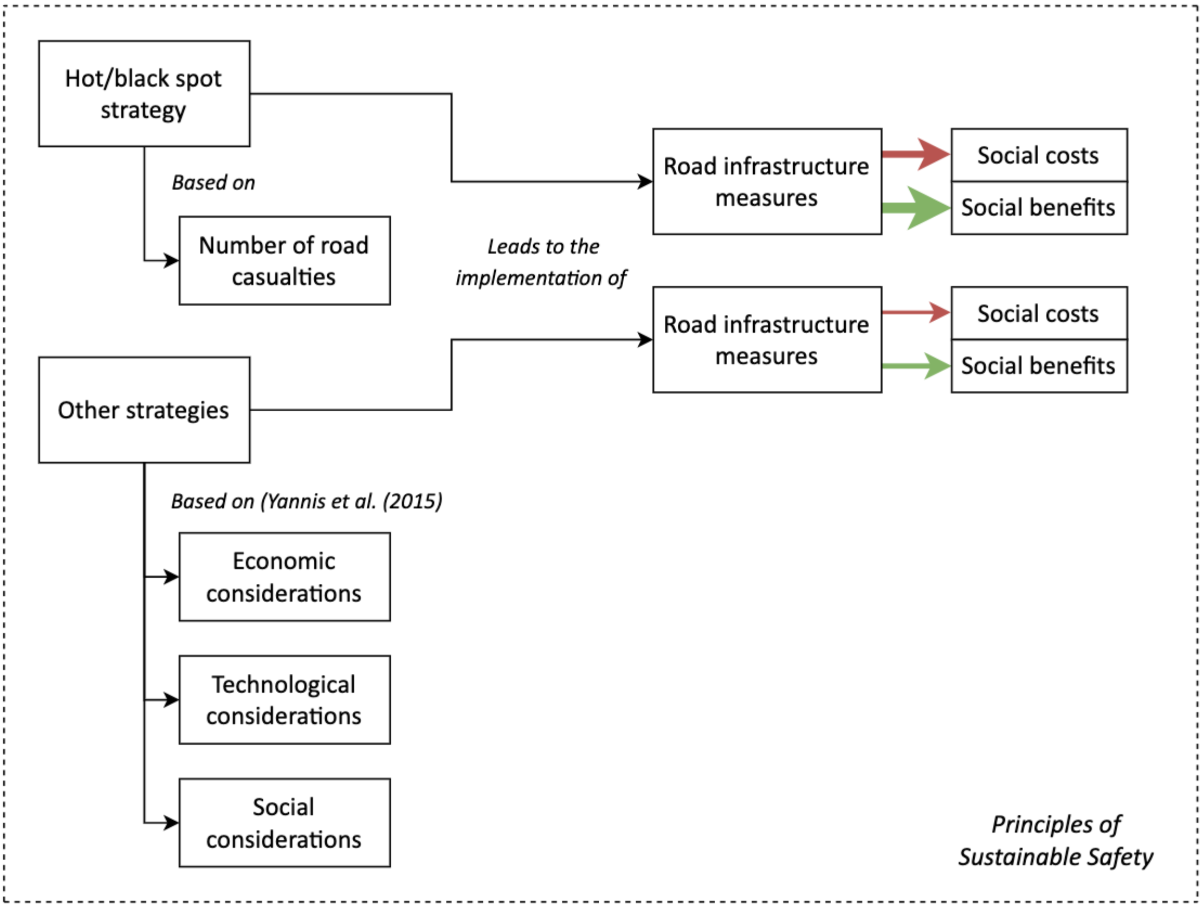



***Figure 3.8*** *Road safety strategies based on scientific literature*

## 3.6 Example of Synergy Effects in a Road Safety Strategy

To illustrate how synergy effects work in road safety strategies and why synergy effects are absent in individual projects, figures 3.9 and 3.10 are included.

Figure 3.9 shows what possible road infrastructure measures could be taken when the hot/black spot strategy is executed. These are measures like construction of new road markings, lowering the speed limit, and improving the road surface. Each of these infrastructure measures has an impact on the costs and benefits. The impact can be strengthened when synergy effects occur. For example, the decrease in the number of road casualties when the speed limit is lowered, and new road markings are constructed can be greater than the sum of the decrease of both measures. This effect is called synergy effects, see figure 3.9. Synergy effects can also be negative. In that case, the value of the combined effects is less than the value of each effect individually.

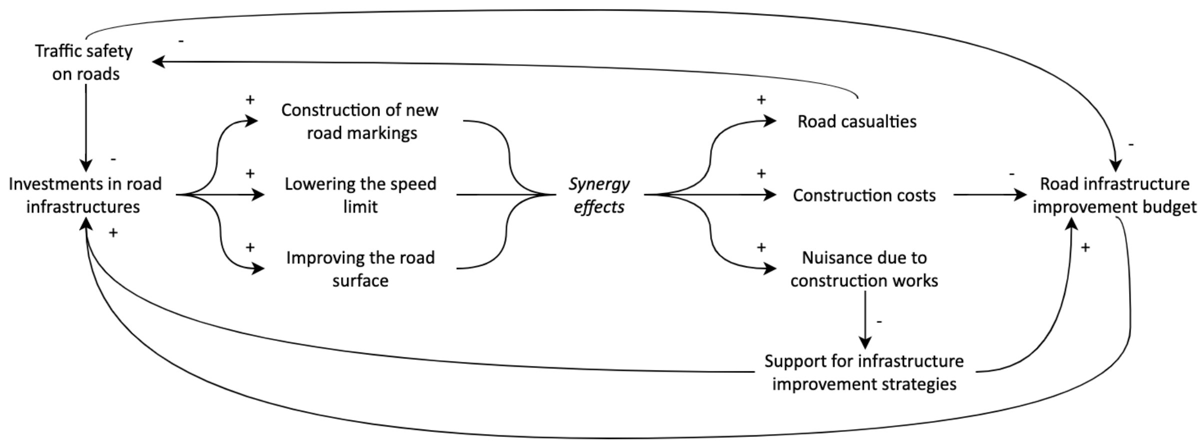



***Figure 3.9*** *Example of synergy effects in the hot/black spot strategy*

Figure 3.10 shows an individual infrastructure improvement project that could be executed, a construction of new road markings. This infrastructure measure has an impact on the costs and benefits, but there are no synergy effects that take place. This is due to the lack of other (infrastructure) measures that reinforce each other. Consequently, the effect of individual projects is often lower than the effect of combined projects in a strategy.

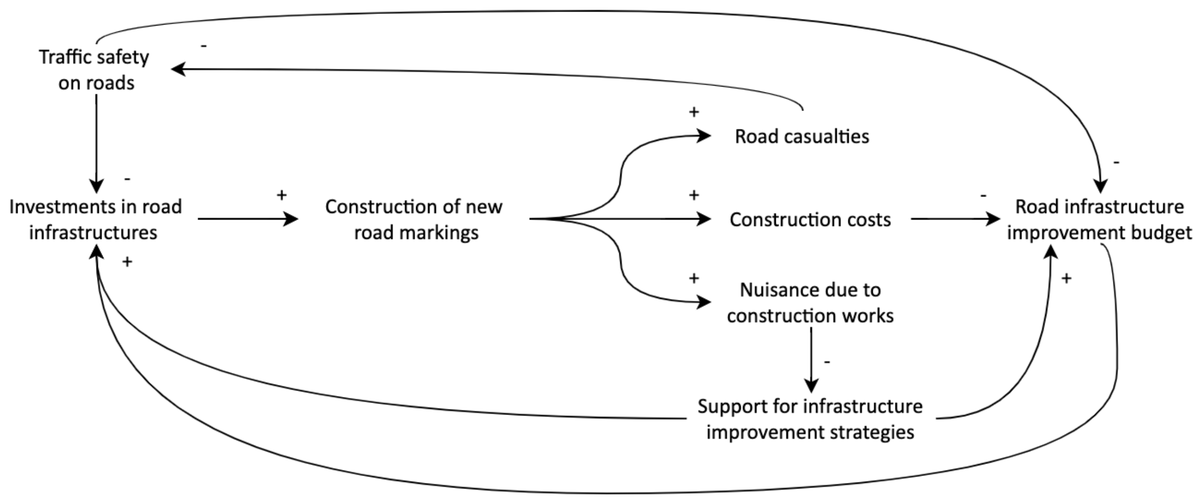



***Figure 3.10*** *Example of the lack of synergy effects during an individual project*

## 3.7 Conclusion

In this chapter, the topic of infrastructure improvement strategies is conceptualized using scientific literature. First, the cyclical process of municipal project management is explained. This is very similar to the cyclical process of project management (Nagaraj, Ramachandra, & Kumar, 2010). Thereafter, it is elaborated how the literature review was conducted. Then, an overview of the scientific literature is given. In the current literature only the hot/black spot strategy and Sustainable Safety strategy are mentioned as possible infrastructure improvement strategies. Based on the literature review, a knowledge gap is identified: Research on road safety strategies instead of individual projects is uncommon but valuable due to synergy effects. In addition, the strategies that can be found in the current scientific literature do not mention specific strategies for municipalities and these strategies are not compared using SCBA.

# 4 The Dutch Case of Traffic Safety

In the previous chapter, the international scientific literature on infrastructure improvement strategies is discussed. This chapter focuses first on the infrastructure improvement strategies that are used in the Netherlands to increase traffic safety, and second, on the infrastructure improvement strategies that are used by the G4 municipalities to increase traffic safety. This section concludes with the modified overview of the strategies provided in the previous chapter.

## 4.1 The Dutch View on Road Safety Strategies

After decades of declining, the number of road deaths is stagnating, and the number of road injuries has been increasing for years (Ministerie van Infrastructuur en Waterstaat, 2018). In response to these developments, the Dutch government created the Strategic Plan Traffic Safety (SPV) to describe the goals of traffic safety and how to reach them. The main goal is zero road casualties per year by 2050 (Ministerie van Infrastructuur en Waterstaat, 2018). In the SPV, various strategies are discussed that government authorities (provinces, municipalities, et cetera) should use to increase their traffic safety. In this paragraph, only the SPV strategies regarding infrastructure improvements are discussed.

*Risk-driven strategy*

According to the Ministerie van Infrastructuur en Waterstaat (2018), the risk-driven strategy starts with reaching an understanding of the risks on all road infrastructures. Gaining insights on the state of the infrastructure and the riskiest elements requires a good analysis and proactive management. This is not something that is already broadly used by road authorities. An explanation for this, is that the development and implementation of this strategy is a major operation, and it usually does not bear fruit immediately. Road safety results often become visible in the long term. The risk-driven strategy consists of four concrete steps (Ministerie van Infrastructuur en Waterstaat, 2018):

1. The risk factors of all road infrastructures must be mapped using scientifically substantiated and road authorities accepted methods.
2. Infrastructure improvements must be prioritized based on the insights of the mapped risk factors.
3. Road authorities must translate these priorities to concrete measures for large-scale renovations and maintenance.
4. Before new road infrastructures are built, a risk analysis must be conducted.

*Heterogeneity strategy*

In the Netherlands, there are many different road users. The differences in speed, mass, and size of all the different transport modes they use are great (Ministerie van Infrastructuur en Waterstaat, 2018). This leads to an increased crash risk and to more (severe) road injuries (SWOV, 2018b). To solve this problem, the SPV suggests that traffic flows and different speeds should be separated on road infrastructures. In addition, extra space on the road can be given to the more vulnerable road users, such as (motorized) two-wheelers (Ministerie van Infrastructuur en Waterstaat, 2018).

*Vulnerable road users strategy*

Vulnerable is defined in the SPV as: task incompetence (people with medical conditions) or brittleness (frail elderly and children). These vulnerable road users have a higher crash risk, and the Dutch government feels that it is their duty to protect them. To do so, the road authorities must consider the characteristics of vulnerable road users during the (re)design of road infrastructures. This can lead to infrastructure measures, such as high-contrast lines, middle island crossings, removing obstacles, improved lighting, more visible zebra crossings, et cetera (Ministerie van Infrastructuur en Waterstaat, 2018).

*Speed in traffic strategy*
There is a positive relationship between the speed of a road user and the number of road crashes. According to SWOV (2016), an increase of the average speed leads to a greater risk of crashes with a greater risk of serious injuries. To reduce the number of people that are speeding in traffic, the design of the road network should be in line with the speed limit, and it should be credible. The road authorities must determine what a safe and credible speed is for all their road segments (Ministerie van Infrastructuur en Waterstaat, 2018).

When looking at all these road infrastructure strategies that are discussed in the SPV, it stands out that only the risk-driven strategy says something about what road infrastructures to improve. The other strategies discuss how the infrastructures should be improved after the decision has been made what infrastructures to improve. It is also stated that there is little support among road authorities for the risk-driven strategy because the road safety results can take a long time to occur (Ministerie van Infrastructuur en Waterstaat, 2018). In other words, in practice this is not a popular strategy and therefore, it not often used. The SPV does not discuss how to tackle this or if there are other strategies road authorities could use.

## 4.2 The G4 Municipal View on Road Safety Strategies

In this paragraph, it is discussed what the traffic safety strategies of the G4 municipalities are, as defined in their traffic safety implementation program. These programs are based on the SPV, see the earlier paragraph. Because the traffic safety implementation programs of the G4 municipalities are very similar, they are discussed as one.

One of the focus points in each of the programs, is the black (or hot) spot approach. All G4 municipalities make a list with the road segments with the highest crash concentration. The infrastructures on these road segments are prioritized over other infrastructures when it comes to improving them (Gemeente Amsterdam, 2016; Gemeente Rotterdam, 2019; Gemeente Den Haag, 2020; Gemeente Utrecht, 2022).

It appeared that the municipalities focus their road safety plans on the various road user groups that they call ‘target audiences’. Emphasis is placed on the vulnerable road users, in particular cyclists, children, and elderly. One of their strategies could therefore be, to prioritize the improvement of the infrastructure that these road users often use. However, this is not specifically mentioned in the traffic safety programs. It does say how these infrastructures can be improved to increase the traffic safety for the vulnerable road users (Gemeente Amsterdam, 2016; Gemeente Rotterdam, 2019; Gemeente Den Haag, 2020; Gemeente Utrecht, 2022).

Finally, all municipalities mention wanting to prevent traffic unsafety from occurring, instead of remedy it. These plans largely correspond to the risk-driven strategy mentioned in the SPV. They want to gain insights on the state of the infrastructure and the riskiest elements. That way, the unsafe infrastructures can be improved before any crashes happen (Gemeente Amsterdam, 2016; Gemeente Rotterdam, 2019; Gemeente Den Haag, 2020; Gemeente Utrecht, 2022).

Again, only this risk-driven strategy and the hot/black spot strategy discussed in the traffic safety programs can really be called strategies as defined in this study. The focus on vulnerable road users strategy focuses mainly on how to change the infrastructure to increase traffic safety and what measures to use. But not how to decide what infrastructures to improve. Consequently, only the risk-driven strategy, and the hot/black spot strategy are included in the strategy overview, see section 4.3.

## 4.3 Revised Strategy Overview

The previous two paragraphs lead to the revision of the strategy overview, see figure 4.1. The difference between figure 3.8 and 4.1 is that in this figure the grey literature is also included. As a result, the risk-driven strategy that is mentioned in the Strategic Plan Traffic Safety and the traffic safety implementation programs of the G4 municipalities is also included. This strategy is based on the infrastructure characteristics. Based on these characteristics it is decided what road segments must be improved (Ministerie van Infrastructuur en Waterstaat, 2018). Again, the costs and benefits vary per road infrastructure measure, and therefore, per strategy. In figure 4.1, the green and red arrows are not representative of the size of the social costs and benefits but are used to show that the social costs and benefits can vary per road infrastructure measure.

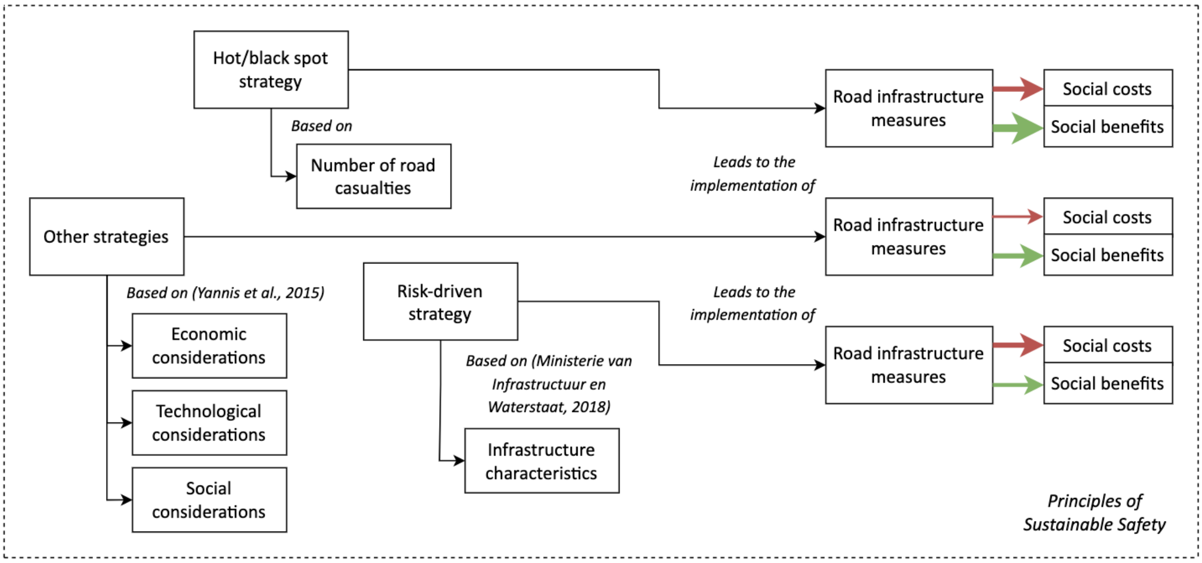



***Figure 4.1*** *Road safety strategies based on scientific and grey literature*

## 4.4 Conclusion

This chapter discussed the infrastructure improvement strategies that are used in the Netherlands, and more specifically by G4 municipalities, to increase traffic safety. The strategies that are used in the Netherlands are explained in the SPV. There are roughly four strategies that are discussed in the SPV: the risk-driven strategy, heterogeneity strategy, vulnerable road users strategy, and speed in traffic strategy. The G4 municipalities use traffic safety implementation programs to explain their traffic safety infrastructure improvement strategies. In these programs roughly three strategies can be distinguished: the black (or hot) spot strategy, focus on vulnerable road users strategy, and risk-driven strategy.

# 5 Municipal Road Infrastructure Improvement Strategies

In this chapter the road safety strategies of the G4 municipalities, Amsterdam, Rotterdam, The Hague, and Utrecht are identified. What strategies do they have to make decisions on what road infrastructure to improve to increase traffic safety? To identify these, interviews with employees from the G4 municipalities were held. First, it is shortly explained how the interviews were conducted and an anonymized overview is given of the municipalities, the interviewees, and their field of expertise. Thereafter, the definitions of both the sub strategies and the main strategy are discussed.

## 5.1 Short Overview of the Interviews

Over a period of one week, six interviews were held with seven employees from the G4 municipalities. The goal of these interviews was to answer the research questions by unraveling the strategies they use for making decisions about what road infrastructures to improve to increase traffic safety. But also, by finding out what complicates these decisions, and how the decision-making processes of these municipalities work. With whom the interviews were conducted and for which of the G4 municipalities they work, will be kept anonymous at the request of the participants. Table 5.1 gives an overview of the municipalities, the interviewees, and their field of expertise. Table 5.2 gives some extra information about the different areas of expertise of the employees.

***Table 5.1*** *Overview of the interviewees*

| Municipality | Interviewee | Field of expertise |
|---|---|---|
| Municipality 1 | Employee 5 | Road infrastructures |
| | Employee 6 | Road safety policies |
| Municipality 2 | Employee 2 | Mobility |
| | Employee 3 | Road safety strategies |
| Municipality 3 | Employee 4 | Road safety strategies |
| Municipality 4 | Employee 1 | Road safety policies |
| | Employee 7 | Road infrastructures |

The employees can be divided in four fields of expertise:

***Table 5.2*** *Fields of expertise of the interviewees*

| | |
|---|---|
| ***Policy experts***<br>Employees 1 and 6 make new policies on road safety for their municipality. This gives them a lot of knowledge about what it entails to increase traffic safety in a municipality and which infrastructure improvements are mostly used. | ***Infrastructure experts***<br>Employees 5 and 7 are very knowledgeable on road infrastructures. One is an expert on road management and the other has a background in traffic engineering. |
| ***Mobility expert***<br>Employee 2 has some broader knowledge about mobility, traffic safety including. | ***Strategy experts***<br>Employees 3 and 4 are responsible for the content of the traffic safety strategies for their municipality. So, their expertise is devising and changing strategies concerning road safety. |

## 5.2 Definition of Strategies

Each municipality has a main strategy when it comes to increasing their traffic safety. This main strategy can be divided in various sub strategies. These sub strategies can partly overlap and consist of various road infrastructure measures. These measures can vary per sub strategy. It differs per municipality which ratio of sub strategies forms the main strategy. It valuable to take this strategy approach compared to the individual project approach, because it gives a new and wider perspective on the choices that are made during the road safety decision-making processes of the G4 municipalities. In addition, it allows for synergy effects to be considered. After the interviews, it appeared that the main strategies can be divided into the degree of reactive- and proactiveness. These are two extremes, and all municipalities are somewhere on that spectrum. In this paragraph, first the sub strategies are identified and afterwards, the main strategy is defined, and it is discussed to what extend each sub strategy is reactive or proactive.

### 5.2.1 Municipal Sub Strategies

In this paragraph the sub strategies of the G4 municipalities for deciding what infrastructures they are going to improve, are discussed.

