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Unbundling of Traffic Flows

Which situations and which circumstances are beneficial for unbundling

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Colophon

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Preface

This thesis is the final step for the degree of Master of Science in Transport, Infrastructure and Logistics (TIL) at the Delft University of Technology. During this degree I specialised in the Design track, which focuses on transport service and infrastructure network design in context of urban design, spatial planning and regional economy.

During this master thesis project, commissioned by Rijkswaterstaat, responsible for the main infrastructure facilities and part of the Dutch Ministry of Infrastructure and the Environment, I aimed to develop a method to determine whether an infrastructure unbundling project might be considered to solve bottlenecks in traffic flows on motorways. This thesis is based on both a literature review and simulations, which are executed in order to gain more insight in under which circumstances unbundling is beneficial or not.

This report describes the approach, execution and results of the study. This report can be useful for consultants or policymakers. It can be used in order to find out if unbundling can be considered an option for infrastructural projects (when bottlenecks arise on motorways).

I would like to specially thank my supervisors Serge Hoogendoorn, Rob van Nes, Jan Anne Annema and Henk Taale for their support and trust in this period. I am thankful to my committee and the help one of its members provided.

Secondly, I would like to thank Alex van Loon and Ton Arninkhof of Rijkswaterstaat. Alex, for providing me with information about unbundling and other information he provided me with throughout the whole period. Ton, for helping me with the estimation of investment and maintenance costs, which were needed for the costs-benefit analysis. Furthermore, I would like to thank all other employees of Rijkswaterstaat who helped me or provided me with information in order to conduct this study.

Lastly I would like to thank my family and friends, especially my boyfriend, who unconditionally supported me.

Enjoy reading this thesis.

L. Hodenius

Delft, February 2017

Executive summary

This study has been conducted in order to develop a method to determine in which situations unbundling (i.e. the separation of traffic flows), can be used to solve bottlenecks on motorways. Although unbundling has already been applied in the Netherlands, success of this method has been varying. Moreover, The Ministry of Infrastructure and the Environment (Rijksoverheid, 2004; Ministerie van Infrastructuur en Milieu, 2012) state that unbundling should be considered during the exploration phases of infrastructural projects on solving bottlenecks on motorways but it remains unclear in which situations this measure can lead to an effective and robust solution.

Two main goals are set for this study. On the one hand, the situations in which unbundling can be considered an option and on the other hand, circumstances under which unbundling can be deemed beneficial. This leads to the following research question:

'To what extend can unbundling of traffic flows be considered as a potential solution in solving bottlenecks on motorways and are there (any) circumstances in which unbundling can be deemed societally beneficial?'

In this study unbundling is understood as separation of through and local traffic on motorways by a physical separated main carriageway and parallel road. Based on literature review, three situations could be determined in which unbundling can be applied: because of policy reasons, safety reasons and/or because of capacity problems. This study focusses on the capacity issues and for that the problem can be described as; traffic flows are not getting the level of service (LoS) they ask for or they should get. In order to provide (one or more) traffic flows with the LoS asked for, redistribution of capacity can be the solution. Therefore, the capacity issue refers to the redistribution of capacity, not necessarily to solving the capacity problem itself. A decision tree was built of these situations in which unbundling can be applied.

In order to find out if there are circumstances in which unbundling can be deemed societally beneficial, simulations are used. One standard situation was chosen to test under different circumstances. The simulation program that was chosen to execute this with was MARPLE. The standard situation, base case, was considered a three lane carriageway with a length of 9 km and a maximum speed of 120 km/h. Two connections are included, which means two on-ramps and two off-ramps.

The alternatives include an extended alternative (four lanes on the main carriageway) and four unbundled alternatives. The first unbundled alternative is the unbundled 2-1 alternative, this means that the main carriageway has initially three lanes and these are divided with two lanes on the main carriageway and one on the parallel road. The same holds for the unbundled 3-1 and 2-2 alternatives for the alternatives with initially four lanes. Since alternatives can only be compared when they have initially the same amount of lanes and in order to not compare separate issues, the networks with initially three lanes are compared and the networks with initially four lanes are compared separately for each circumstance (different distribution of through and local traffic).