***Frequency strategy*** *(Employees 1, 2, 3, 4, 5, 6, 7)*

The first sub strategy that is identified, is a strategy based on the number of road casualties. All the interviewed employees indicated that the number of road casualties plays a major role in the decision on what road infrastructures to improve. The strategies that they execute is mostly the same: Employees 1 and 7 indicated that first a list is drafted with the road segments where the most (severe) crashes were reported. These reports are mostly from the police, but some municipalities also include crashes that are reported by citizens or neighborhood organizations. After that, an analysis is carried out to see if the road infrastructure was (partly) the cause of the crash, according to employee 3 and 4. If so, the infrastructure of this road segment is given priority to be improved with the goal to increase traffic safety. The improvement of the road infrastructure that is implemented can vary from a small measure, such as building a speed bump, to a complete redesign of the road, according to employees 3, 5, and 6.

Part of the frequency strategy is the black spot approach. Black spots are road segments where at least 6 injury crashes happen in 3 consecutive years, according to employees 3 and 4. Employees 5 and 6 indicated that within their municipality there is a separate program to deal with these black spots. The approach is the same as the strategy mentioned above. However, more often than other unsafe road segments, these black spots lead to a redesign of the road. Municipalities are willing to spend a lot of resources on these problem locations because of the high number of road casualties.

***Combining projects strategy*** *(Employees 1, 2, 4, 5, 6, 7)*

The second strategy mentioned during the interviews by employees 1, 2, 4, 5, 6, and 7, consists of combining infrastructural projects. When traffic safety projects are carried out without cooperation with other departments within the municipality, the costs can be high. The before-mentioned employees said that a lot can be saved on the budget if projects are combined. In practice this means that more traffic safety projects can be executed. In particular, road maintenance and work on pipes and pipelines is combined with traffic safety projects. But also, the construction of green facilities and other projects, according to employees 1, 4, 5, and 6. As mentioned before, the biggest gain of combining projects is financial. However, there are other benefits to this strategy as well. For example, according to employee 4 and7, there is less nuisance for local residents because the road is broken up only once. In addition, combined projects have a greater impact on society because there are other benefits besides traffic safety, such as a more pleasant atmosphere in a city when there is more greenery and happier residents when their wishes are included, according to employee 7.

A downside to this strategy, as mentioned by employees 2, 4, and 7, is that combined projects are more time consuming. This applies to both the planning phase and the construction phase. Employee 4 also indicated that when one project is delayed, often the choice is made to delay all projects. Because traffic safety projects are often too expensive to be carried out alone.

***Subjective road safety strategy*** *(Employees 1, 2, 3, 4, 5, 6, 7)*
The third strategy that can be derived from the interviews bases decisions about infrastructure investments on subjective road safety. Subjective road safety is defined by Sorenson & Mosslemi (2009, p. i) as: "*The feeling or perception of safety i.e., how people subjectively experience accident risk in traffic.*" In all G4 municipalities, citizens can submit their complaints, including complaints about road safety. In addition, all employees indicated that they have close contacts with neighborhood organizations and these organizations also express their concerns regarding traffic safety. If these concerns and complaints are based on feelings instead of objective crash data, this can be considered subjective road safety. All these complaints combined determine to a greater or lesser extent where road infrastructure investments will be made. Employees 4, 5, and 6 indicated that within their municipality subjective safety projects are often prioritized over objective safety projects. So, it depends on the municipality how much weight is given to this form of traffic safety in the decision-making process. But in all G4 municipalities it is a factor that is considered. Employee 3 argues that subjective road safety is becoming increasingly more important for municipalities because people who feel unsafe will not walk or cycle that often. Since all G4 municipalities have the goal to realize a mobility transition from a driver-based city to a cyclist and pedestrian-based city, it is important that these more vulnerable road users feel safe.

***Vulnerability strategy*** *(Employees 1, 2, 3, 4, 5, 6)*
The fourth strategy focuses on investing in road infrastructures that vulnerable road users use. There are two types of vulnerable road users: Road users without any shells to protect them, such as pedestrians, cyclists, and light moped riders. And road users with a limited task ability, such as children and elderly (SWOV, 2012a). In the interviews it was indicated by employees 1, 2, 3, 4, 5, and 6 that their municipality tends to prioritize the safety of these road users. Especially the interests of cyclists and children were emphasized. Consequently, many investments are made in road infrastructures used by vulnerable road users, for example, school zones (employees 2 and 4) and bicycle paths (employees 1, 2, 3, 5, and 6). Creating a school zone is done by visually changing the road environment so that road users are made aware that a school is nearby. In practice this means writing 'school zone' on the road surface and placing a sign that says the same, according to employee 4. The most frequently mentioned changes to bicycle infrastructures are the removal of bollards, the widening of bicycle paths and lanes, and the construction of separate bicycle paths.

***Data driven strategy*** *(Employees 1, 2, 3, 4, 7)*
The fifth and last strategy mentioned in the interviews, is the data driven strategy. The employees of municipalities 2, 3, and 4 indicated during the interview that they use data to decide which infrastructures are going to be improved. They use data such as road characteristics, the number of road casualties, and complaints from citizens, et cetera. This data is used as input for a traffic safety model that predicts where road safety issues are most likely to occur. The employees call this a risk-driven approach. However, in the scientific literature a risk-driven approach is defined as: An approach that looks at specific risk factors such as road characteristics, circumstances, or behaviour, that can identify possible unsafe road segments without the use of actual crash data (Kennisnetwerk SPV, n.d.-c). Therefore, in this research the fifth strategy is called a data driven strategy instead of a risk-driven strategy, because the municipalities also base their decisions on crash data and other factors instead of predicting risk factors alone. Employees 1, 2, 4, and 7 indicated that decisions are never solely based on these data driven models alone because the input data is incomplete. The police are not willing to share all their detailed information and not all crashes are registered in the first place.

Consequently, this strategy is currently not used to make decisions about infrastructure investments but only as a check or first indication of risk areas.

### 5.2.2 Final Strategy Overview

Figure 5.1 shows an overview of all municipal traffic safety strategies that are used by the G4 to make decisions about what infrastructure to improve. The data driven strategy is not included in this figure since it is currently not used to make decisions but only as an indication, according to all employees. Again, the costs and benefits vary per road infrastructure measure, and therefore, per strategy. In figure 5.1, the green and red arrows are not representative of the size of the social costs and benefits but are used to show that they can differ.

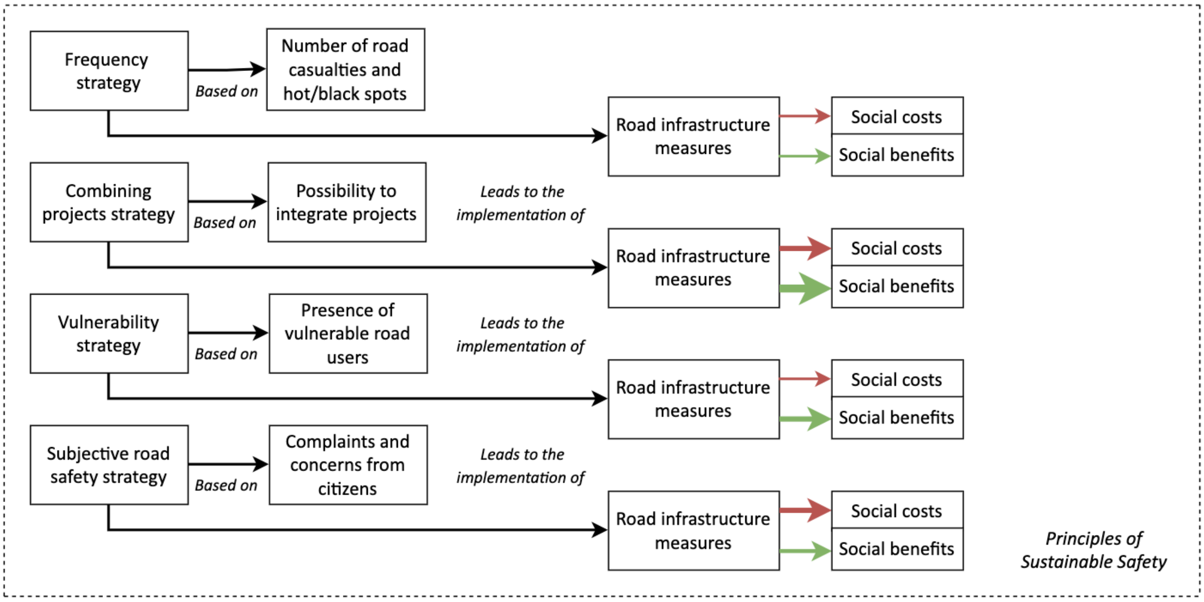



***Figure 5.1*** *Municipal road safety strategies based on the interviews*

### 5.2.3 Municipal Main Strategy

The main strategy of a municipality consists of combinations of the four sub strategies mentioned above. The ratio of the sub strategies that are used by the G4 municipalities can differ, but the content of the sub strategies are broadly the same. So, how to define the main strategy of these municipalities? Each sub strategy can be labeled as proactive, reactive, or anything in between. The ratio of these strategies determines if the main strategy is considered proactive, reactive, or somewhere in the middle. So, the main strategy of the G4 municipalities can be defined by the spectrum from proactive to reactive. What this exactly entails, is discussed hereafter.

***Proactive***

A proactive policy is designed to prevent problems or emergencies, in this case traffic crashes, from occurring (United Nations, 2016). In this research, that means that the G4 municipalities do not wait with investing in road infrastructures until a traffic crash has occurred, but that they already improve the infrastructures in advance. It can be difficult to find enough support base for investments in road infrastructures where traffic crashes have not yet occurred (United Nations, 2016). There is only a certain budget that municipalities can spend and roads that already have proven to be unsafe, because traffic crashes have occurred there, often are prioritized.

***Reactive***
A reactive policy acts in response to a certain situation that already has occurred, instead of preventing it (National Geographic Society, 2019). In this research, that means that the G4 municipalities only invest in road infrastructures where a traffic crash has occurred, because it is proven that these roads are unsafe and therefore worth the investment. In practice, this means that the road segments with the highest number of road casualties are prioritized.

As mentioned earlier, the main strategy is a combination of the sub strategies. To what extent this main strategy is proactive or reactive depends on the nature of the sub strategies and the ratio in which they are used by a certain municipality. To figure out if the main strategy of the municipalities is more proactive or reactive, it is discussed for each sub strategy if it is more proactive or reactive.

The *frequency strategy* focuses on the number of fatalities per road segment. The decision what infrastructures to improve is based on those numbers. Therefore, this strategy is 100% reactive. It reacts to a problem, in this case traffic unsafety, after it has occurred. And it fixes the problem areas, in this case specific segments of road infrastructure, afterwards.

The *combining projects strategy* focuses on projects, such as road maintenance, greenery, replacing pipelines, et cetera, and tries to combine them with traffic safety projects. So, the decision about which road infrastructure to improve is based on which projects can be combined with traffic safety projects. Depending on the situation this strategy can either be proactive or reactive. When during road maintenance the road safety is increased by improving some unsafe infrastructure while, the strategy is proactive. Because the road infrastructures are improved before crashes have occurred. However, when a road safety project is executed because a lot of crashes happened and some pipelines are replaced because the road is broken up anyway, the strategy is reactive. The road infrastructures are improved because crashes have occurred. In short, if road infrastructures are improved where no traffic crashes have (yet) occurred, the strategy is proactive, otherwise it is reactive.

The *subjective road safety strategy* says that investments should be made in road infrastructures where people feel unsafe. If people feel unsafe on a road segment, this does not mean that the road infrastructure is unsafe. In other words, subjective road unsafety does not per se lead to objective road unsafety. In fact, the relationship between the two is very weak. In general, approximately half of the road segments where people feel unsafe, are objectively unsafe and the other way around (SWOV, 2012b). Therefore, this strategy can be considered proactive because many of the road segments that people complain about are not the road segments where the most traffic crashes happen. So overall, improving road infrastructures based on subjective road safety, is proactive because in many cases the infrastructure is improved before road crashes occur.

The *vulnerability strategy* focuses on the more vulnerable people that take part in traffic, and more specifically, children and cyclists. The interviews with the G4 municipalities indicated that regardless of the road safety situation near schools and on bicycle paths, the safety and wellbeing of children and cyclists is of paramount importance. Therefore, this strategy can be labelled proactive because the number of road casualties is not considered. The vulnerable road users simply get higher priority over other road users. However, research shows that in the Netherlands the number of fatal bicycle crashes keeps increasing (SWOV, 2021b). So, that could be an underlying reason for municipalities to invest more in bicycle infrastructures. If this is the case, this strategy would be more reactive than proactive.

The *data driven strategy* is a strategy that uses a model with data about road characteristics, the number of road casualties, complaints from citizens, et cetera, to predict road safety risk areas. This strategy is partly proactive and partly reactive. If the risk factors that are used by the model are mostly focused on road characteristics, driving behaviour, complaints of citizens, et cetera, the strategy is mostly proactive because it predicts unsafe road segments without crash data.

If the model focuses mainly on the number of road casualties, the strategy is mostly reactive because it predicts unsafe road segment with crash data. However, as mentioned in the previous paragraph, this strategy is currently not used by the G4 municipalities to make decisions about road infrastructure investments. Therefore, this strategy is not included in the definition of the main strategy and in figure 5.2.

Figure 5.2 shows where each sub strategy is on the spectrum from reactive to proactive.

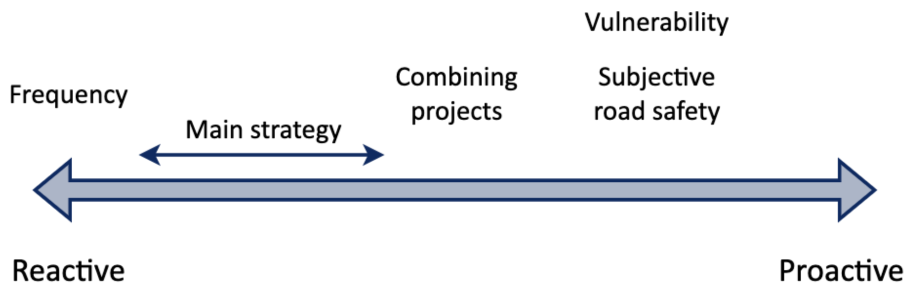



***Figure 5.2*** *The sub and main strategies of the G4 municipalities placed on the reactive-proactive spectrum*

All employees, except for employee 4 and 7, indicated during the interview that they think their current main strategy is more reactive than proactive. Employee 7 indicated that the ratio is approximately 50/50. This is caused by the fact that the emphasis of all G4 municipalities' main strategies is still on road segments where road crashes occur, so the number of casualties strategy. The future goal is to move more and more towards a proactive main strategy and away from the reactive main strategy. They aim to do this by developing a more data and risk driven strategy using traffic safety models, as discussed above. Due to a lack of data and the fact that it is a totally new approach, this strategy is still in its infancy.

## 5.3 Conclusion

In this chapter the road safety strategies of the G4 municipalities are identified. To do so, first, it is discussed which employees of the G4 municipalities were interviewed. It concerned policy, infrastructure, mobility, and strategy experts of these municipalities. Due to privacy considerations all interviewees were anonymized. The outcome of the interviews was that the G4 municipalities roughly use five sub strategies: the frequency strategy, combining projects strategy, vulnerability strategy, subjective road safety strategy, and data driven strategy. The latter was not considered in the rest of this study because it is currently not used to make decisions about infrastructure investments but only as a check or first indication of risk areas. The interviews also led to the insight that each municipality uses the four sub strategies in a certain ratio, and the combination of these strategies can be considered the main strategy. Each sub strategy, and therefore also the main strategy, is to a greater or lesser extend proactive or reactive. This means that problems are prevented (proactive) or solved after they have occurred (reactive).

# 6 Governance of Traffic Safety

So, now we know which strategies the G4 municipalities use to determine which road infrastructures they are going to improve to increase traffic safety. But why are these strategies used? What does the process from decision to implementation look like? And what are complications in the decision-making process and execution phase? In this section, based on the interviews, the governance side of the municipal road safety strategies is discussed to gain insights on why certain choices are made by the G4 municipalities. It is necessary to investigate this because it gives a better understanding of where the strategies are placed in the decision-making process and what this implicates. Ultimately, this will improve the quality of the policy recommendations at the end of this research.

## 6.1 Steps in the Decision-Making Process

In the traffic safety decision-making process of the G4 municipalities, various actors play a role. To understand what their function and power is, first some definitions must be given. Thereafter, the high- and low-level decisions that are made within the municipalities are discussed. The decision-making processes that are described, came up during the interviews

### 6.1.1 Some Definitions

All parties within the municipality that have a say at any time, are briefly explained. Starting with the city council and its councilors.

***City Council***

According to the Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2022), the City Council is the highest governing body of the municipality. The members of the Council, called councilors, make all the important decisions for the municipality and its citizens, including decisions on traffic safety. Each four years they are elected by the citizens of the municipality.

***College of Mayor and Aldermen***

The mayor and aldermen together form the board of the municipality. They implement the decisions made by the City Council. In addition, they implement laws and regulations of the central government and the province. Lastly, they are responsible for the finances of the municipality (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2019).

***Coalition***

After the municipal elections, negotiations take place to form a coalition, often between the winning political parties of the election. This coalition determines the composition of the College of Mayor and Aldermen. Which political party gets which aldermen post is part of the negotiations (Nederlandse Vereniging voor Raadsleden, n.d.)

***Alderman***

In terms of function, an alderman in a municipality can be compared to a minister within the cabinet. They have a portfolio of subjects for which they are responsible. In this chapter, the alderman means the alderman responsible for road safety (Nederlandse Vereniging voor Raadsleden, n.d.). He or she is the administrative client of road safety projects.

***Traffic Safety Department***

The department responsible for all road safety decisions is often a sub-department of the Department of Traffic and Transport. The Department of Traffic Safety develops new road safety strategies, makes plans to increase road safety, and in some cases, they implement these plans, according to employees 1, 2, 4, 5, and 6.

### 6.1.2 High-Level Decisions

The budget that the Traffic Safety Department can spend on traffic safety related measures is set by the coalition, according to all interviewed employees. Employee 4 also stated that the budget is fixed during the term of office, this is a period of 4 years. And that simultaneously, the road safety program for the same period is drawn up and approved by the City Council. The purpose of this is to establish the broad outline of the program so that the Traffic Safety Department does not have to request permission from the City Council for every minor decision, according to employees 2, 3, 4, 5, 6, and 7. Employees 1, 2, 3, 5, and 6 stated that during the execution of projects, the Traffic Safety Department keeps the alderman informed and the alderman keeps the City Council informed about the progress of those projects. Sometimes, a desired project cannot be carried out given the set budget for traffic safety expenses. In consultation with other departments within the municipality, the Traffic Safety Department can decide to combine projects, according to Employees 1, 2, 4, 5, 6, and 7. This way the costs of the project can be reduced. Employees 1, 2, 3, 5, 6, and 7 state that if this is not possible, an additional budget can be requested. The Traffic Safety Department consults with the alderman whether this is desired and if so, what plan they will present. Thereafter, the alderman consults with the College of Mayor and Aldermen to see what their opinions are. And if they agree, the request for extra budget is submitted to the City Council. They ultimately must decide whether the budget will be allocated or not, according to employees all employees. Employees 1, 2, 3, 5 and 6 stated that requests for extra budget are usually made in the Spring Statement and is awarded (or not) during the Autumn Statement. For an overview of this decision-making process and the actors involved, see figure 6.1.

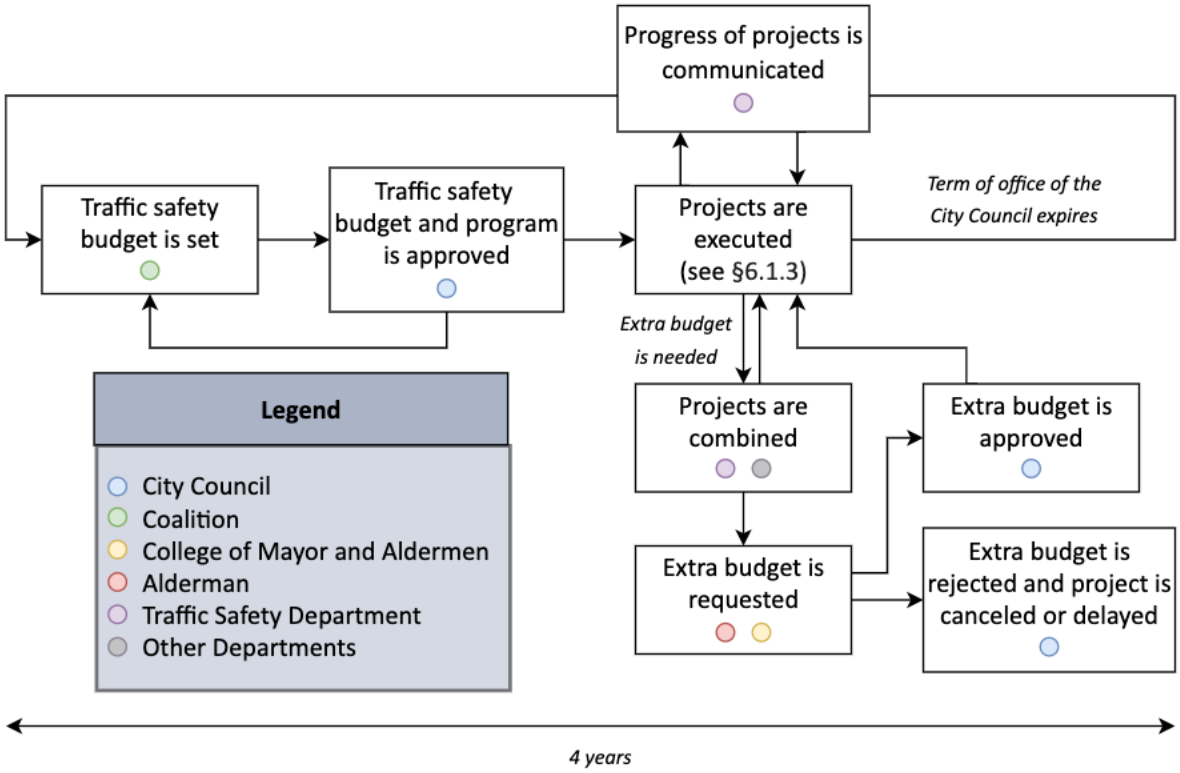



***Figure 6.1*** *High-level traffic safety decision-making process within a G4 municipality*

### 6.1.3 Low-Level Decisions

The low-level decision-making process of improving road infrastructures begins with the decision on what infrastructures to improve. Most of the time this is something that the Traffic Safety Department decides, sometimes in consultation with the alderman, according to employees 1, 2, 3, 5, 6, and 7. They make this decision using the strategies that are discussed in the previous chapter. However, employees 2, 3, 4, 5, and 6 stated that current affairs can also play a role in this decision.

If a severe road crash occurs within a municipality, this can have a big impact on the community. The City Council and alderman can decide to improve the road infrastructure involved in the crash more quickly, due to pressure from the community. "*The Traffic Safety department needs to act immediately to these requests from the City Council and the alderman, even if these road segments are not necessarily the bottlenecks that are really unsafe*", according to employee 4. When it is clear what road infrastructure is going to be improved, the budget for the project is determined, according to employees 1, 2, and 3. Since the overall traffic safety budget is already fixed, these project budgets can be determined by the Traffic Safety Department itself. If there is not enough budget to improve a certain road infrastructure, they must decide if they still want to go through with it (and ask for extra budget, see paragraph 6.1.2) or improve another part of the infrastructure. Afterwards, a project team is put together. According to employee 1, this team exists of a team leader, traffic engineer(s), landscape architect(s), infrastructure designer(s), et cetera. The composition and size of project teams differ per project. Subsequently, the project team of the Traffic Safety Department develops the project further, so that there is clear plan that can be implemented. Employees 4, 5, and 6 stated that part of this, is finding a time slot within which the project can be carried out. Not every road can be closed at any time for a longer period, for example because of the traffic flow in a city. If the traffic safety project is combined with another project within the municipality, the department of that project is also included in this process, according to employees 1 and 7. Before the project can be executed, all parties involved must be informed. Residents must be informed about the project because they can experience nuisance from the renovation, and they have the right to object to the project (Ministerie van Justitie en Veiligheid, 2021). In addition, consultation takes place with emergency and public transport services to ensure that these parties experience as little inconvenience as possible during the renovation and afterwards, according to employees 1, 3, 4, 5, 6, and 7. When all parties agree, the project will be carried out in the agreed time slot. For an overview of this decision-making process and the actors involved, see figure 6.2. In some municipalities, the district councils also have a say in this decision-making process.

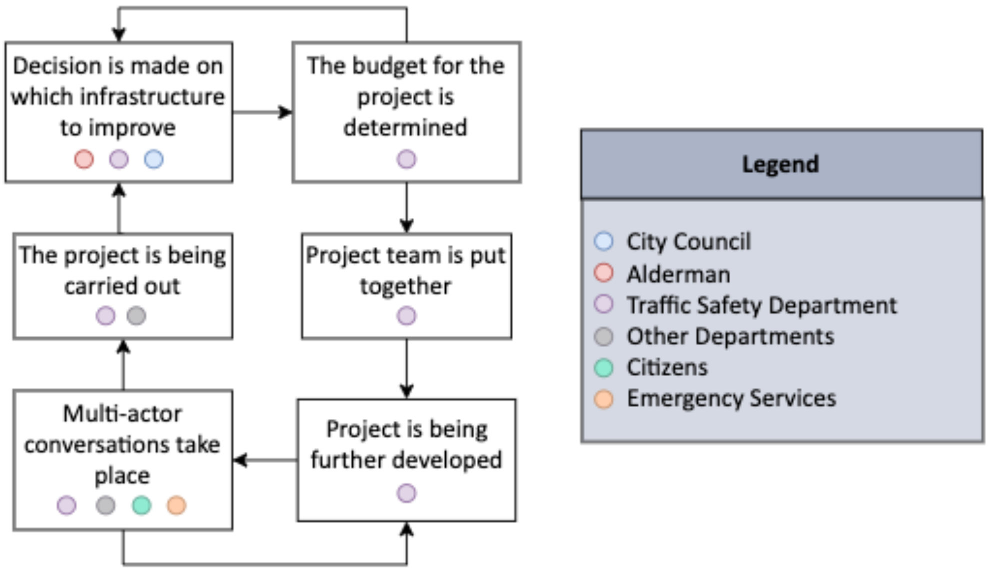



***Figure 6.2*** *Low-level traffic safety decision-making process within a G4 municipality*

## 6.2 Strategies Placed in the Decision-Making Process

What the main strategy will be for the next term of office of the City Council is decided during the budget and program discussions of the coalition and the City Council. This decision is made early on, and it is part of a process that is a loop, see figure 6.1. First, the road safety budget is set by the coalition. This budget is fixed for a period of 4 years. After that, the City Council must approve the road safety budget.

Simultaneously, the road safety program for the same period is drawn up and approved by the City Council. In this program it is decided what main strategy, and therefore, what sub strategies are used. Making this choice for what strategies to use so early in the decision-making process has consequences for the rest of the process. In other words, path dependency arises. According to Baláž and Williams (2007, p. 39): "*Path dependence exists when the outcome of a process depends on its past history, on a sequence of decisions made by agents and resulting outcomes, and not only on contemporary conditions.*" This is also the case in the traffic safety decision-making process of the G4 municipalities. Because early on decisions regarding the infrastructure improvement strategies are made, the decisions later on in the process are limited because of the lock-in effect. A lock-in effect is a trap from which the system cannot escape without the involvement of an outside shock (Greener, 2002). G4 municipalities stick to their choices for certain strategies until an external impulse arrives such as, a crash with a major impact on the society. Then, they may be willing to reconsider their choice. But if the external impulse in not forthcoming, their strategy decision will remain the same. To illustrate this, see figure 6.2. The decision on which infrastructure to improve is limited by the choice for certain strategies. For example, if one of the G4 municipalities decides to completely focus on improving the roads where the crash rates are the highest (frequency strategy), the roads where people feel unsafe but objectively are not that unsafe (subjective road safety strategy) will not likely be improved. Unless there is an external impulse such as, a large number of citizens that is filing complaints about roads where they feel unsafe. Due to the external impulse the G4 municipality can decide to improve the infrastructures where these citizens feel unsafe, and therefore, to use the subjective road safety strategy.

## 6.3 Complicating Factors in the Process

During the interviews it appeared that there are several complicating factors that make it more difficult for G4 municipalities to stick to their road safety strategy and execute the corresponding road infrastructure measures. In this paragraph, all the complicating factors mentioned during the interviews are discussed.

### 6.3.1 Limited Budget

The first and most frequently mentioned complicating factor, is the budget of the G4 municipalities. Employees 1, 3, 5, 6, and 7 indicated that this factor has a big influence on the traffic safety projects they want to execute. According to employee 1, estimates for the project budget are made in advance, but sometimes a project turns out to be more expensive than expected. This budget deficit can emerge during the planning phase as well as the execution phase. The project must then be downsized, postponed, or canceled completely. Employee 3 and 7 indicated that it is always a battle between the desire to increase road safety and the lack of money to finance it. 'Nobody is against road safety, but finding the financial resources is sometimes a challenge', according to employee 7. Employees 5 and 6 said that the parking revenues in their municipality have plummeted during the COVID-19 pandemic. Normally, a significant share of the road safety projects is paid with these revenues. Consequently, the budget is now smaller than normal.

### 6.3.2 Political Considerations

Employees 5 and 6 indicated that the approach of the alderman has a big influence on what decisions are made. If the alderman does not prioritize road safety, fewer (large) projects are carried out in this area. According to employee 7, it also depends on whether the alderman engages in short-term or long-term politics. Short-term politics focuses mainly on satisfying citizens by, for example, addressing current events, and thereby winning votes in the next elections. When the strategy is more long-term oriented, the ultimate result for road safety is better. However, this can come at the expense of potential votes. A sidenote made by employee 7, is that the alderman must receive the power to make these decisions from the City Council. This is not always the case.

### 6.3.3 Project Execution Time Slots

For the implementation of infrastructure projects, a time slot must be established at which the road may be broken up and closed if necessary. According to employee 3, this time slot is discussed with and approved by all parties involved. In particular, public transport companies can cause an enormous delay in the process. They do not want the road to be broken up, because they then have to divert or even shut down some of their public transport connections. Employees 5 and 6 also indicated that this causes a lot of delay in their municipality.

### 6.3.4 Multi-Actor Decision-Making

When a project is arranged integrally, many parties are involved. As a result, the lead time of the project is longer then for an individual project. Reaching an agreement takes more time if there are many parties involved. But in the end, it does yield a better result, according to employee 7. Employee 4 also indicated that combined projects often take longer. However, the cause for this is different than described by employee 7. Employee 4 said that when projects are combined, all projects delay if one of the projects delays. This is because the projects often have to be combined for budgetary reasons. Otherwise, when projects are executed individually, the budget will simply fall short. That is why most of the time the decision is made to delay or postpone all projects, if one delays.

### 6.3.5 Administrative Capacity

According to employee 3, the administrative capacity of the municipality is too small. The amount of work is increasing, and the number of employees is not growing fast enough. Recently, this department not only makes the road safety policies, but they also (partly) implement it. They have too few employees for this change, and specifically too few experts in the field of project management, technology, et cetera.

## 6.4 Conclusion

In this section, the governance side of the municipal road safety strategies is discussed to gain insights on why certain choices are made by the G4 municipalities. First, the steps of the municipal decision-making process were explained. This process is divided into high- and low-level decisions. The high-level process is about the decisions that are made before and after a traffic safety project is approved. The low-level process is about the decisions that are made on a certain traffic safety project. The decision for what strategies to use early on in the decision-making process has some implications for the remainder of the process due to path dependency and the lock-in effect. The decision-making process also has some complicating factors: There are limited budgets, political considerations, project execution time slots, multi-actor decision-making, and administrative capacity. All these complicating factors lead to a more reactive strategy, because the G4 municipalities are limited in their choice for a certain traffic safety approach.

# 7 Social Cost and Benefit Analysis

In the previous chapters the infrastructure improvements strategies have been identified. In this chapter these strategies are compared using SCBAs. First, the base alternative is discussed. After that, the valuation and estimation of the social costs and benefits is considered. Then, the results of the SCBAs for each of the four strategies are discussed. Fourth, the results of the sensitivity analysis are discussed when the factors of the SCBAs are varied individually. Thereafter, the scenarios of the sensitivity analysis are explained. This chapter concludes with the results of the scenario sensitivity analysis and the conclusion.

## 7.1 Base Alternative

The first step when conducting a SCBA is to draw up the base alternative, see table 7.1. This base alternative captures the most likely developments without a new project or strategy (MKBA informatie, n.d.-b). In this study, the base alternative consists of the forecast of the number of traffic deaths, traffic injuries, and material damages in the municipality of Amsterdam multiplied by the costs of a traffic death, traffic injury, or material damage. For the road safety forecast of the municipality of Amsterdam, see section 7.2.2. The costs of a traffic death, traffic injury, or material damages is based on a report from SWOV (2020). For the exact calculations, see the Excel file.

***Table 7.1*** *Base alternative road safety costs in the municipality of Amsterdam in the period 2022-2040*

| | Present value x 1,000,000,000 | | |
|---|---|---|---|
| | € | (1) | Costs of traffic deaths |
| | € | (14) | Costs of serious traffic injuries |
| | € | (3) | Costs of material damage |
| **Total costs** | **€** | **(18)** | |

## 7.2 Valuation and Estimation of Social Costs and Benefits

In a SCBA costs and benefits must be estimated to conduct the analysis. In this paragraph, it is discussed per strategy what costs and benefits are included and how the effects of the infrastructure improvement strategies are estimated and translated into costs and benefits in a measurable unit, in this case euros.

### 7.2.1 Costs Monetization

In the SCBAs of the frequency, combining projects, and subjective road safety strategy the *costs of improving the infrastructure* are based on the budget that is made available by the municipality of Amsterdam to increase traffic safety. This number can be found in the budget of 2021 (Gemeente Amsterdam, 2020). In the SCBAs it is assumed that each strategy spends this total budget, except for the combining projects strategy. In that strategy the costs are not only borne by the department of traffic safety, but also by other departments.

In the SCBA of the vulnerability strategy the costs of improving the infrastructure are captured in the costs of constructing school zones, the costs of removing bicycle poles, the costs of widening bicycle paths, and the costs of applying edge and axle markings. The *costs of constructing school zones* are calculated by multiplying the number of schools in Amsterdam and the costs for constructing a school zone. The *costs of removing bicycle poles* are calculated by estimating the number of bicycle poles in Amsterdam and multiplying it by the costs of removing bicycle poles. The costs of constructing a school zone and removing bicycle poles were given by the municipality of Amsterdam.

The *costs of widening bicycle paths* are calculated by multiplying the total length of bicycle paths in Amsterdam with the costs of widening 1 kilometer bicycle path. The *costs of applying edge and axle markings* are calculated by multiplying the total length of bicycle paths in Amsterdam with the costs of applying 1 kilometer edge and axle markings. The prize book of the investment impulse SPV drawn up by Arcadis (2020) is used to establish the costs of widening bicycle paths and applying edge and axle markings.

In the SCBAs of all strategies the *costs of negative effects* are considered. The negative effects that occur because of the execution of infrastructure improvement projects are CO2 emissions, noise disturbance, and other hindrance during construction. The amount of emissions and nuisance was estimated and the associated costs have been taken from various sources. In table 7.2, an overview is shown of alle the costs of negative effects.

***Table 7.2*** *Costs of negative effects of infrastructure improvement projects*

| **Negative effects** | **Costs** x 1,000 per year |
|---|---|
| CO2 emissions | € 15 |
| Noise disturbance | € 2,250 |
| Hindrance during construction | € 435 |
| Total | € 2,700 |

In the SCBAs of the combining projects, vulnerability, and subjective road safety strategy the labor costs are taken into account. It is assumed that to execute these strategies more labor force is needed than that is currently available within the traffic safety department. It depends on the strategy how many fulltime equivalents (FTEs) are needed. In the SCBAs salary scale 10 is used as the average costs that need to be paid for an extra employee (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). In the frequency strategy labor costs are not included because it is assumed that the labor force that is needed is equal to the labor force in the base alternative. For the exact calculations of all costs mentioned above, see the Excel file.

### 7.2.2 Benefits Monetization

The benefits in the SCBAs exist of the increase in traffic safety compared to the base alternative. The increase in traffic safety can be calculated by multiplying the forecast of the number of road deaths in the municipality of Amsterdam by the Value of Statistical Life (VSL) and the effect of the infrastructure improvement of the specific strategy. The costs that can be saved by preventing road injuries and material damage are derived from the VSL and are calculated the same as the saved costs of road deaths. For the exact calculations of the benefits, see the Excel file.

The forecast of the numbers of road deaths, road injuries, and material damage for the frequency strategy, combining projects strategy, and subjective road safety strategy are based on BRON road safety numbers (SWOV, n.d.-b), road safety numbers of SWOV (2018a) and the road safety forecast of SWOV (2021d), see figures 7.1-7.3. The forecast of the numbers of road injuries, and material damage for the vulnerability strategy are not based on BRON road safety numbers, but only on data from SWOV (2018a) and the road safety forecast of SWOV (2021d). Because BRON data underestimates the number of road injuries and road damages on bicycle paths. Unilateral traffic crashes in particular are heavily underestimated. This is due to incomplete data collection because not all crashes are reported or noticed by the sources of BRON i.e., police, hospitals, et cetera. For the number of road deaths the same data is used as for the other strategies since these numbers are not underestimated in BRON data. The forecast for the Netherlands is projected on the traffic safety numbers of the municipality of Amsterdam. Since there is no forecast for material damages, it is assumed that the forecast of traffic injuries equals the forecast of material damages.

These assumptions mentioned above must be made in order to conduct the SCBAs. In an SCBA the value of, in this case, a strategy within a certain time frame is calculated. The time frame of this study is 2022-2040. In order to estimate the possible future road safety gains, it must be determined how many road deaths, injuries, and material damages occur in the period of 2022 to 2040 without the implementation of one of the four strategies. This requires some estimations and assumptions.

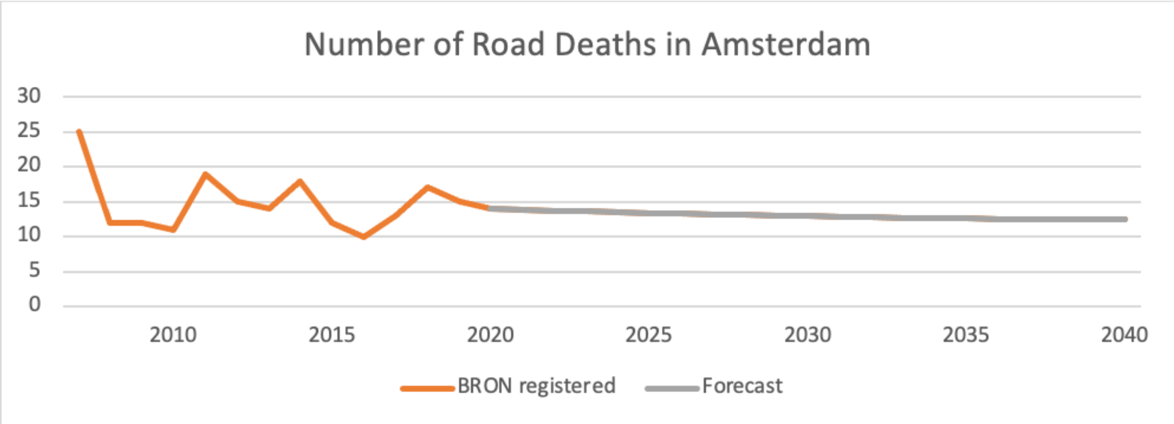



***Figure 7.1*** *Forecast of the number of road deaths in Amsterdam (SWOV, n.d.-b; SWOV, 2021d)*

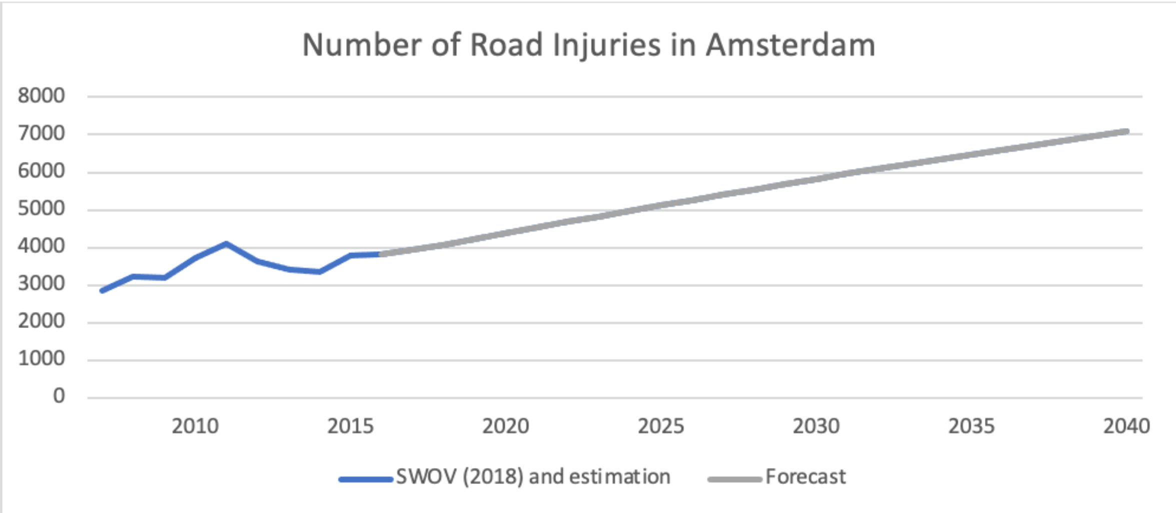



***Figure 7.2*** *Forecast of the number of road injuries in Amsterdam (SWOV, 2018a; SWOV, 2021d)*

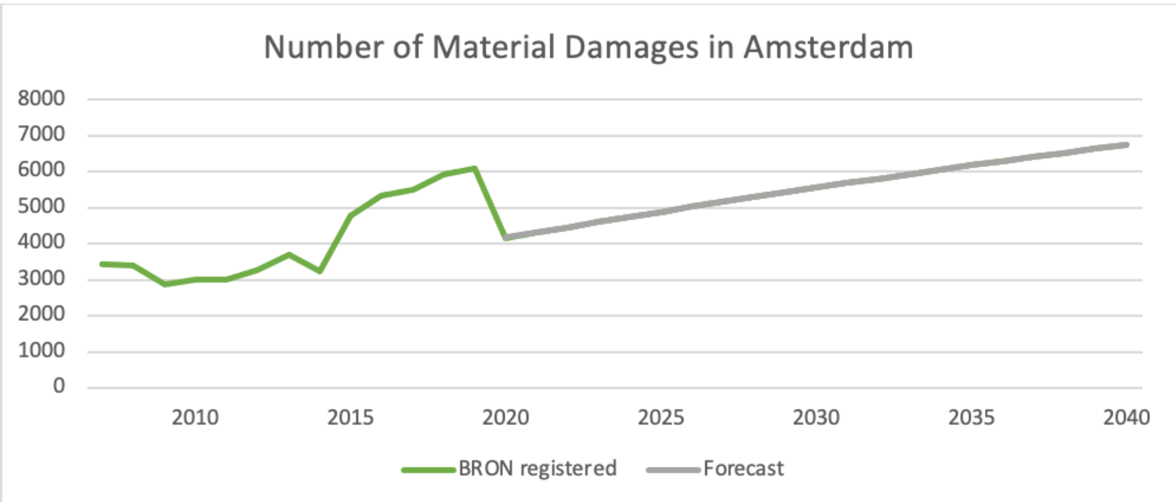



***Figure 7.3*** *Forecast of the number of material damages in Amsterdam (SWOV, n.d.-b; SWOV, 2021d)*

### 7.2.3 Non-Monetizable Benefits

In the SCBAs there are two benefits included that cannot be monetized, the synergy impact and the benefit of feeling safe. The synergy impact benefit is included in the combining projects strategy. The Cambridge Dictionary (2022a) defines synergy as: "*The combined power of a group of things when they are working together that is greater than the total power achieved by each working separately.*" This also goes for the combining projects strategy. When multiple departments of the municipality of Amsterdam work together, the outcome of the project is better than if all departments execute their projects individually. As mentioned before, synergy effects can occur in all road safety strategies. However, these effects are explicitly named for this strategy because it concerns not only synergy effects between road safety measures, but also between other measures such as including greenery. The benefit of feeling safe is included in the subjective road safety strategy. When the roads where people feel unsafe are improved, their overall safety feeling will increase. It is hard to monetize this benefit, but it is of great value to this strategy.