The circumstances under which the alternatives have been tested are the distribution of through and local traffic, and the (total) traffic demand. The six different distributions are:

- 50% through traffic - 50% local traffic
- 60% through traffic - 40% local traffic
- 70% through traffic - 30% local traffic
- 80% through traffic - 20% local traffic
- 90% through traffic - 10% local traffic
- 100% through traffic - 0% local traffic

Besides, the simulations are executed for an initial determined demand which is the same for all simulations. Additionally the simulations are executed for a 10% and 20% increase of the initial determined demand. There were six alternatives, six distributions of through and local traffic and three amounts of traffic demand. Therefore, 108 simulations were executed.

The simulations were evaluated by performance indicators and cost-benefit analysis. The performance indicators that were taken into account are: the amount of vehicles loss hours (total delay), total distance travelled, congestion, average speed and the total time spent in the network (total travel time). In the cost-benefits analysis the investment (& maintenance) costs, travel time gains, safety effects, emissions effects and noise pollution effects were taken into account.

Unbundling of traffic flows can be considered a potential solution in solving bottlenecks on motorways, but to a limited extend. The unbundling measure can only be deemed societally beneficial for one alternative. The unbundled alternative is societally beneficial under the circumstances of 50% through traffic and 50% local traffic and the initial traffic demand. This alternative consists of a main carriageway with two lanes and the parallel road exits of two lanes as well (the unbundled 2-2 alternative). This result that the unbundling measure is only societally beneficial in one situation can partly be explained by the high investment & maintenance costs for unbundled alternatives in comparison to building an extra lane.

Besides, in order to say something about the robustness of the unbundling measure, the traffic demand were increased with 10% and 20%. From this it can be concluded that the performances of the alternatives come closer together when the traffic demand increases. Moreover, it can be concluded that the extended and the unbundled 2-2 alternatives perform the best under increased traffic demand circumstances and therefore are the most robust alternatives.

There are three main limitations considered in this study. First of all, besides the circumstances all data was static. Secondly, the simulations were strongly simplified. For instance, only two types of vehicles are taken into account and no weather conditions or accidents were taken into account. Lastly, the effects of safety and noise pollution are not properly take into account in the CBAs. Since safety effects can have a much bigger impact than travel time effects and unbundled situations are considered safer than not-unbundled situations, the CBAs are probably underestimated for unbundled situations.

Besides, whether the CBA is positive or not, the decision for implementing one of the alternatives or changing the road infrastructure, is still a decision of the government.

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Abbreviations

CBA	Cost-benefit analysis
LoS	Level of Service
RWS	Rijkswaterstaat
VoT	Value of Time

Definitions

Circumstances	Two circumstances are determined in this study: distribution of through and local traffic & amount of traffic demand
Level of Service	According the Transportation Research Board (2000): *"[…] is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comforts and convenience".*
Situations	Situation in which unbundling can be applied; because of policy reasons, safety and/or capacity problems.
Turbulence	Disruption of the traffic flow by merging and exiting traffic.
Weaving movement	Movement in which two vehicles cross each other's paths.
Value of Time	Gives the societal benefit of the decrease of the average travel time or gives the societal costs of the increase of travel time.

1 Introduction

This study has been conducted in order to develop a method to determine in which situations unbundling (i.e. the separation of traffic flows), can be used to solve bottlenecks on motorways. Although unbundling has already been applied in the Netherlands, success of this method has been varying. Therefore research into success factors was needed. The research consists of a literature review, traffic simulations and a Cost-Benefit Analysis (CBA). The literature study leads to a decision tree of the situations in which unbundling could be applied. Based on the decision-tree, simulations and CBA were executed to evaluate the circumstances in which (if any), unbundling could be deemed beneficial. The developed method supports consultants and policymakers to make a structured and faster decision in which situations, and under which circumstances unbundling can be considered an option.

1.1 Unbundling of traffic flows

In 2015, the construction of a parallel carriageway on the motorway A4 near Leiden, in southward direction, was finished (Rijkswaterstaat & Goudappel Coffeng, 2015). The function of this carriageway was to 'collect' traffic that had the intention of leaving the motorway and to 'distribute' entering traffic from two provincial roads (N11 and N206) back onto the motorway (ibid.). With the construction of this parallel carriageway, all the entering and exiting traffic, also known as local traffic, was separated from the through-going traffic. Therefore, through-going traffic was expected to be less hampered and suffered from less turbulence caused by the movements of merging and exiting traffic. The situation regarding the A4 near Leiden serves as a typical example of unbundling.