## 7.3 Results of the SCBAs

In this paragraph the results of the SCBAs of each of the four strategies are discussed. In every SCBA the benefits exist of the saved costs of traffic deaths, traffic injuries, and material damage. The costs exist of the costs to carry out the strategy and other negative effects, such as noise disturbance and other hindrance during the construction of infrastructures. These costs and benefits vary per strategy.

### 7.3.1 Frequency Strategy

The frequency strategy focuses on the number of fatalities per road segment and bases the decision what infrastructures to improve on this number. Table 7.3 shows the SCBA output of the frequency strategy. The saved costs of traffic injuries are the largest share of benefits, and the costs of improving the infrastructure are the largest costs. When all the costs and benefits are added, there is a positive balance and a benefits/costs ratio larger than 1.

In the frequency strategy the benefits are mostly allocated to car drivers and cyclists who use the roads with the highest number of traffic crashes. In municipal areas these are the roads with a speed limit of 50 km/h (SWOV, 2022). The costs for improving the infrastructure are borne by the municipality of Amsterdam, and more specifically, the department of traffic safety. The costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road.

***Table 7.3** Balance SCBA Frequency strategy in the municipality of Amsterdam in the period 2022-2040*

| | Present value x 1,000,000 | | |
|---|---|---|---|
| | € | 12 | Saved costs of traffic deaths |
| | € | 337 | Saved costs of traffic injuries |
| | € | 65 | Saved costs of material damage |
| | € | (84) | Costs of improving the infrastructure |
| | € | (36) | Costs negative effects |
| **Balance of SCBA** | **€** | **294** | |
| **Benefits/costs ratio** | | **3.5** | |

### 7.3.2 Combining projects strategy

The combining projects strategy focuses on projects, such as road maintenance, greenery, replacing pipelines, et cetera, and tries to combine them with traffic safety projects. Table 7.4 shows the SCBA output of the combining projects strategy. The saved costs of traffic injuries are the largest share of benefits, and the costs of improving the infrastructure are the largest costs. When all the costs and benefits are added, there is a positive balance and a benefits/costs ratio larger than 1. It is expected that the real value of this strategy is higher than stated in table 7.4 because the synergy impact is not included in the balance and benefits/costs ratio.

In this strategy the benefits are partly allocated to the car drivers and cyclists who use the roads that are improved when executing this strategy, and partly allocated to the passers-by who enjoy, for example, the newly created greenery. The infrastructures that are improved will mainly be roads that are dangerous in terms of road safety and roads that are scheduled for maintenance work. The costs for improving the infrastructure and labor costs are borne by various departments of the municipality of Amsterdam. The costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road.

***Table 7.4*** *Balance SCBA Combining projects strategy in the municipality of Amsterdam in the period 2022-2040*

| | Present value x 1,000,000 | | |
|---|---|---|---|
| | € | 7 | Saved costs of traffic deaths |
| | € | 192 | Saved costs of traffic injuries |
| | € | 37 | Saved costs of material damage |
| | € | (42) | Costs of improving the infrastructure |
| | € | (13) | Labor costs |
| | € | (18) | Costs of negative effects |
| | + | | Synergy impact |
| **Balance of SCBA** | **€** | **163** | |
| **Benefits/costs ratio** | | **3.2** | |

### 7.3.3 Vulnerability Strategy

The vulnerability strategy focuses on the more vulnerable people that take part in traffic, and more specifically, children and cyclists. It improves the infrastructures that these road users us such as, school zones and bicycle paths. Table 7.5 shows the SCBA output of the vulnerability strategy. The saved costs of traffic injuries cyclists are the largest share of benefits, and the costs of widening bicycle paths are the largest costs. When all the costs and benefits are added, there is a positive balance and a benefits/costs ratio larger than 1.

In this strategy the benefits are allocated to two groups. The first group consists of all road users in school zones. These road users are mainly children, (grand)parents, and residents of the area. The second group concerns cyclists on bicycle paths. The benefits are allocated to these groups because the vulnerability strategy only improves school zones and bicycle paths. All costs are borne by the traffic safety department of the municipality of Amsterdam except for the costs of negative effects. The costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road.

*__Table 7.5__ Balance SCBA Vulnerability strategy in the municipality of Amsterdam in the period 2022-2040*

| | Present value x 1,000,000 | | |
|---|---|---|---|
| | € | 10 | Saved costs of traffic injuries school zone |
| | € | 10 | Saved costs of material damage school zone |
| | € | (23) | Costs of constructing school zone |
| | € | 8 | Saved costs of traffic deaths cyclists |
| | € | 470 | Saved costs of traffic injuries cyclists |
| | € | 9 | Saved costs of material damage cyclists |
| | € | (96) | Costs of widening bicycle paths |
| | € | (4) | Costs of applying edge and axle markings |
| | € | (2) | Costs of removing bicycle poles |
| | € | (2) | Labor costs |
| | € | (6) | Costs of negative effects |
| **Balance of SCBA** | **€** | **380** | |
| **Benefits/costs ratio** | | **3.8** | |

### 7.3.4 Subjective Road Safety Strategy

The subjective road safety strategy says that infrastructures should be improved where people feel unsafe instead of the roads that are objectively unsafe. Table 7.6 shows the SCBA output of the subjective road safety strategy. The saved costs of traffic injuries are the largest share of benefits, and the costs of improving the infrastructure are the largest costs. When all the costs and benefits are added, there is a positive balance and a benefits/costs ratio larger than 1. It is expected that the real value of this strategy is higher than stated in table 7.6 because the benefit of feeling safe is not included in the balance and benefits/costs ratio.

In this strategy the benefits are mostly allocated to the more vulnerable road users, such as cyclists and pedestrians. This strategy improves the infrastructures where people feel unsafe. Because it is expected that the more vulnerable road users feel unsafe more quickly, they also receive the largest share of benefits. All costs are borne by the traffic safety department of the municipality of Amsterdam except for the costs of negative effects. The costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road.

*__Table 7.6__ Balance SCBA Subjective road safety strategy in the municipality of Amsterdam in the period 2022-2040*

| | Present value x 1,000,000 | | |
|---|---|---|---|
| | € | 6 | Saved costs of traffic deaths |
| | € | 168 | Saved costs of traffic injuries |
| | € | 32 | Saved costs of material damage |
| | € | (84) | Costs of improving the infrastructure |
| | € | (6) | Labor costs |
| | € | (36) | Costs of negative effects |
| | + | | Benefit of feeling safe |
| **Balance of SCBA** | **€** | **115** | |
| **Benefits/costs ratio** | | **1.6** | |

### 7.3.5 Comparison of the Strategies

When looking at table 7.7, it stands out that all strategies have a positive balance. This means that the execution of all these strategies leads to more social benefits than costs. However, there are big differences between the strategies as well. The vulnerability strategy has the largest benefits of all strategies, but also the highest costs. This is because in Amsterdam the number of bicycle crashes is very high, so many safety benefits can be gained. The high costs are due to the construction costs of widening bicycle paths. The combining projects strategy has the lowest costs because this strategy entails that the construction costs are shared with other departments, such as road maintenance. The subjective road safety strategy has the smallest benefits compared to the other strategies. This can be explained by the fact that roads where people feel unsafe are not necessarily less safe (SWOV, 2012b). Consequently, not a lot of objective safety benefits can be gained by executing this strategy.

It is also striking that the frequency strategy and the combining projects strategy have nearly the same balance while the costs and benefits of both strategies are very different. The costs of the combining strategy are lower because all construction costs are shared with other departments (see above). The benefits of the frequency strategy are higher because it improves only the infrastructure of the roads with the highest number of injuries and fatalities. The combining projects strategy also improves less dangerous road infrastructures due to the participation of the other departments that have other interests.

In reality, the combining projects strategy and the subjective road safety strategy will be higher than stated in table 7.7. This is due to the non-monetary effects that are not considered in the SCBA numbers.

***Table 7.7*** *Overview SCBAs of all strategies when conducted in the municipality of Amsterdam in the period 2022-2040*

| **Strategy** | **Frequency strategy** | **Combining projects strategy** | **Vulnerability strategy** | **Subjective road safety strategy** |
|---|---|---|---|---|
| **Total benefits** (€) x 1,000,000 | 414 | 236 | 506 | 206 |
| **Total costs** (€) x 1,000,000 | (120) | (73) | (132) | (126) |
| **Balance of SCBA** (€) x 1,000,000 | 294 | 163 | 380 | 115 |
| **Benefits/costs ratio** | 3.5 | 3.2 | 3.8 | 1.6 |
| **Non-monetary effect** | n/a | + | n/a | + |

## 7.4 Sensitivity Analysis

In this paragraph the results of the sensitivity analysis are discussed. First, it is discussed what factors in the SCBA were used in the sensitivity analysis. Then, the most notable results are considered. After that, the results of the scenario sensitivity analysis are discussed, including the scenarios itself. The calculations of the sensitivity analysis can be found in the attached Excel file.

### 7.4.1 Factor Choice

To conduct a sensitivity analysis first a choice must be made regarding what factors to increase or decrease. In this study, these factors are chosen because they have the largest share of costs/benefits on the balance of the SCBA or because they have the highest uncertainty.

Therefore, the factors that were altered are costs of traffic injuries, expenses of traffic safety of the municipality of Amsterdam, costs of negative effects, costs of widening bicycle paths, and effects of removing bicycle poles. The costs of negative effects and the effects of removing bicycle poles have the highest uncertainty of all factors in the SCBAs because they are rough estimates and there is little literature to back them up. The remaining factors are chosen because they are a part of the factor that is responsible for the largest share of benefits or costs in the SCBAs. The fixed percentages that are used to vary the factors are based on the amount of uncertainty that the factors have. So, the ones with the largest impact on the balance of the SCBAs are varied by 20% and the ones with the highest uncertainty are varied by 40%.

### 7.4.2 Results Sensitivity Analysis

Tornado plots are used to illustrate the results of the sensitivity analysis, see figures 7.4-7.7. These plots show with what percentage the balance of the SCBA changes, compared to the base situation, when a factor is varied with a fixed percentage. For example, if the factor 'costs of negative effects' is increased by 40%, the balance of the SCBA decreases with 11%. If the factor is decreased by 40%, the balance increases with 13%, see figure 7.4. So, the change in the balance of the SCBA is smaller than the change made to the factor itself. The colors in the legend indicate the percentage by which the factors are changed.

Looking at the specific factors in the results in the tornado plots of figures 7.4-7.7, a few things stand out. First, the factor costs of traffic injuries is the most sensitive to changes in the sensitivity analysis of every strategy. This means that changes in this factor have the biggest impact on the balance of the SCBAs. This can be explained by the fact that this factor is responsible for the largest share of benefits. So, changing this factor has a large impact on the total benefits. Second, the factors that have the highest uncertainty, i.e., costs of negative effects and effects of removing bicycle poles, are varied with 40% but they produce a relatively small percentage of change in the balance of the SCBAs, see figures 7.4-7.7. For the costs of negative effects factor this is due to it being a factor that is used in the calculation of a relatively small part of the total costs in the SCBA. Therefore, a change in this factor does not impact the balance as much. For the effects of removing bicycle poles factor this is due to it being a small component in the calculations of large shares of benefits. Because the factor is only a small component, changes in this factor has little impact on the balance of the SCBA.

Then, there are some overall observations in the sensitivity analysis. First, altering the factors with a negative percentage has a bigger impact on the balance of the SCBAs than altering the factors with a positive percentage. This is because increasing the factor, increases the size of the costs or benefits and therewith, the impact on the balance of the SCBA increases, and vice versa. Second, all factors are relatively insensitive to changes. This means that the balance of the SCBA changes with a smaller percentage compared to the base situation than the percentage that the factor is changed with. This can be explained by taking a closer look at the calculations. These factors are not individually responsible for the outcome of specific costs and benefits. They are only a part of the calculations. Consequently, changing them will only slightly influence the balance of the SCBA. For a complete overview of the exact results of the sensitivity analysis, see appendix G.1-4.

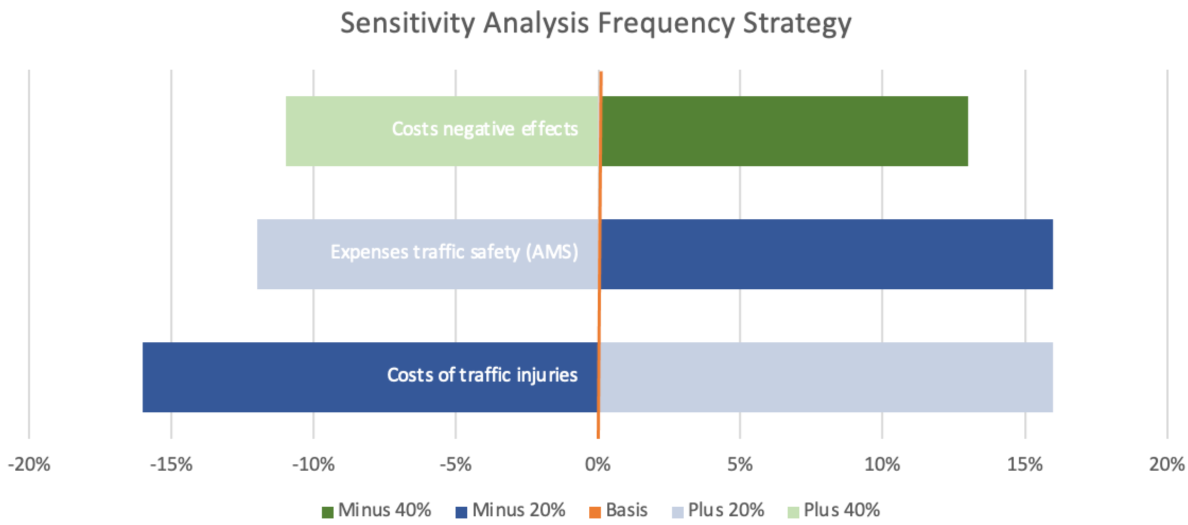



***Figure 7.4*** *Sensitivity analysis results frequency strategy tornado plot*

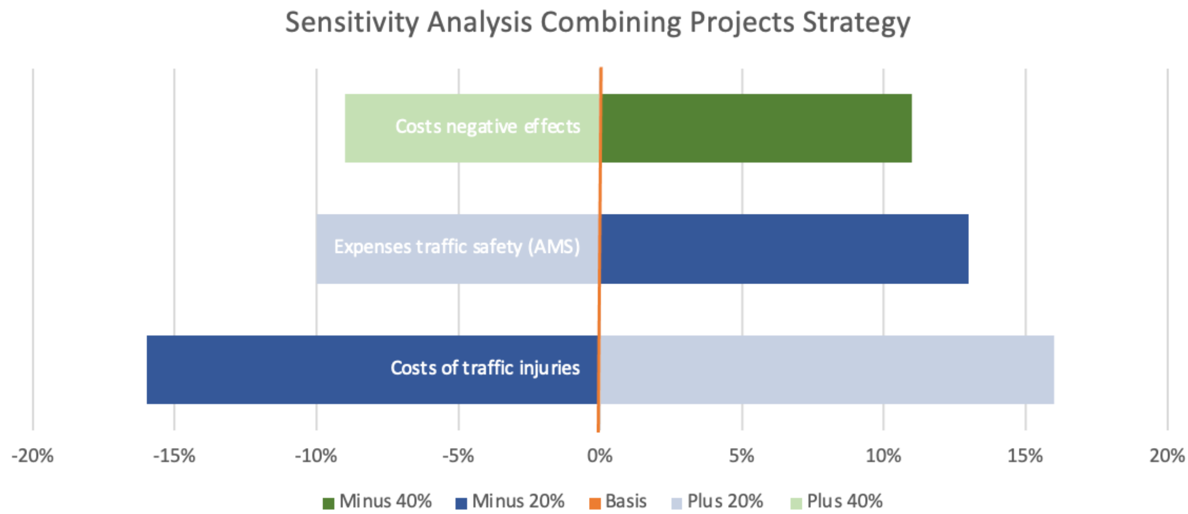



***Figure 7.5*** *Sensitivity analysis results combining projects strategy tornado plot*

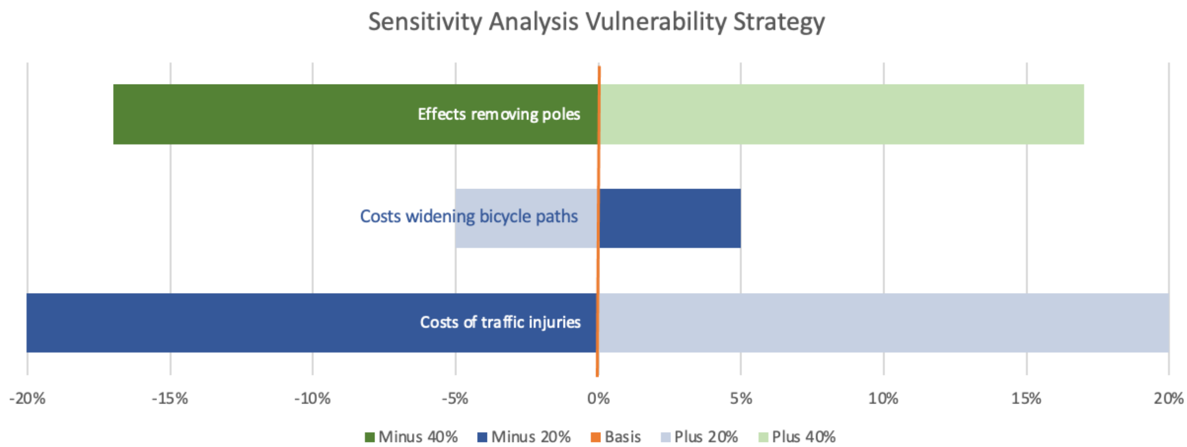



***Figure 7.6*** *Sensitivity analysis results vulnerability strategy tornado plot*

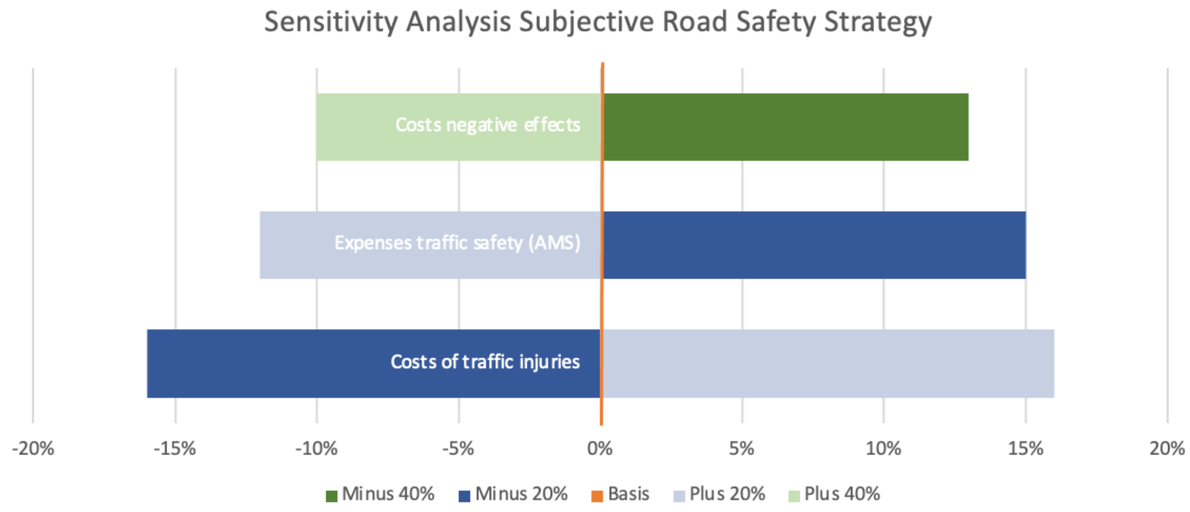



***Figure 7.7*** *Sensitivity analysis results subjective road safety strategy tornado plot*

### 7.4.3 Sensitivity Analysis Scenarios

In the previous paragraph the results of the sensitivity analysis are discussed if each factor is altered individually. In this paragraph, two scenarios are described, and the factors are altered simultaneously for each scenario. The factors in the scenario sensitivity analysis are varied with the same percentages as in the previous paragraph, see appendix G.5.

There are two scenarios for which a sensitivity analysis is conducted, a positive and a negative scenario. In the **positive scenario** the costs of traffic injuries turn out to be higher because the VSL is underestimated in the Netherlands. Consequently, the benefits of the SCBA are higher because more costs of traffic injuries can be saved. Also, the expenses of traffic safety of the municipality of Amsterdam are lower than expected. Due to small interventions that have major effects, costs can be saved. In this scenario, the costs of negative effects are also lower. The infrastructure that is improved is located in areas with a low population density. Consequently, there are fewer people experiencing negative effects of the construction. In addition, the costs of widening the bicycle paths are lower than expected. The bicycle paths that already have been widened where the ones that were the smallest and therefore, the remaining bicycle paths are relatively wider, and less widening is needed. This will decrease the costs. Lastly, in the positive scenario the effect of removing bicycle poles is larger than expected. Many tourists in Amsterdam ride a bike for the first time when they are visiting the city. Before this visit they had never encountered a bicycle pole before leading to many crashes with these poles. Consequently, removing the bicycle poles would have a positive impact on the traffic safety effect.

In the **negative scenario** the costs of traffic injuries turn out to be lower because the VSL is overestimated in the Netherlands. Consequently, the benefits of the SCBA are lower because less costs of traffic injuries can be saved. Also, the expenses of traffic safety of the municipality of Amsterdam are higher than expected. Due to all the large investments that have to be made to improve the traffic safety. In this scenario, the costs of negative effects are also higher. The infrastructure that is improved is located in areas with a high population density. Consequently, there are more people experiencing negative effects of the construction. In addition, the costs of widening the bicycle paths are higher than expected. There are many bicycle paths in the municipality of Amsterdam and due to the tight labor market, it is difficult to find workers that can widen all these paths. In order to get the needed labor force, the wages are increased which also causes the costs to increase. Lastly, in the negative scenario the effect of removing bicycle poles is smaller than expected. Most of the bicycle poles already have been removed.

The remaining bicycle poles stand on property boundaries of residential areas to prevent cars drivers from driving on roads that are not suited for cars. Since the bicycle poles are in residential areas where the speed is cycling speed is lower, removing the bicycle poles would have a smaller impact on the traffic safety.

### 7.4.4 Results Scenario Sensitivity Analysis

In this paragraph the results of the scenario sensitivity analysis are discussed. Figure 7.8 and table 7.8 give an overview of the results of the scenario sensitivity analysis for all four strategies. The exact results can be found in appendix G.6.

Looking at the results, the combining projects strategy is the most insensitive to changes made to the factors when looking at the results of the analysis. The net present value (NVP) of the SCBA in the scenarios differ the least from the base situation in the combining projects strategy. The vulnerability strategy is the most sensitive to changes made to the factors. The difference in sensitivity between the two strategies is considerable with 7% in the negative scenario and 9% in the positive scenario. This means that the combination of factors that were varied in the scenario analysis of the combining projects strategy have a bigger impact on the balance of the SCBA than the combination of factors that were varied in the scenario analysis of the vulnerability strategy. In other words, these combination of factors for this strategy is more sensitive to changes. What is also striking is that in the positive scenario the balances of the SCBAs are more sensitive to the changes in the factors than in the negative scenario. This is the due of the fact that in the base scenario all strategies have a positive balance. Consequently, in the positive scenario the benefits increase, and the costs decrease causing a bigger percentual change in the SCBA balance than in the negative scenario where the benefits decrease, and the costs increase. The last thing that stood out, is that all SCBAs for all strategies have a positive NVP in both the positive and the negative scenario. Which means that in every scenario for every strategy there are more benefits than costs. So, even if all factors mentioned in appendix G.5 are altered negatively with 20% or 40%, it would still be financially beneficial to execute these strategies.

***Table 7.8*** *Balance overview scenario sensitivity analysis*

| | **Balance of SCBA** (€) x 1,000,000 | | |
|---|---|---|---|
| | **Negative scenario** | **Base** | **Positive scenario** |
| **Frequency strategy** | 196 | 294 | 393 |
| **Combining projects strategy** | 109 | 163 | 217 |
| **Vulnerability strategy** | 213 | 380 | 571 |
| **Subjective road safety strategy** | 65 | 115 | 166 |

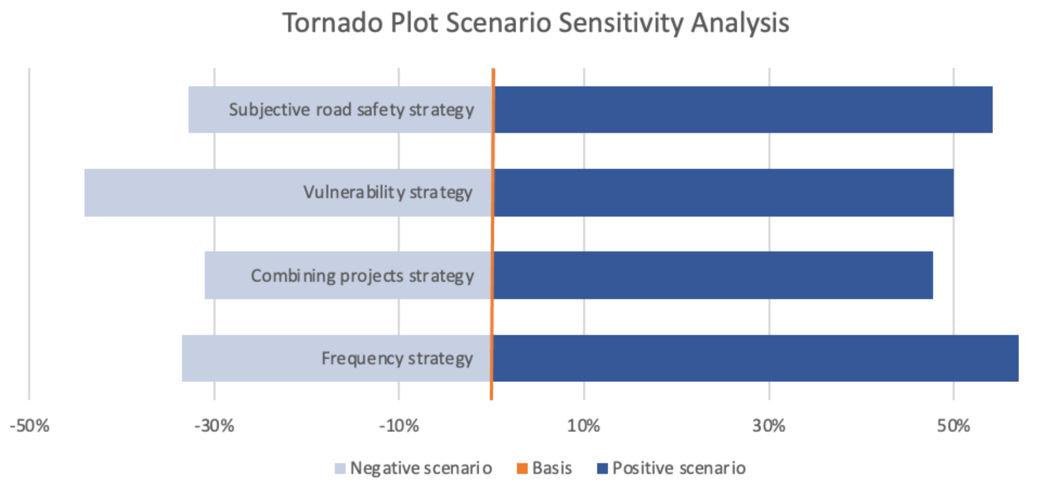



***Figure 7.8*** *Tornado plot of the results of the scenario sensitivity analysis for all four strategies*

## 7.5 Conclusion

The outcome of the SCBA showed that all four strategies have a positive balance. This means that the execution of all these strategies leads to more social benefits than costs. However, every strategy has different implications for who will bear those costs and benefits. In general it can be said that most of the benefits are allocated to the people who use the improved road infrastructures. The costs for improving the infrastructure are borne by the traffic safety department of the municipality of Amsterdam and sometimes other departments as well. The costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road. The sensitivity analysis showed that all included factors are relatively unsensitive to changes.

# 8 A Revised Look on Traffic Safety Strategies of G4 Municipalities

In the previous chapters the infrastructure improvement strategies of the G4 municipalities were identified and compared using SCBAs. During the execution of the research different insights were gathered about the decision-making process of the G4 municipalities. In this chapter policy recommendations are given based on these insights and a conversation with an expert in the field of traffic safety and municipal decision-making processes.

## 8.1 Goals of Policy Recommendations

The goal of the policy recommendations is to increase the traffic safety in the G4 municipalities. In the Netherlands, the SPV was drawn up based on EU road safety guidelines. The G4 municipalities have based their road safety strategies on the SPV. This research shows that the main strategy of the municipalities can be defined by four sub strategies: the frequency strategy, the combining projects strategy, the vulnerability strategy, and the subjective road safety strategy. They are used to increase traffic safety. The policy recommendations discuss how the road safety in the G4 municipalities can be increased by giving advice on how to make decisions about the road safety (sub) strategies.

## 8.2 Expert Consultation

In this section the expert consultation is discussed. First, it is explained who was chosen to be the expert in this study and why. After that, the results of the conversation with this expert are discussed.

### 8.2.1 Expert Choice

The expert that is consulted is Eric de Kievit from CROW. CROW is one of the parties that ensures that infrastructure, public space, and traffic and transport are properly organized in the Netherlands (CROW, n.d.). De Kievit is the Program Manager of the Knowledge Network SPV at CROW. This Knowledge Network supports road authorities, including municipalities, in making the SPV road safety policy process knowledgeable. Before he started his current position at CROW, de Kievit worked at the municipality of Amsterdam for 6 years. He worked on the risk-driven approach to increase road safety. So, de Kievit has worked the largest part of his working life in the field of road safety. That, in combination with the experience he gained at the municipality of Amsterdam, make him a good and knowledgeable expert. Because knowledge about both traffic safety and the decision-making processes of large municipalities are needed to give valuable advice on what are useful and realistic policy recommendations, and what are not.

### 8.2.2 Expert Opinion

Various things were discussed during the conversation with de Kievit about the policy recommendations. The statements that are most useful for this study are discussed in this section. First, de Kievit stated that choices that municipalities make are often made on irrational grounds e.g., the interests of an elderman, baseless assumptions, and decision-making authority based on reputation. That is not always a problem because irrational, or subjective, reasons are a significant part of the political decision-making processes of municipalities. However, there are several arguments for choosing a strategy or not, and in the decision-making process all sides need to be highlighted, not just the irrational ones. For example, the cost effectivity should also have a place in the decision-making process. This is currently only rarely the case. After that, he stated that including SCBAs in the road safety strategy decision-making process could be a good way to ensure that the objective side is included as well. "*Often goals are set by municipalities through risk analysis, but without keeping track of the costs and benefits it cannot be determined afterwards whether the goal was achieved or not*." Furthermore, de Kievit stated that evaluation and monitoring of projects and measures are essential to make good decisions about what strategies to use.

According to de Kievit there are two types of SCBAs: ex post and ex ante. When conducting an ex post SCBA it is calculated afterwards whether the project or measure was worthwhile. When conducting an ex ante SCBA it is calculated in advance whether it is expected if the project or measure will be worthwhile. Both should be used in the decision-making processes of municipalities. An ex ante SCBA should be used to determine if a project is going to be carried out or not, and an ex post SCBA should be used to determine afterwards if the set goals were met. Lastly, de Kievit noticed that municipalities often use the excuse that their budget is not sufficient to do certain projects or to conduct certain strategies. He thinks this is not a correct way to deal with it. "*Municipalities should start with stating their ambitions and then see what is possible within those ambitions, not the other way around*." A spending or implementation program is needed to do this.

## 8.3 Policy Recommendations

The results of the interviews and the SCBAs, and the expert consultation led to two policy recommendations. These recommendations are addressed to the G4 municipalities. In the next sections they are explained.

### 8.3.1 Gain Insight on the Strategies and Consider Them

From the results of this study, several insights can be gained. Every sub strategy has its own advantages and actor groups that benefit more than others. The frequency strategy intervenes in the roads that have the highest number of traffic fatalities and injuries. Consequently, it has the largest positive traffic safety effect. The combining projects strategy is a relatively cheap way to improve the road infrastructure because the costs are divided among different departments of the G4 municipalities. The vulnerability strategy focuses on increasing the traffic safety for vulnerable road users, and more specifically, cyclists and children. This can be considered an advantage because many people prioritize the safety of these road users because they are the weak link in many road crashes (Constant & Lagarde, 2010). And lastly, the subjective road safety strategy makes citizens feel safer when participating in traffic and it makes them feel like their complaints are being listened to. So, overall, this strategy increases the satisfaction of the citizens. All these insights on the four sub strategies lead to the first policy recommendation: The G4 municipalities should gather insights on the effects of the infrastructure improvement strategies they use to increase traffic safety and consider them when making decisions. They should ask themselves questions like: What are the total social costs and benefits of this strategy? Should we increase or decrease the ratio in which we use this strategy, or should it stay the same? What actor groups benefit the most or the least from this strategy and are we ok with that? Based on these insights they can make an argued choice about which strategies to use and in what ratio.

### 8.3.2 Use SCBAs in the Decision-Making Process

Part of the first policy recommendation is keeping track of the effects of the strategies, and therefore of the projects. In order to do this, municipalities must keep track of the social costs and benefits of their strategies and projects. This brings us to the second policy recommendation. The second policy recommendation is about using SCBAs in the traffic safety decision-making process. During the interviews the G4 municipalities stated that SCBAs, or other methods for expressing projects and strategies in monetary units, are rarely used. The consulted expert, Eric de Kievit, also confirmed this image. It is a missed opportunity as SCBAs can add a lot to the decision-making process. A study of Mouter, Annema, & van Wee (2012) stated multiple benefits of using SCBAs in a decision-making process, even if the direct outcome of the SCBA is not adopted. "*First, when using a SCBA, it is possible to better reflect on the usefulness, necessity, and design of a project. Second, SCBA ensures better discussions, decision-making, and decisions about usefulness, necessity, and design of a project. Third, SCBA provides objective and independent information. And lastly, SCBA provides insight on the order of magnitude of welfare effects and the ratio between costs and benefits*."

Considering all these benefits, it is advised to the G4 municipalities that they make more use of SCBAs to improve their traffic safety decision-making process. Using SCBAs will allow the municipalities to better compare different strategies with each other, and therefore, they will be able to make more effective and cost-efficient main strategies. A good time to include the use of SCBAs in the decision-making process could be during the traffic safety budget and program discussions of the coalition and the city council. These are the moments where the biggest decisions about the infrastructure improvement strategies to increase traffic safety are made.

## 8.4 Conclusion

In this chapter policy recommendations were formulated based on the insights that were gathered during the execution of the research and the opinion of a traffic safety and municipal decision-making expert, Eric de Kievit. The first policy recommendations reads as follows: The G4 municipalities should gather insights on the effects of the infrastructure improvement strategies they use to increase traffic safety and consider them when making decisions. The second policy recommendation follows from the first one: G4 municipalities should make more use of SCBAs to improve their traffic safety decision-making process. A good time to include the use of SCBAs in the decision-making process could be during the traffic safety budget and program discussions of the coalition and the city council.

# 9 Conclusion, Discussion, and Recommendations

The overall conclusion of this study is discussed in section 9.1. A discussion of this research and the resulting limitations are provided in section 9.2. Lastly, the recommendations for future research are discussed in 9.3.

## 9.1 Conclusion

Many lives are lost in traffic every day. For young adults, traffic crashes are the primary cause of death worldwide (AD, 2018). In an effort to change this, the EU set a target to reduce road traffic deaths and injuries with 50% by 2030 compared to 2021, and to reach zero fatalities by 2050, as stated by the European Commission (2019). This is known as the 'Vision Zero'. Despite a good start, the decline in the number of road deaths and injuries has leveled off in recent years (European Commission, 2019). Based on the EU 'Vision Zero', the Netherlands has drawn up the Strategic Road Safety Plan (SPV) (Ministerie van Infrastructuur en Waterstaat, 2018). The targets in this strategic plan are to reach zero road casualties in the long run (SWOV, n.d.-a). Similar to the EU figures, there has been no downward trend in the number of road deaths and injuries in the Netherlands over the past 10 years (SWOV, 2021a). So, more knowledge about traffic safety was needed to get back on track and meet the set targets.

In the current scientific literature, there were many papers on how to increase traffic safety. What many of these studies in the research field of traffic safety had in common was that they focus on a specific project or intervention. This study distinguished itself by researching multiple projects together which are part of a specific road safety strategy. Strategies are a long-range plan for achieving something or reaching a goal (Cambridge Dictionary, 2022b). In this study, this plan is a combination of projects that are selected based on a vision So, specific safety projects within a strategy together aim to achieve the higher 'vision' and, thus, a strategy gives direction to selecting specific safety projects. In other words, a strategy is more than the sum of individual projects. This is due to possible synergy effects. Synergy can be defined as: "*The combined power of a group of things when they are working together that is greater than the total power achieved by each working separately.*" With this focus on strategies instead of individual projects, this study aims to offer insights into which policy safety vision can decrease traffic deaths and injuries against what social costs. Furthermore, in the field of road safety SCBA was often used to compare various individual projects or interventions on social costs and benefits (Wijnen, Wesemann, & de Blaeij, 2009). However, in this research the method was used to compare the effects of multiple projects simultaneously, again, so called strategies. This was more complex than conducting an SCBA for individual projects, but this new research angel made it possible to compare different strategies based on social costs and benefits and this could not be found in the literature before. It is important to gain insights on the social costs and benefits of these strategies because road authorities can then make more argued decisions about their traffic safety approach. Even if the direct outcomes of the SCBAs in this study are not adopted directly, it can still be a useful tool during the decision-making process. For example, it provides more objective information, and it ensures better discussions (Mouter, Annema, & van Wee, 2012).

This study focused on road safety strategies that intervene in the infrastructure to increase traffic safety. The geographical scope of this research concerned the G4 municipalities (Amsterdam, Rotterdam, The Hague, and Utrecht). Considering the above, the main research question of this study is:

*What are infrastructure improvement strategies used by G4 municipalities to increase traffic safety and how do the societal costs and benefits of these strategies relate?*

The main research question is answered by means of five sub questions. Each of these will be answered separately.

1. *What is already known about infrastructure improvement strategies that are used by Dutch government authorities to increase traffic safety?*

This first sub research question was answered in chapter 4. In the Netherlands, the SPV was created as a response to the 'Vision Zero' of the EU (Ministerie van Infrastructuur en Waterstaat, 2018). In the SPV, various strategies are discussed that government authorities (provinces, municipalities, et cetera) should use to increase traffic safety. Four strategies concern the improvement of infrastructures to increase road safety:

1. the risk-driven strategy,
2. the heterogeneity strategy,
3. the vulnerable road users strategy, and
4. the speed in traffic strategy

The risk-driven strategy aims to increase traffic safety by identifying the risk factors in an infrastructure, prioritize these risks, translating these risks into concrete measures, and executing these measures (Ministerie van Infrastructuur en Waterstaat, 2018). The heterogeneity strategy aims to increase traffic safety by separating transport modes with a different speed, mass, and size. In addition, it gives extra space on the road to vulnerable road users (Ministerie van Infrastructuur en Waterstaat, 2018). The vulnerable road users strategy aims to increase traffic safety by considering the characteristics of vulnerable road users in the design of infrastructures. In the SPV vulnerable road users are defined as: task incompetence (people with medical conditions) or brittleness (frail elderly and children) (Ministerie van Infrastructuur en Waterstaat, 2018). The speed in traffic strategy aims to increase traffic safety by redesigning road infrastructures so that the road network is in line with the speed limit, and that the speed limit is credible (Ministerie van Infrastructuur en Waterstaat, 2018). The G4 municipalities translated the SPV into their own implementation programs. The infrastructure improvement strategies that are discussed in these implementation programs are very similar to those discussed in the literature.

The overview of these strategies that are mentioned in the literature are relevant for this study because they serve as a starting point for the identification of the strategies later on in the research.

2. *What G4 municipal infrastructure improvement strategies to increase traffic safety can be distinguished?*

This second sub research question was answered in chapter 5. In addition, the strategies are characterized to give a better understanding of what each strategy entails. In this chapter the interviews showed that there are four infrastructure improvement strategies that are used by the G4 municipalities:

1. the frequency strategy,
2. the combining projects strategy,
3. subjective road safety strategy, and
4. the vulnerability strategy

These strategies do not fully correspond with the strategies discussed in the literature. This confirms the expectation that research into infrastructure improvement strategies is not yet saturated. The G4 municipalities use infrastructure improvement strategies to determine their decisions about which infrastructures to improve, and in which order, with the aim to increase traffic safety.

The frequency strategy aims to increase traffic safety by improving the road infrastructure segments with the highest absolute number of road casualties. Part of this strategy is the hot/black spot approach. The combining projects strategy aims to increase traffic safety by combing road safety projects with other projects such as, maintenance and greenery. The subjective road safety strategy aims to increase traffic safety by improving the road infrastructures where citizens feel the most unsafe. The vulnerability strategy aims to increase traffic safety by improving the road infrastructures where vulnerable road users make use of such as, school zones and bicycle paths.

Furthermore, the interviews led to the insight that using a certain strategy leads to the implementation of specific road infrastructure measures. These measures can (partly) overlap with measures of other strategies. Each road infrastructure measure has an impact on society that can be translated into social costs and social benefits. The size of these costs and benefits differ per measure and therefore per strategy. This insight is captured in figure 9.1.

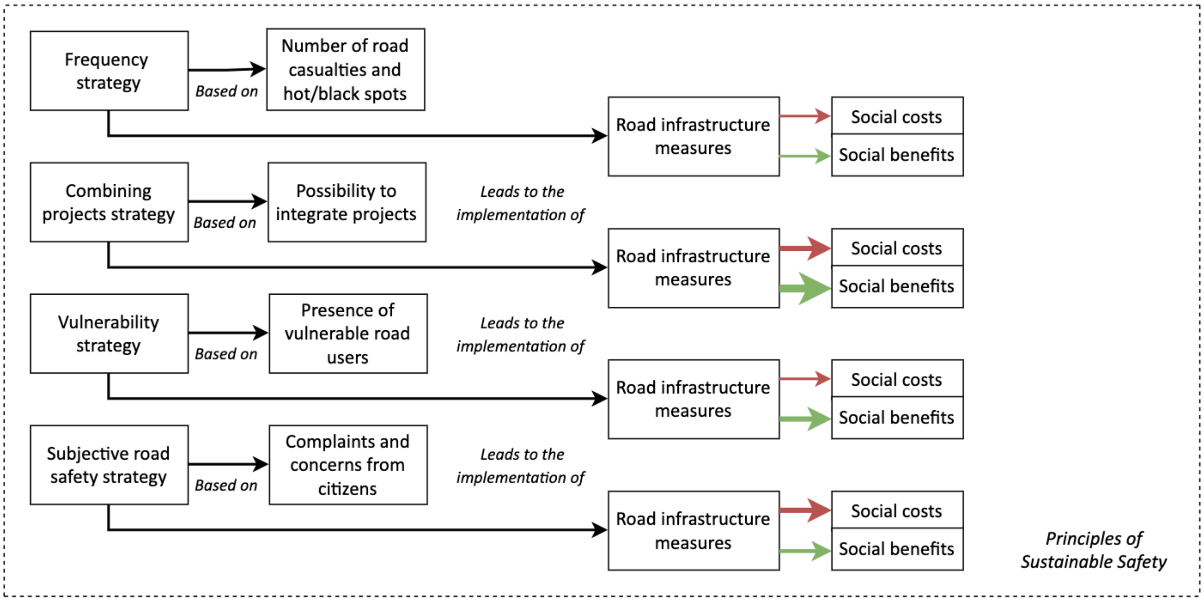



***Figure 9.1*** *Municipal road safety strategies based on the interviews*

Each of the sub strategies that were identified are to a more or lesser extent proactive or reactive. A proactive policy is designed to prevent problems or emergencies, in this case traffic crashes, from occurring (United Nations, 2016). A reactive policy acts in response to a certain situation that already has occurred, instead of preventing it (National Geographic Society, 2019). The main strategy of the G4 municipalities consists of all four sub strategies combined in a certain ratio. Depending on the ratio in which the strategies are used, the main strategies becomes more or less proactive. From the interviews it was derived to what extent every strategy is reactive or proactive, see figure 9.2.

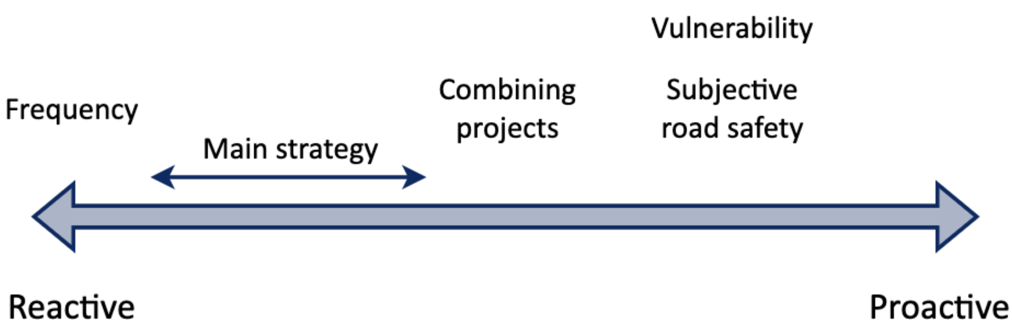



***Figure 9.2*** *The sub and main strategies of the G4 municipalities placed on the reactive-proactive spectrum*

The interviews showed that the G4 municipalities were not aware that the infrastructure improvement safety strategy that they use, can be divided into four sub strategies and that these strategies all have different implications. Since all G4 municipalities indicated that in the long run they want to move towards a more proactive infrastructure improvement strategy, these insights can help them decide what strategies to use.

3. *How is the decision-making process of the G4 municipalities structured when it comes to making decisions about what infrastructures to improve to increase traffic safety?*

The third research question was answered in chapter 6. In this chapter the decision-making process of the G4 municipalities was mapped out to see when the road safety strategies were chosen and what impact this has on the remainder of the process. The interviews led to the insight that the decision-making process can be divided into a high-level and a low-level decision-making process. The high-level decision-making process addresses all the steps from setting the budget and the traffic safety program, the execution of the projects, and the process of requesting extra budget needed to complete the chosen road infrastructure measures. The low-level decision-making process consists of all steps that are needed to execute a project: from the decision about what infrastructures to improve, to the conversations with stakeholders, and the project being carried out.

Early on in the high-level decision-making process of the G4 municipalities the decision is made what strategies to use during the entire term of office of 4 years. This has implications for the remainder of the decision-making process because it limits the possibilities of decisions that are made later in the process, due to path dependency and the lock-in effect. This affects for example the decision that is made in het low-level decision-making process about what infrastructures to improve to increase traffic safety. This could be considered undesirable because it means that the municipalities cannot always take the decisions they want, and they think are desirable in the moment. However, it does create a certain predictability and transparency that is also desirable in municipal decision-making processes. After all, it is good for citizens to know which policies are being implemented without these being changed often.

In addition, the interviews showed that there are various complicating factors that make it more difficult for the G4 municipalities to stick to their road safety strategy and execute the corresponding road infrastructure measures. These complicating factors are: a limited budget, political considerations, project execution time slots, multi-actor decision-making, and administrative capacity.

4. *What are the costs and benefits for the society of each of the G4 municipal infrastructure improvement strategies to increase traffic safety?*

The fourth research question was answered in chapter 7. In this chapter an SCBA is conducted to be able to compare the four infrastructure improvement strategies of the G4 municipalities. The outcome of the SCBA showed that all four strategies have a positive balance, see table 9.1. This means that the execution of all four strategies leads to more social benefits than costs. However, every strategy has different implications for who will bear those costs and benefits, also see table 9.1.

In the frequency strategy the benefits are mostly allocated to car drivers and cyclists who use the roads with the highest absolute number of traffic crashes. In municipal areas these are the roads with a speed limit of 50 km/h. In the combining projects strategy the benefits are partly allocated to the car drivers and cyclists who use the roads that are improved when executing this strategy, and partly allocated to the passers-by who enjoy, for example, the newly created greenery. The infrastructures that are improved will mainly be roads that are dangerous in terms of road safety and roads that are scheduled for maintenance work. In the vulnerability strategy the benefits are allocated to two groups. The first group consists of all road users in school zones.

These road users are mainly children, (grand)parents, and residents of the area. The second group concerns cyclists on bicycle paths. The benefits are allocated to these groups because the vulnerability strategy only improves school zones and bicycle paths. In the subjective road safety strategy the benefits are mostly allocated to the more vulnerable road users, such as cyclists and pedestrians. This strategy improves the infrastructures where people feel unsafe. Because it is expected that the more vulnerable road users feel unsafe more quickly, they also receive the largest share of benefits. In every strategy the costs for improving the infrastructure are at least partly borne by the municipality of Amsterdam, and more specifically, the department of traffic safety. In addition, the costs of negative effects are borne by the residents and road users who are affected by the infrastructure improvement projects because they experience noise nuisance, or they have to make a detour due to a broken-up road.

So, the allocation of costs is very similar for every strategy. However, who will bear the benefits varies greatly. If the goal of the G4 municipalities is to increase road safety on the locations with the lowest traffic safety, the frequency strategy would be fitting. If the goal is to execute road safety projects efficiently, the combining projects strategy would be fitting. If the goal is to protect vulnerable road users, the vulnerability strategy would be fitting. And lastly, if the goal is to make citizens feel safe and heard, the subjective road safety strategy would be fitting. In other words, depending on the goal(s) that the municipalities set themselves, increasing the use of one or more of these strategies is preferred.

***Table 9.1*** *Overview SCBAs of all strategies when conducted in the municipality of Amsterdam between 2022-2040 and the allocation of costs and benefits*

| **Strategy** | **Frequency strategy** | **Combining projects strategy** | **Vulnerability strategy** | **Subjective road safety strategy** |
|---|---|---|---|---|
| **Balance of SCBA** (€) x 1.000.000 | 294 | 163 | 380 | 115 |
| **Benefits/costs ratio** | 3.5 | 3.2 | 3.8 | 1.6 |
| **Non-monetary effect** | n/a | + | n/a | + |
| **Benefits allocation** | Car drivers and cyclists on risky roads | Car drivers and cyclists on improved roads and passers-by | Road users in school zones and cyclists on bicycle paths | Cyclists and pedestrians |
| **Costs allocation** | Municipality of Amsterdam, residents experiencing noise nuisance, and road users that have to make a detour | | | |

There is also a difference in the simplicity with which the strategies can be implemented. As discussed in section 6.3, there are various complicating factors that make the implementation of the strategies challenging. In table 9.2 it is shown per strategy to what extent every complicating factor is applicable. The combining projects strategy is the most challenging strategy to implement. Finding project execution time slots is difficult since combined projects are often large projects that cause many disruptions during the execution for road users. In addition, there are many parties involved in the decision-making process that have different interests. Consequently, reaching a consensus can take a lot of time. And lastly, extra administrative capacity is needed to steer these large projects in the right direction. The vulnerability strategy is the easiest strategy to implement. A limited budget and political considerations are the only complicating factors that play a significant role.

The SCBA was only conducted for the municipality of Amsterdam. However, it expected that the other G4 municipalities would have similar results. Consequently, the results of the SCBAs of the municipality of Amsterdam are expected to be generalizable to the municipalities of Rotterdam, The Hague, and Utrecht.

*Table 9.2* *Overview complicating factors per road infrastructure improvement strategy*

| **Strategy →**<br>**Complicating factor ↓** | **Frequency strategy** | **Combining projects strategy** | **Vulnerability strategy** | **Subjective road safety strategy** |
|---|---|---|---|---|
| Limited budget | | | | |
| Political considerations | | | | |
| Project execution time slots | | | | |
| Multi-actor decision-making | | | | |
| Administrative capacity | | | | |

Not applicable ←→ Most applicable

5. *What would be advised to the G4 municipalities regarding their infrastructure improvement strategies and their traffic safety decision-making processes?*

The fifth research question was answered in chapter 8. The results of the interviews and the SCBAs led to two policy recommendations addressed to the G4 municipalities. The first policy recommendation is about gaining insights on the effects of the infrastructure improvement strategies to increase traffic safety. In the interviews it turned out that the G4 municipalities are currently not aware that they use various strategies that can be identified individually. In addition, they do not have a clear overview of the effects of each. In order to make argued choices about what strategies to use and to what extent, it is necessary to understand the pros and cons, as well as the costs and benefits of every strategy. Therefore, the first policy recommendation is: Keep track of the effects of each strategy, compare them, and use these insights to make argued traffic safety decisions.

The second policy recommendation is about using SCBAs in the traffic safety decision-making process. During the interviews the G4 municipalities stated that SCBAs, or other methods for expressing projects and strategies in monetary units, are rarely used. This is a missed opportunity as SCBAs can add a lot to the decision-making process. A study of Mouter, Annema, & van Wee (2012) stated multiple benefits of using SCBAs in a decision-making process, even if the direct outcome of the SCBA is not adopted. "*First, when using a SCBA, it is possible to better reflect on the usefulness, necessity, and design of a project. Second, SCBA ensures better discussions, decision-making, and decisions about usefulness, necessity, and design of a project. Third, SCBA provides objective and independent information. And lastly, SCBA provides insight on the order of magnitude of welfare effects and the ratio between costs and benefits*." Considering all these benefits, it is advised to the G4 municipalities that they make more use of SCBAs to improve their traffic safety decision-making process. A good time to include the use of SCBAs in the decision-making process could be during the traffic safety budget and program discussions of the coalition and the city council. These are the moments where the biggest decisions about the infrastructure improvement strategies to increase traffic safety are made.

## 9.2 Discussion and Limitations of this Study

In this section, the four main limitations resulting from the selected scope and research methods are discussed.

### 9.2.1 Uncertainty of the SCBAs

The SCBAs that were conducted during this study have some uncertainty due to multiple factors. First, some assumptions were made regarding the road safety numbers. There were no road safety forecasts specifically for the municipality of Amsterdam but there were forecast for the Netherlands as a whole. Therefore, the assumption was made that the road safety numbers in Amsterdam would progress the same as was forecasted for the Netherlands.

Second, not all effects of the road safety measures that are used in the strategies have been studied before. So, estimations were made in the SCBA e.g., the negative effects of each strategy and the effect of removing bicycle poles from bicycle paths. Thirdly, there were some factors that could not be monetized: the synergy impact of the combining projects strategy, and the benefit of feeling safe. Therefore, these factors were included as a plus in the SCBA overview. However, these factors are not included in the balance of the SCBA. All these factors increase the uncertainty of the SCBA. Lastly, the synergy effects that can occur were not considered in the SCBA of this study. Consequently, some of the social costs and benefits can be over- or underestimated.

### 9.2.2 Interview Bias

Due to time constraints of the research and the availability of employees, only 2 employees, and in one case only 1 employee, of each of the G4 municipalities were interviewed. The biases of these employees can influence the results of the interviews. If only 1 or 2 employees are interviewed per municipality, the chances that a dissenting opinion ends up in the results is greater than if you speak to more employees. Because with a larger group of interviewees, the outliers are easier to detect and can, if needed, be removed from the results. This will decrease the biases in the results. However, in this study the interviews with the employees of the same municipality were separated. The goal of this was to extract the real opinions and experiences of the interviewee without the influence of a colleague. Afterwards, the statements of the two employees of the same municipality were compared to see if they agreed on most things. So, with this approach it was attempted to limit the uncertainty in the study due to a small group of interviewees.

### 9.2.3 Focus on G4 Municipalities and the Generalizability

In this research the focus was on the G4 municipalities because these municipalities have the largest number of road crashes compared with other Dutch municipalities. Consequently, the largest share of traffic safety benefits can be gained in these municipalities. But are the results of this study that is focused on the G4 municipalities also generalizable to other smaller municipalities in the Netherlands, and to what extent? It is expected that the smaller the municipality, the less the results of this study can be generalized to that municipality. Larger municipalities often face the same road safety problems and have similar infrastructures. Moreover, the somewhat larger municipalities are similar to the G4 municipalities with regard to the road safety decision-making process and the available budget. The somewhat smaller municipalities differ a lot from the G4 municipalities in this area, and therefore, the current research is less generalizable.

### 9.2.4 Focus on Road Infrastructure Measures

This study focused on road safety strategies that led to the implementation of road infrastructure measures. By only focusing on the infrastructure part of traffic safety, reality is simplified. As stated by Treat (1977), human and vehicle factors are also contributing factors to road crashes. Consequently, strategies can be executed, and measures can be taken to decrease the number of road crashes that are caused by one of these factors. Due to scoping decisions, this is currently not considered in the research.

## 9.3 Recommendations for Future Research

In this section, the recommendations for future research are discussed. They are aimed to either improve the reliability of this study or to extend this study.

First, it is recommended to conduct studies on the most uncertain factors that are used in the SCBA. As mentioned in section 9.2.1 there are some factors that bring uncertainty to the SCBAs in this study. First, the assumption that the road safety forecast of the Netherlands is generalizable to the municipality of Amsterdam. Second, the estimation of some of the effects of road safety measures.

And third, the non-monetizability of some of the factors. When these factors are researched instead of roughly estimated or assumed, the reliability of the SCBAs would increase.

Second, it is recommended to redo the study with a larger number of interviewees per municipality. This can rule out the possible bias that might be present in the current data and gives a more complete view on the infrastructure improvement strategies of each of the G4 municipalities.

Third, it is recommended to conduct this research on the infrastructure improvement strategies to increase traffic safety focused on smaller municipalities. As mentioned in 9.2.3 it is expected that the results from the current research are not generalizable or to a small extent to smaller municipalities. So, conducting a study focused on smaller municipalities would lead to new insights that can be useful during the road safety decision-making process of these municipalities as well.

Fourth, it is recommended to investigate what must be changed in the data collection of the G4 municipalities to successfully conduct a data-driven strategy. During the interviews the G4 municipalities stated that they want to conduct a more proactive main strategy by increasing the use of the data-driven strategy. However, this is not yet possible due to a lack of (reliable) data. Conducting research on how to get the appropriate data would be the first step in the process of putting the data-driven strategy in practice.

Fifth, it is recommended to extend the current research by including synergy effects in the SCBA. As mentioned in section 1.3, this research takes the first steps in including synergy effects by conducting a strategies approach instead of an individual projects approach. However, given the time constraints it was not feasible to also include the synergy effects in the SCBA. The next step in the process of including synergy effects in the research on road infrastructure improvement strategies, would be including them in the SCBA. This will give a more accurate view on the social costs and benefits.

Sixth, it is recommended to conduct research on municipal strategies on human and vehicle factors that contribute to road crashes. This study focused on the environmental and infrastructure factor of traffic safety, but other factors have an influence on traffic safety as well. Municipalities also have strategies to improve road safety concerning these factors. Identifying and comparing these strategies could lead to new insights and therefore improve traffic safety.

Seventh, it is recommended to study the ratios in which the infrastructure improvement strategies are currently used by the G4 municipalities. From the interview it was derived that the municipalities use all four identified strategies in a certain ratio, and this can be defined as the main strategy. However, the current study could not identify the ratio in which each of strategies is used nowadays. Researching these ratios, in combination with the costs and benefits that are given in this study, will give more insights on the current cost effectiveness of the main strategy that the G4 municipalities conduct.

Finally, it is recommended to conduct studies on the effects of the individual projects that are executed within the strategies. As mentioned before, it is valuable and innovative to look at strategies instead of individual projects when conducting research on road safety using SCBA. However, when we investigate the distribution of the costs and benefits over various actor groups, it might be necessary to research the individual projects as well. Some of the individual projects that are included in the strategy might not contribute to the goal that is set by that strategy. To find out whether this is the case, the effects of each individual project on social costs and benefits and the distribution over actor groups must be researched.

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# Appendix A: Background & Traffic Safety Definition

## A.1 Traffic Safety Situation in the Netherlands

### A.1.1 Traffic Safety Definition

To describe the current situation in the Netherlands when it comes to traffic safety, we first need to define what traffic safety is. In this research, traffic safety refers to road traffic safety. According to Botha (2005, p. 515), road traffic safety is: "*A measure of the number of road traffic crashes and casualties resulting from crashes per time period*". The number of crashes and casualties can be expressed in rates, such as the number of crashes per 100,000 citizens or fatalities per travelled kilometers (Botha, 2005). In this chapter the numbers of fatalities and casualties are given as a percentage of the total number of fatalities and casualties.

### A.1.2 Traffic Fatalities

Traffic fatalities are defined as road users who die because of a sudden occurrence on a public road related to traffic, involving at least one moving vehicle. When death occurs more than 30 days after the crash, it is no longer considered a road death (CBS, 2020b). Since 1996 the Dutch Central Bureau for Statistics (CBS) and the Ministry of Infrastructure and Water Management together determine the number of road deaths. Data from three different sources is used (SWOV, 2022):

1. Details of cause of death forms completed by a doctor.
2. The files of the district public prosecutor's offices on unnatural causes of death.
3. The (provisional) File Registered Accidents in the Netherlands (BRON), which is based on the crash reports drawn up by the police.

The number of road deaths in these sources can overlap, see figure A.1. Combing the information of all three sources gives the final number of road deaths in the Netherlands.

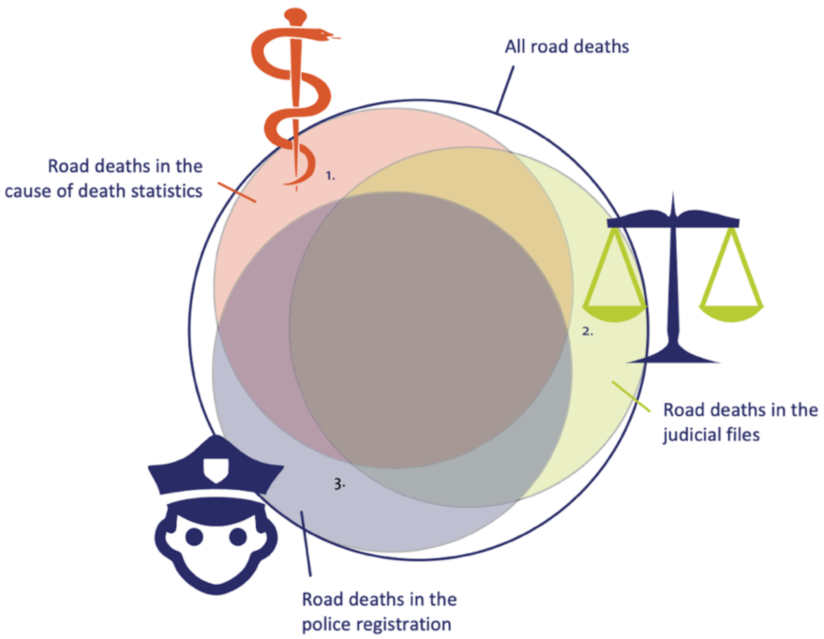


***Figure A.1*** *Sources to determine the number of Dutch road deaths (SWOV, 2022)*

Most of fatal traffic crashes happen on 50 and 80 km/h roads (SWOV, 202). Of the 610 road deaths in 2020, 23% of the total number of fatal traffic crashes occurred on these roads (CBS, 2021; SWOV, 2022). Roads with a speed limit of 70, 120, or 130 km/h have relatively the smallest number of road deaths with 1% or 2% of the total road deaths (SWOV, 2022), see appendix B.1.

When it comes to the parties responsible for the construction and maintenance of certain roads, municipal governed roads had the highest number of fatal traffic crashes in 2020 with 52% of the total road deaths (SWOV, 2022). Roads that are managed by the water board of the Netherlands had the smallest share of road deaths in 2020 with only 2% (SWOV, 2022), see appendix B.2.

### A.1.3 Serious Traffic Injuries

In the Netherlands, the total number of road injuries is not recorded. However, there are some estimates of the number of serious road injuries has been estimated by the Institute for Road Safety Research (SWOV). The definition of a serious road injury is: "*A casualty with moderate to serious injuries who has been admitted to a hospital as a result of a road crash and who has not died within thirty days*." (SWOV, 2021b). How severely someone is injured is measured by the Maximum Abbreviated Injury Scale (MAIS). The scales are as follows: 1 = lightly injured, 2 = moderately injured, 3 = seriously injured, 4 = heavily injured, and 5 = life-threatening (SWOV, 2007). Injuries with a MAIS score of 3 or more are considered to be serious road injuries (Nuyttens et al., 2016). SWOV estimates the number of the MAIS3+ injuries based on two sources (SWOV, 2021b):

1. The File Registered Accidents in the Netherlands (BRON), it contains characteristics of the accident but no good information about the injured people.
2. The National Basic Register Hospital Care (LBZ), it contains injury data from hospital discharged patients.

In 2020, an estimated 19,700 people were moderately injured or worse (MAIS2+) in traffic in the Netherlands. 6,500 of those people were seriously injured or worse (MAIS3+) (SWOV, 2021b). There are a lot of unknowns about the location and severity of serious road casualties. The reason for this is that the location information is only available in the File Registered Accidents in the Netherlands (BRON), and in this file only a part of the serious road injuries is captured (SWOV, 2021b). BRON registered the location of traffic crashes that included a motor vehicle until 2009. Of these crashes involving a motor vehicle, it is known that approximately 70% took on municipal roads (SWOV, 2011), see appendix B.3. Most of these crashes where motor vehicles were involved happened on 50 km/h roads, approximately 50% (SWOV, 2011), see appendix B.4.

### A.1.4 Traffic Safety Targets and Trends

The target of the EU, as stated by the European Commission (2019), is to reduce road traffic deaths and injuries with 50% by 2030 and to reach zero fatalities by 2050. This is known as the 'Vision Zero'. Despite a good start, the decline in the number of road deaths and injuries has leveled off in recent years, see appendix B.5. Based on the EU 'Vision Zero', the Netherlands has drawn up the Strategic Road Safety Plan (SPV) (Ministerie van Infrastructuur en Waterstaat, 2018. The targets in this strategic plan are to reach zero road casualties in the long run (SWOV, n.d.-a). Similar to the EU figures, there has been no downward trend in the number of road deaths and injuries in the Netherlands over the past 10 years (SWOV, 2021a). So, more investments in traffic safety are needed to get back on track and meet the set targets. In the Netherlands, the implementation of this is largely transferred to the municipalities. Therefore, most municipalities have drawn up their own strategic road safety plan. Examples are the '*Meerjarenplan Verkeersveiligheid 2016-2021*' of the Gemeente Amsterdam (2016) and the '*Uitvoeringsprogramma Mobiliteit*' of the Gemeente Rotterdam (2021).

### A.1.5 Traffic Safety Scope

As discussed in previous paragraphs, the largest share of traffic fatalities and serious injuries happen on municipal roads, and more specifically, 50 km/h roads (SWOV, 2011; SWOV, 2022). Therefore, interventions on these roads have the largest potential to improve traffic safety. The municipalities with the most traffic deaths per year are Amsterdam, Rotterdam, The Hague, and Utrecht (Verkeersveiligheidsvergelijker, n.d.), see appendix B.6. These are also the municipalities with the most inhabitants relative to other municipalities (CBS, 2020). Together they are called the G4.

Taking all these observations into consideration, it is decided to focus the scope of this study on municipal roads in the G4 municipalities. The 50 km/h roads in Amsterdam will be used as a use case for SCBA.

## A.2 Road Authorities in the Netherlands

This section discusses the public decision-making regarding the establishment and maintenance of road infrastructure in the Netherlands. There are four public road authorities: the national government, the provinces, the municipalities, and the regional water authorities (Ministerie van Infrastructuur en Waterstaat, 2022b). As mentioned in the previous section, the focus of this research is on municipal roads. Therefore, municipalities as road authorities are discussed in more detail.

### A.2.1 Public Road Authorities

The vast majority of road infrastructure in the Netherlands is owned by governments and therefore falls under a governments' responsibility. There is a lot of cooperation with the private sector when it comes to the maintenance, designing, and building of these road infrastructures but the management of the roads rests exclusively with governments (Wynia, 2006). There are four public road authorities that take on this task. First, there is the national government that outsources the management of roads to Rijkswaterstaat (Bouma, 2011). Rijkswaterstaat is the executive organization of the Ministry of Infrastructure and Water Management and amongst other things they manage and develop the national highways (Rijksoverheid, n.d.). Second, there are the twelve provinces of the Netherlands that manage the provincial roads. These roads are mainly outside built-up areas. In some cases, there are provincial roads that run within built-up areas. The road is then managed by the municipality in which the road is located. The province pays a fee to the municipality for the costs incurred (Bouma, 2011). Third, there are the municipalities that manage the local roads within their municipality (Ministerie van Algemene Zaken, 2018). A more detailed description of the tasks of the municipalities as road authorities is given in the next paragraph. Fourth, there are the regional water authorities that traditionally manage the roads built on dikes in the Netherlands. Today this is only the case in the provinces of Noord-Holland, Zuid-Holland, Zeeland, and Utrecht (Hoogheemraadschap Hollands Noorderkwartier, 2022). To get an idea of how the roads of different road authorities relate to each other, see figure A.2. This figure shows the road sections per road authority for the Amsterdam region.

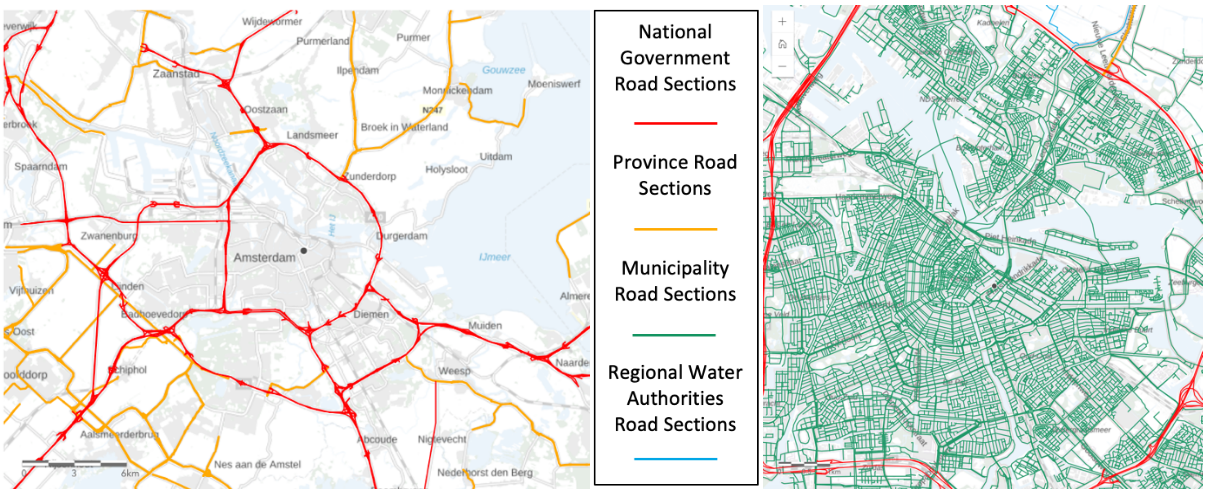


***Figure A.2** Road sections in Amsterdam managed by different road authorities (Ministerie van Infrastructuur en Waterstaat, 2022a)*

### A.2.2 Municipalities as Road Authorities

Dutch municipalities have the authority to make independent decisions on many matters. One of these matters is the construction and maintenance of municipal roads. This includes car roads but also, for example, bicycle paths located in the municipality (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021a). Before a new road can be built, the zoning plan of that area must be checked and sometimes changed. In a zoning plan, the municipality determines what an area should look like and therefore also where roads may or may not be built (ProDemos, 2020). These zoning plans apply not only to municipal roads, but also to provincial roads, national roads, and highways (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021b). To ensure that all traffic runs smoothly, many municipalities draw up a traffic and transport plan. In this plan it is stated what roads are intended for which traffic (e.g., local traffic, passing traffic) (ProDemos, 2020). When municipalities implement traffic measures, such as infrastructural changes, they often take the national guidelines into account. These guidelines are drawn up by CROW, an 'organization that ensures that the infrastructure, public space, and traffic and transport are properly organized in the Netherlands' (CROW, 2022a). The CROW guidelines are legally binding only when referenced in regulations or policies (CROW, 2022b). To make changes to a municipal road, a traffic order may be required in accordance with the Road Traffic Act (Kenniscentrum InfoMil, n.d.).

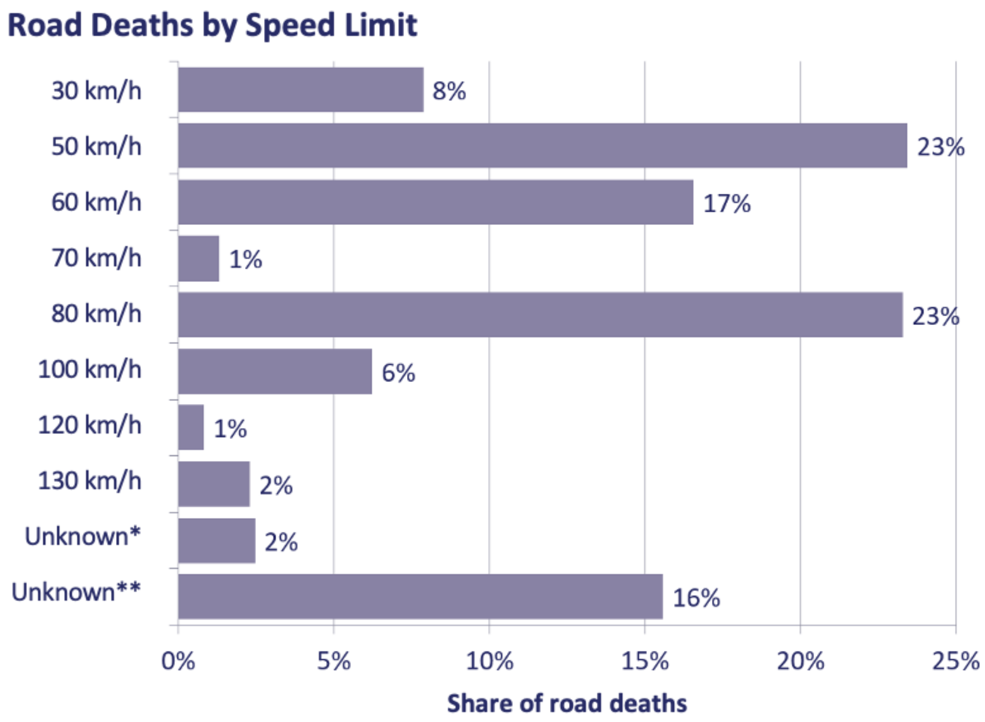


***Figure B.1*** *Percentage of road deaths per speed limit 2020 (SWOV, 2022)*

**Included in BRON **Not included in BRON*

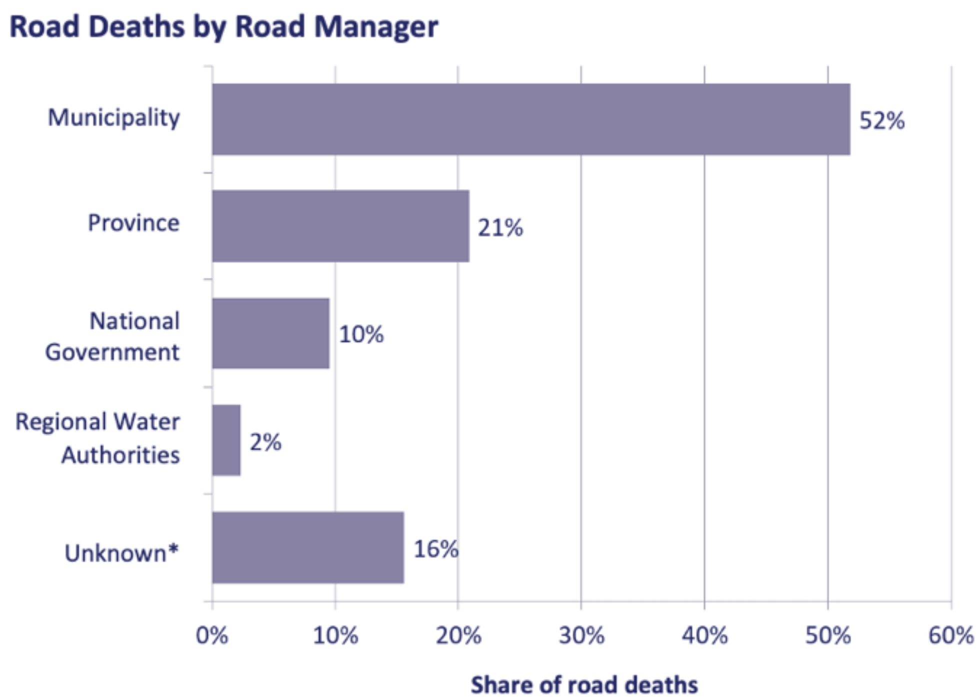


***Figure B.2*** *Percentage of road deaths per road manager 2020 (SWOV, 2022)*

**Included in BRON*

**Serious Road Injuries by Road Manager**

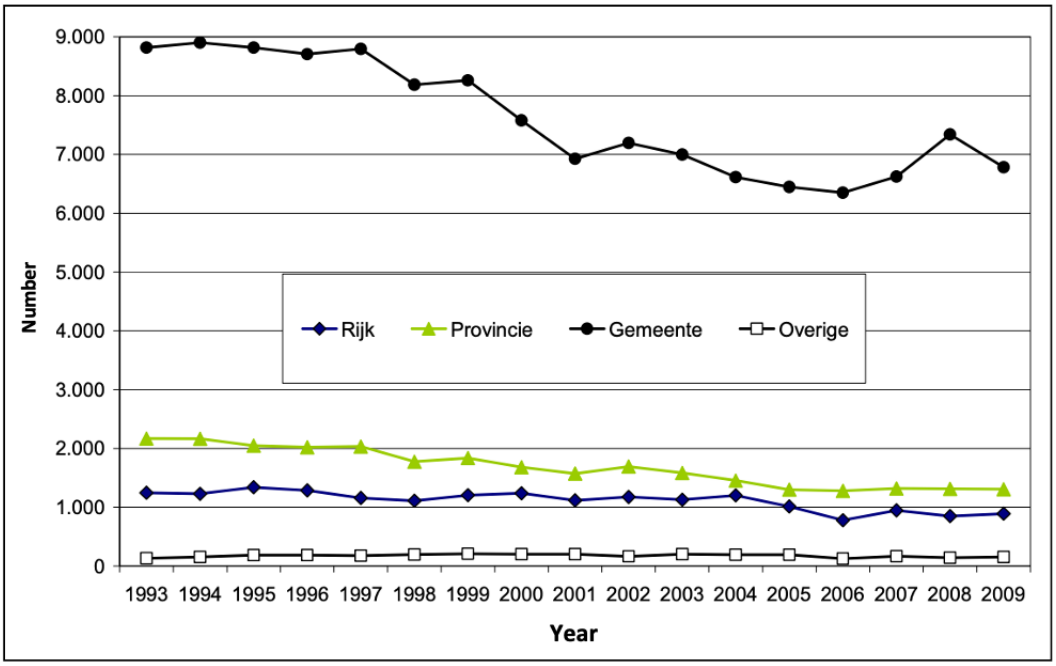


***Figure B.3*** *Number of serious road injuries in motor vehicle crashes per road manager 1993-2009 (SWOV, 2011)*

**Serious Road Injuries by Speed Limit**

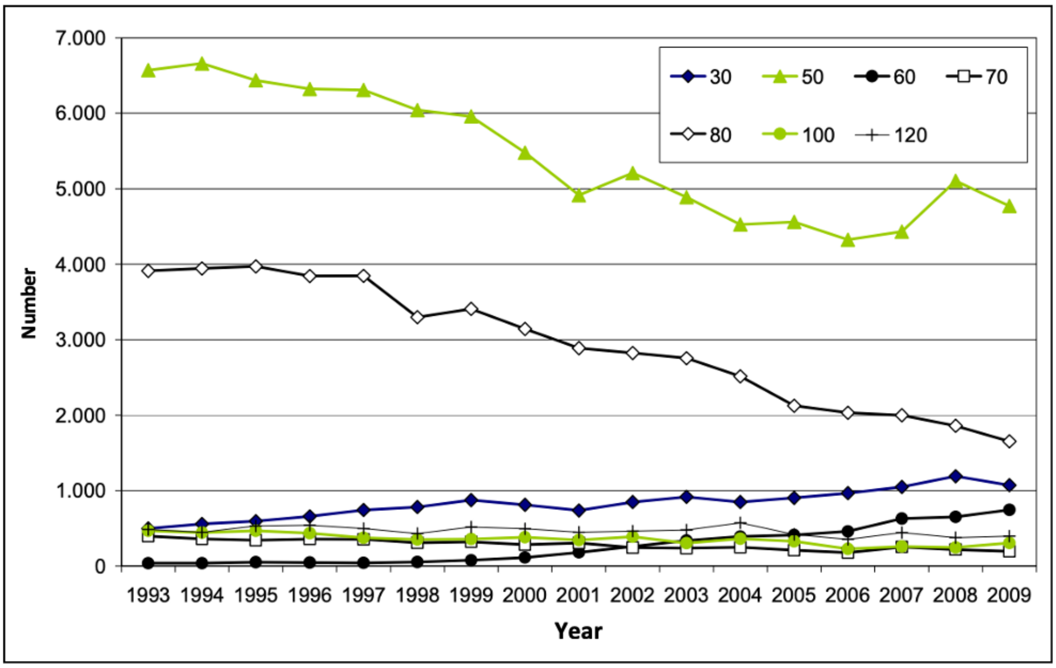


***Figure B.4*** *Number of serious road injuries in motor vehicle crashes per speed limit 1993-2009 (SWOV, 2011)*

### Number of Road Deaths in Europe

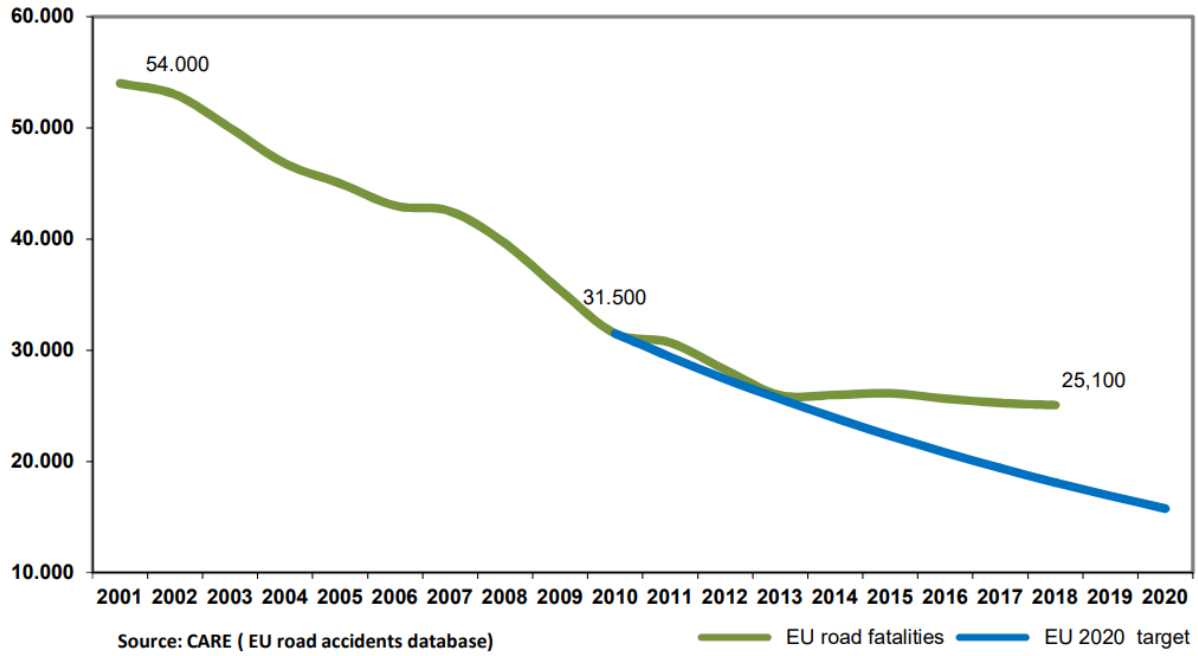


***Figure B.5*** *Evolution of road deaths in the EU and targets for 2001-2020 (European Commission, 2019)*

### Number of Road Deaths in the G4 Municipalities

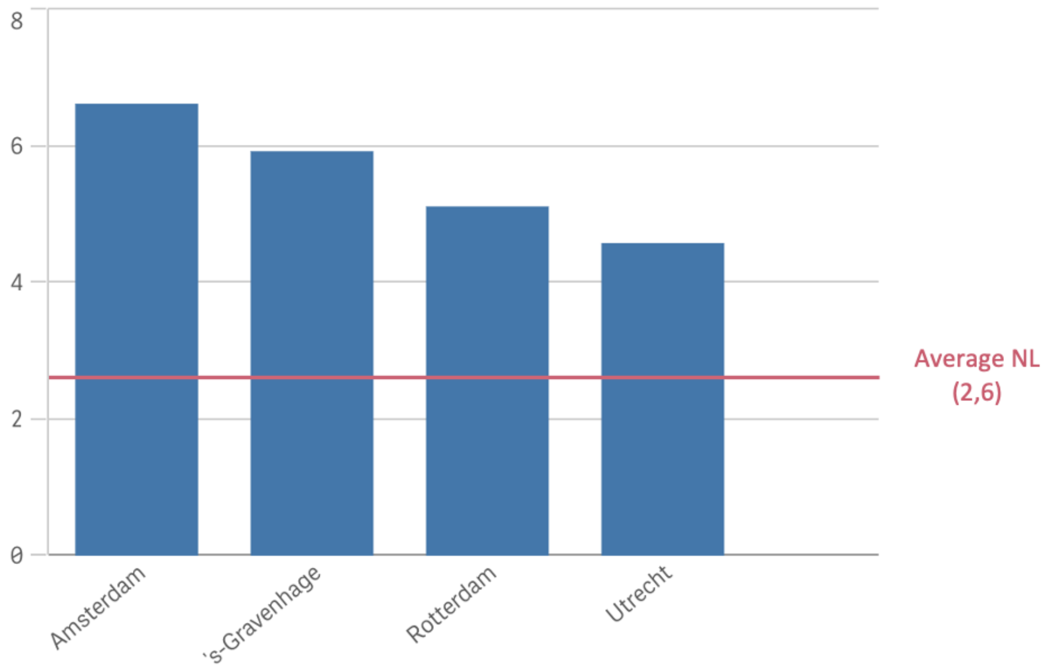


***Figure B.6*** *Number of registered road deaths per 100 km of total road length 2011-2020 (Verkeersveiligheidsvergelijker, n.d.)*

# Appendix C: Document of Informed Consent

U wordt uitgenodigd om deel te nemen aan een onderzoek naar strategieën van Nederlandse gemeenten omtrent verkeersveiligheid. Dit onderzoek wordt uitgevoerd door Elze Kamerling van de Technische Universiteit Delft in samenwerking met SWOV Instituut voor Wetenschappelijk Onderzoek Verkeersveiligheid.

Het doel van dit interview is om inzicht te krijgen in de besluitvormingsprocessen die plaatsvinden binnen de gemeente en de verkeersveiligheid strategieën die hierbij gebruikt worden. Het interview zal ongeveer een uur in beslag nemen. De data zal gebruikt worden voor het schrijven van de master thesis van Elze Kamerling, hierin zal uw naam niet genoemd worden. U wordt gevraagd om antwoord te geven op vragen rond het onderwerp verkeersveiligheid strategieën vanuit het perspectief van de gemeente waar u werkzaam bent.

Door deel te nemen aan het interview met SWOV, accepteer ik het volgende:

- Ik heb schriftelijke informatie over het onderzoek gelezen en begrepen.
- Ik ben in de gelegenheid gesteld om vragen over het onderzoek te stellen.
- Ik heb voldoende tijd gehad om goed over deelname aan het onderzoek na te denken.
- Ik ben me ervan bewust dat mijn medewerking geheel vrijwillig is.
- Ik begrijp dat ik op elk moment zonder opgaaf van redenen mijn deelname aan het onderzoek kan beëindigen zonder dat dit voor mij nadelige consequenties heeft.
- Ik begrijp dat mijn gegevens en onderzoeksresultaten vertrouwelijk behandeld worden.
- Ik ga akkoord met het maken van een opname van geluid tijdens het interview. Ik ontvang na het interview een schriftelijk verslag ter correctie. Daarna wordt de opname gewist. De naam van mijn gemeente maakt onderdeel uit van het verslag en de naam van de gemeente kan worden opgenomen in het onderzoeksrapport.
- Ik begrijp dat mijn emailadres wordt gebruikt voor terugkoppeling van het interviewverslag en de resultaten na afloop van het onderzoek. Hierna wordt mijn emailadres gewist.
- Ik weet dat ik bij vragen contact kan opnemen via: elze.kamerling@swov.nl.

Indien u vragen, opmerkingen of klachten heeft, kunt u contact opnemen met Elze Kamerling: elze.kamerling@swov.nl.

# Appendix D: Interview Questions

**Basis vragenlijst:**

- Bij welke gemeente bent u werkzaam?
- Wat is binnen deze gemeente uw functie?
- Wat houdt deze functie in?
- Heeft u het geïnformeerde toestemming document doorgelezen?

**Interview vragen strategieën:**

- Wat is de aanpak in uw gemeente om te bepalen in welke weginfrastructuur wordt geïnvesteerd om de verkeersveiligheid te vergroten?
- In welke mate worden de beslissingen rondom verkeersveiligheid in uw gemeente proactief of reactief genomen? Geef indien mogelijk aan waar de gemeente zich bevindt op het spectrum volledig reactief – volledig proactief.
- Waarom is er gekozen voor deze aanpak?
- Welke kosten nemen jullie mee in de besluitvorming?
- Welke overwegingen nemen jullie mee in de beslissingen van dag tot dag?
- Waarom is de praktijk weerbarstiger dan de theorie?
- In wat voor weginfrastructuur is er de afgelopen jaren het meest geïnvesteerd? (Bijv. losse fietspaden, snelheidswijzigingen, wegdek onderhoud etc.)
- Zijn de infrastructuurmaatregelen waar het meeste geld aan wordt uitgegeven ook het meest tijdintensief?

**Interview vragen besluitvormingsproces:**

- Wat zijn belangrijke stappen in het besluitvormingsproces binnen de gemeenten om te bepalen in welke weginfrastructuur er geïnvesteerd wordt om de verkeersveiligheid te vergroten?
- Welke partijen spelen een rol in dit besluitvormingsproces?
- Wie heeft op welk moment de autoriteit om beslissingen te maken?
- Hoe vaak worden infrastructuurmaatregelen die in de ogen van de verkeersafdeling noodzakelijk zijn goedgekeurd?
- Worden er in uw gemeente MKBA’s gebruikt tijdens het besluitvormingsproces? Zo ja, wat is de rol van MKBA’s in het bovengenoemde besluitvormingsproces?
- Hoe belangrijk zijn financiën in het bovengenoemde besluitvormingsproces?
- In welke mate is het aantal verkeersslachtoffers (verkeersdoden en zwaargewonden) leidend bij de beslissing in welke infrastructuur er wordt geïnvesteerd?

Indien nodig, bent u bereid om een tweede gesprek aan te gaan of via de mail wat vragen te beantwoorden?

# Appendix E: Literature Overview

***Table E.1*** *Literature overview*

| Authors | Risk factors | Governmental strategies | Infrastructure measures | Effects of measures |
|---|---|---|---|---|
| Ahmed (2013) | X | | | |
| Alblate, Férnandez, & Yarygina (2013) | | X | X | X |
| Bos & Dijkstra (1998) | | | X | X |
| Botteghi et al. (2017) | | | X | X |
| Deac & Tarnu (2019) | | | X | X |
| de Leur, Abdelwahab, & Navin (1994) | X | | | |
| Farnsworth (2013) | | X | | |
| Fu, Miranda-Moreno, & Saunier (2018) | | | X | X |
| Geurts & Wets (2003) | | X | | |
| Jackett & Frith (2013) | X | | | |
| Kennisnetwerk SPV (2018) | X | | X | |
| Kennisnetwerk SPV (n.d.-a) | | | X | X |
| Kennisnetwerk SPV (n.d.-b) | | | X | X |
| Konstantopoulos, Chapman, & Crundall (2010) | X | | | |
| Leblud (2017) | | | X | X |
| Lee, Nam, & Abdel-Aty (2015) | X | | | |
| Nabavi Niaki, Wijlhuizen, & Dijkstra (2021) | | | X | X |
| Noella (2017) | | | X | X |
| Noland & Oh (2004) | | | X | X |
| Pembuain, Priyanto, & Suparma (2019) | X | | | |
| Papadimitriou et al. (2019) | X | | | |
| Petegem & Wegman (2014) | X | | | |
| Quigley (2017) | | | X | X |
| Retting, Ferguson, & Hakkert (2003) | | | X | X |
| Rosik & Goliszek (2015) | | | X | X |
| Sakhapov & Nikolaeva (2018) | X | | | |
| Shah & Ahmed (2019) | | X | | |
| SWOV (2018) | | | X | |
| Teng (2003) | X | | | |
| Turner & Mansfield (1990) | X | | | |
| Usami (2017) | | | X | X |
| Wang et al. (2018) | | X | | |
| Wiethoff et al. (2012) | | X | X | |
| Yannis et al. (2015 | | X | X | X |
| **Number of papers** | **12** | **7** | **19** | **16** |

# Appendix F: Road Design Principles to Increase Traffic Safety

***Table F.1*** *(Bio)mechanics road requirements of Sustainable Safety (SWOV, 2018b, p. 18)*

| Potential conflicts and requirements associated with | Safe speed |
|---|---|
| • Possible conflicts with vulnerable road users in home zones (woonerfs) (no footpaths and pedestrians using the carriageway) | 15 km/h |
| • Possible conflicts with vulnerable road users **on roads, at intersections**, including situations with **bike lanes or advisory bike lanes** | 30 km/h |
| • **No conflicts with vulnerable road users, except with helmet-protected riders of motorized two-wheelers (mopeds in the carriageway)**<br>• Possible right-angle conflicts between motorized vehicles, possible frontal conflicts between motorized vehicles<br>• **Stopping sight distance ≥ 47 m** | 50 km/h |
| • No conflicts with vulnerable road users<br>**No right-angle conflicts between motorized vehicles,** possible frontal conflicts between motorized vehicles<br>**Obstacles shielded or obstacle-free zone ≥ 2.5 m, (semi-)hard shoulder**<br>**Stopping sight distance ≥ 64 m** | 60 km/h |
| • No conflicts with vulnerable road users<br>No right-angle conflicts between motorized vehicles, possible frontal conflicts between motorized vehicles<br>Obstacles shielded or **obstacle-free zone ≥ 4.5 m**, (semi-)hard shoulder<br>**Stopping sight distance ≥ 82 m** | 70 km/h |
| • No conflicts with vulnerable road users<br>**No right-angle or frontal conflicts between motorized vehicles**<br>Obstacles shielded or **obstacle-free zone ≥ 6 m**, (semi-)hard shoulder<br>**Stopping sight distance ≥ 105 m** | 80 km/h |
| • No conflicts with vulnerable road users<br>No interactive and frontal conflict between motorized vehicles<br>Obstacles shielded or **obstacle-free zone ≥ 10 m, hard shoulder**<br>**Stopping sight distance ≥ 170 m** | 100 km/h |
| • No conflicts with vulnerable road users<br>No right-angle or frontal conflict between motorized vehicles<br>Obstacles shielded or **obstacle-free zone ≥ 13 m**, hard shoulder<br>**Stopping sight distance ≥ 260 m** | 120 km/h |
| • No conflicts with vulnerable road users<br>No right-angle or frontal conflict between motorized vehicles<br>Obstacles shielded or **obstacle-free zone ≥ 14.5 m**, hard shoulder<br>**Stopping sight distance ≥ 315 m** | 130 km/h |

***Table F.2*** *Safe speeds for some conflict types (Kennisnetwerk SPV, 2018)*

| Wegtypen in combinatie met toegestane verkeersdeelnemers | Veilige snelheid (km/uur) |
|---|---|
| Wegen met mogelijke conflicten tussen auto's en onbeschermde verkeersdeelnemers | 30 |
| Kruisingen met mogelijke dwarsconflicten tussen auto's | 50 |
| Wegen met mogelijke frontale conflicten tussen auto's | 70 |
| Wegen waarbij frontale of zijdelingse conflicten met andere verkeersdeelnemers onmogelijk zijn | ≥100 |

***Table F.3*** *Conflict types between different road users and the associated maximum speed (Kennisnetwerk SPV, 2018)*

| | Conflicteert met (op wegvak GOW, op oversteekpunt of op kruispunt) | Veilige snelheid [km/uur] | Randvoorwaarde of kenmerk |
|---|---|---|---|
| G langs | F dwars | 30 | |
| G langs | V dwars | | |
| F langs | G dwars | | |
| G langs | F zelfde richting | | |
| G langs | G tegemoet | | Op dezelfde rijstrook of rijloper (geen ruimte voor asmarkering) |
| G langs | G dwars | 50 | |
| G langs | F zelfde richting | | Alleen bij aanwezigheid fietspad |
| G langs | G tegemoet | 70 | Gescheiden door markering |
| G langs | G tegemoet | (≥) 80 | Fysieke scheiding van rijrichtingen |
| G langs | G zelfde richting | (≥) 100 | |

F = fietser; V = voetganger; G = gemotoriseerd voertuig
(Drie conflicttypen, namelijk F langs vs F dwars, F langs vs V langs en F langs vs V dwars, zijn niet in de tabel opgenomen omdat hier qua snelheidslimiet geen specifieke eisen behoeven te gelden.
Het conflict G langs - V langs is alleen toegestaan op woonerven.)

***Table F.4*** *Facilities, closed statement on main carriageway, and speed limit per conflict type (Kennisnetwerk SPV, 2018)*

| Conflicttype | Voorziening of situatie | Gesloten-verklaring op hoofdrijbaan | Veilige snelheid (ongeacht de geldende limiet) |
|---|---|---|---|
| Tegemoetkomend verkeer | geen | niet | 60 bij weinig verkeer, anders 30 |
| | rijrichtingscheiding met markering | wel | 70 |
| | fysieke rijrichtingscheiding | wel | ≥ 80 |
| Enkelvoudig | geen | wel | 50 |
| | obstakelvrije zone | wel | 70 |
| | semi-verharde berm | wel | 70 |
| | verharde berm | wel | 80 |
| Overstekend verkeer | drempels of plateaus | niet | 30; 60 bij weinig verkeer |
| | oversteekvoorziening | wel | 50 |
| | erfaansluiting | wel | 50 |
| Geparkeerde voertuigen | op de rijbaan of vakken langs de rijbaan | niet | 30 |

***Table F.5*** *Characteristics of sufficiently safe roads in built-up areas (Kennisnetwerk SPV, 2018)*

| **Binnen bebouwde kom** | **Maatregelen ter voorkoming van** | | | | |
|---|---|---|---|---|---|
| **Snelheidslimiet in km/uur** | **conflicten met tegemoet-komend verkeer** | **enkelvoudige conflicten** | **conflicten met overstekend verkeer** | **conflicten met geparkeerde voertuigen** | **langsconflicten tussen gemotoriseerd snelverkeer en langzaam verkeer** |
| **30** | geen voorziening noodzakelijk | geen voorziening noodzakelijk | drempels of plateaus | parkeren op de rijbaan of vakken langs de rijbaan | mengen van gemotoriseerd snelverkeer en langzaam verkeer |
| **50** | rijrichting-scheiding met markering | geen voorziening noodzakelijk | oversteek-voorziening en/of uitritconstructie | niet parkeren op of langs de rijbaan | fietsers op fietspad of parallelweg |
| **70** | rijrichting-scheiding met markering | obstakelvrije zone en semi-verharde berm | oversteken en uitritten niet toestaan | niet parkeren op of langs de rijbaan | fietsers en brom-fietsers op fiets-/bromfietspad of parallelweg |

***Table F.6*** *Characteristics of sufficiently safe roads outside built-up areas* (Kennisnetwerk SPV, 2018)*

**Excluding highways*

| **Buiten bebouwde kom** | **Maatregelen ter voorkoming van** | | | | |
|---|---|---|---|---|---|
| **Snelheidslimiet in km/h** | **conflicten met tegemoet-komend verkeer** | **enkelvoudige conflicten** | **conflicten met overstekend verkeer** | **conflicten met geparkeerde voertuigen** | **langsconflicten tussen gemotoriseerd verkeer en langzaam verkeer** |
| **60 met weinig gemotoriseerd verkeer** | geen voorziening noodzakelijk | geen voorziening noodzakelijk | drempels of plateaus | niet parkeren op of langs de rijbaan | mengen van gemotoriseerd snelverkeer en langzaam verkeer |
| **60 met veel gemotoriseerd verkeer** | geen voorziening noodzakelijk | geen voorziening noodzakelijk | drempels of plateaus | niet parkeren op of langs de rijbaan | fietsers op fietspad |
| **80** | fysieke rijrichting-scheiding | berijdbare berm en obstakelvrije zone | oversteken en uitritten niet toestaan | niet parkeren op of langs de rijbaan | fietsers en brom-fietsers op fiets-/bromfietspad of parallelweg |
| **100*** | fysieke rijrichting-scheiding | berijdbare berm en obstakelvrije zone | oversteken en uitritten niet toestaan | niet parkeren op of langs de rijbaan | fietsers en brom-fietsers op fiets-/bromfietspad of parallelweg |

*__Table F.7__ Overview of the most promising infrastructure investments (Yannis et al., 2015)*

| | | Safety effect: High | Safety effect: Low |
|---|---|---|---|
| Implementation costs | Low | Introduction of median (without widening of the road) | Traffic signs (guide) |
| | | Introduction of 2 + 1 roads | Traffic signs (warning)* |
| | | Implementation of safety barriers | Delineators and road markings |
| | | Replacing safety barriers to meet the EN 1317 standard | Raised road markers |
| | | Lowering existing speed limit | Chevrons |
| | | Changing from unrestricted speed to speed limit | Post-mounted delineators |
| | | Creation of speed transition zones | Navigation routing |
| | | Traffic signs (regulatory) | Implementation of yield signs |
| | | Traffic signs (warning)* | Implementation of artificial lighting |
| | | Rumble strips | Improving existing lighting |
| | | Improvement of existing traffic lights | Minor traffic calming schemes* |
| | | Implementation of artificial lighting | |
| | | Improving existing lighting | |
| | | Protection of road/rail level crossings | |
| | | Junction channelization | |
| | | Implementation of stop signs | |
| | | Minor traffic calming schemes* | |
| | | Improvement of land use regulations | |
| | High | Development of motorways | Reducing the frequency of curves (horizontal) |
| | | Development of interchanges | Reducing the frequency of curves (vertical) |
| | | Increasing curve radii | Superelevation treatment* |
| | | Increasing the number of lanes* | Increasing the number of lanes* |
| | | Introduction of transition curves | Increasing median width* |
| | | Superelevation treatment* | Individual info VMS* |
| | | Reducing gradient | Improving road surface evenness |
| | | Improvement of sight distances | Improving road surface brightness |
| | | Increasing lane width | Junction realignment* |
| | | Introduction of shoulder | |
| | | Increasing shoulder width | |
| | | Introduction of median (with widening of the road) | |
| | | Increasing median width* | |
| | | Introduction of 2 + 1 roads | |
| | | Flattening side slopes | |
| | | Establishment of clear zones | |
| | | Creation of speed transition zones | |
| | | Weather info VMS | |
| | | Congestion info VMS | |
| | | Individual info VMS* | |
| | | Vision Enhancement Systems | |
| | | Ordinary resurfacing | |
| | | Improving friction | |
| | | Introduction of rail/road grade crossings | |
| | | Development of roundabouts | |
| | | Junction staggering | |
| | | Junction realignment* | |
| | | Implementation of traffic lights | |
| | | Major traffic calming schemes* | |
| | | Development of bypasses | |
| | | Improvement of land use regulations | |

*Safety effect and implementation costs can vary between countries as they depend on national/local conditions.

# Appendix G: Sensitivity Analysis

***Table G.1** Sensitivity analysis frequency strategy*

| **Costs traffic injuries** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 226,845,728.12 | € 294,164,412.80 | € 361,483,097.48 |
| Benefits/costs ratio | 2.9 | 3.5 | 4.0 |
| Delta | -16% | - | 16% |

| **Expenses traffic safety Amsterdam** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 311,003,938.31 | € 294,164,412.80 | € 277,324,887.29 |
| Benefits/costs ratio | 4.0 | 3.5 | 3.0 |
| Delta | 16% | - | -12% |

| **Costs negative effects** | | | |
|---|---|---|---|
| | **-40%** | **Base** | **40%** |
| Balance of SCBA | € 308,375,321.71 | € 294,164,412.80 | € 279,953,503.89 |
| Benefits/costs ratio | 3.9 | 3.5 | 3.1 |
| Delta | 13% | - | -11% |

***Table G.2** Sensitivity analysis combining projects strategy*

| **Costs traffic injuries** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 124,614,926.98 | € 162,961,013.19 | € 201,307,099.39 |
| Benefits/costs ratio | 2.7 | 3.2 | 3.8 |
| Delta | -16% | - | 16% |

| **Expenses traffic safety Amsterdam** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 171,380,775.94 | € 162,961,013.19 | € 154,541,250.43 |
| Benefits/costs ratio | 3.7 | 3.2 | 2.9 |
| Delta | 13% | - | -10% |

| **Costs negative effects** | | | |
|---|---|---|---|
| | **-40%** | **Base** | **40%** |
| Balance of SCBA | € 170,066,467.64 | € 162,961,013.19 | € 155,855,558.73 |
| Benefits/costs ratio | 3.6 | 3.2 | 3.0 |
| Delta | 11% | - | -9% |

***Table G.3** Sensitivity analysis vulnerability strategy*

| **Costs traffic injuries** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 283,730,192.08 | € 379,717,646.79 | € 475,705,101.50 |
| Benefits/costs ratio | 3.1 | 3.8 | 4.6 |
| Delta | -25% | - | 25% |

| **Costs widening bicycle paths** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 398,947,082.91 | € 379,717,646.79 | € 360,488,210.66 |
| Benefits/costs ratio | 4.5 | 3.8 | 3.3 |
| Delta | 5% | - | -5% |

| **Effects of removing bicycle poles** | | | |
|---|---|---|---|
| | **-40%** | **Base** | **40%** |
| Balance of SCBA | € 316,244,471.27 | € 379,717,646.79 | € 443,190,822.30 |
| Benefits/costs ratio | 3.3 | 3.8 | 4.3 |
| Delta | -17% | - | 17% |

***Table G.4** Sensitivity analysis subjective road safety strategy*

| **Costs traffic injuries** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 81,771,128.89 | € 115,293,616.73 | € 148,816,104.58 |
| Benefits/costs ratio | 1.4 | 1.6 | 1.9 |
| Delta | -16% | - | 16% |

| **Expenses traffic safety Amsterdam** | | | |
|---|---|---|---|
| | **-20%** | **Base** | **20%** |
| Balance of SCBA | € 132,133,142.25 | € 115,293,616.73 | € 98,454,091.22 |
| Benefits/costs ratio | 1.9 | 1.6 | 1.4 |
| Delta | 15% | - | -12% |

| **Costs negative effects** | | | |
|---|---|---|---|
| | **-40%** | **Base** | **40%** |
| Balance of SCBA | € 115,293,616.73 | € 115,293,616.73 | € 115,293,616.73 |
| Benefits/costs ratio | 1.8 | 1.6 | 1.5 |
| Delta | 13% | - | -10% |

***Table G.5** Scenario Percentages*

| Numbers | Positive scenario | Negative scenario |
|---|---|---|
| Costs traffic injuries | +20% | -20% |
| Expenses traffic safety | -20% | +20% |
| Costs negative effects | -40% | +40% |
| Costs widening bicycle paths | -20% | +20% |
| Effect of removing bicycle poles | +40% | -40% |

***Table G.6** Scenario Sensitivity Analysis Results*

| **Frequency strategy** | | | |
|---|---|---|---|
| | **Negative scenario** | **Base** | **Positive scenario** |
| Balance of SCBA | € 195,795,293.71 | € 294,164,412.80 | € 392,533,531.90 |
| Benefits/costs ratio | 2.3 | 3.5 | 5.4 |
| Delta | -34% | - | 57% |

| **Combining projects strategy** | | | |
|---|---|---|---|
| | **Negative scenario** | **Base** | **Positive scenario** |
| Balance of SCBA | € 109,089,709.77 | € 162,961,013.19 | € 216,832,316.60 |
| Benefits/costs ratio | 2.2 | 3.2 | 4.8 |
| Delta | -31% | - | 48% |

| **Vulnerability strategy** | | | |
|---|---|---|---|
| | **Negative scenario** | **Base** | **Positive scenario** |
| Balance of SCBA | € 570,669,141.63 | € 379,717,646.79 | € 213,289,008.94 |
| Benefits/costs ratio | 6.0 | 3.8 | 2.4 |
| Delta | 50% | - | -44% |

| **Subjective road safety strategy** | | | |
|---|---|---|---|
| | **Negative scenario** | **Base** | **Positive scenario** |
| Balance of SCBA | € 64,931,603.37 | € 115,293,616.73 | € 165,655,630.09 |
| Benefits/costs ratio | 1.1 | 1.6 | 2.5 |
| Delta | -33% | - | 54% |