Moreover, other examples of unbundling include public transport/bus lanes, freight lanes and very commonly in the Netherlands; separation of cyclists from remaining traffic by bicycle paths, to name a few (Haak, 2010; Eichler & Daganzo, 2006; Methorst, et al., 2014). When unbundling is mentioned, any of these ways of unbundling can be referred to. Unbundling can in general be defined as follows: separation of disparate traffic (traffic flows) which all ask for different handling qualities (speed, travel time, etc.).

Additionally, there are various ways to realise unbundling. For instance, traffic flows can be separated by a continuous line on the pavement or by a concrete barrier. A more comprehensive list on how to realise unbundling, can be found in Section 2.1.2.

Based on literature (see Section 2.2), unbundling can be applied in three different situations: because of policy reasons, safety reasons and/or because of capacity problems. These situations will be discussed further in Section 2.2. This study, however, will mainly focus on capacity problems in terms of separation of through and local traffic on motorways. The unbundled situation at the A4 near Leiden is an example of this way of unbundling. Arguments for this scoping can be found in Section 2.1.3.

1.2 Problem Statement

The Dutch government has the ambition of realising reliable and smooth travel times for all journeys (Rijksoverheid, 2004). In order to achieve this goal, measures are needed for solving bottlenecks, which are the main cause of delays and unreliable travel times.

The Dutch Mobility Policy Document '*Nota Mobiliteit'* (Rijksoverheid, 2004) states that unbundling should always be considered as one of the possible measures when bottlenecks appear on the main road network. Furthermore, when investing in the main road network, unbundling of through and local traffic has become an integral and permanent part of possible solutions in exploration and planning studies (Ministerie van Infrastructuur en Milieu, 2012).

However, the problem is that it remains unclear in which situations unbundling leads to an effective and robust solution (Kijk in de Vegte, et al., 2012). This has been illustrated by varying results in already unbundled situations in the Netherlands (Walhout, 2016). For example, unbundling through and local traffic at the A4, near Leiden, did not completely solve the through-flow problems and congestion problems are rising again (Rijkswaterstaat & Goudappel Coffeng, 2015). Moreover, due to the many ways to realise unbundling, it is sometimes even unclear what exactly is meant by the term 'unbundling'. All reports (Section 2.2) address merely one way of doing it without ever mentioning the overarching concept.

Furthermore, The Ministry of Infrastructure and the Environment (Rijksoverheid, 2004; Ministerie van Infrastructuur en Milieu, 2012) states that unbundling should be considered during the exploration phases of infrastructural projects on solving bottlenecks on motorways but remains unclear in which situations this measure can lead to an effective and robust solution (Kijk in de Vegte, et al., 2012). Several studies (see Section 2.2) have been performed on unbundling/separation of traffic flows. This has provided a lot of knowledge on the several ways of unbundling and their advantages and disadvantages. However, scientific structuring and guidelines are missing on which situations and under which circumstances unbundling might be a beneficial measure.

Thus, based on the above stated problem indication; the following problem statements can be specified:

"It is unclear what is exactly meant by unbundling, and in which situations and under which circumstances unbundling is a societally beneficial measure"

1.3 Study Objective

This study aims to develop a general tool (i.e. a decision tree) which helps to decide whether unbundling is a true alternative in a considered situation. Secondly, this study attempts to find out whether it is possible to determine circumstances in which unbundling can always be deemed beneficial (or not). It needs to be noted that this tool only indicates whether unbundling is a measure to be considered an alternative, not if it is the best possible solution.

1.4 Relevance of research

Research can provide added value in several ways. This section will discuss the scientific, practical and social relevance of this study.

1.4.1 Scientific relevance

Currently, no research exists on how to relate different ways of unbundling to specific situations and circumstances in which they must be considered (Ministerie van Infrastructuur en Milieu, 2012). The few researches, discussed in Sections 2.1 and 2.2, look deeply into one specific way of unbundling. However, there is a need for a research that provides an overview of situations and circumstances in which unbundling can be one of the potential solutions.

This research aims at filling that knowledge gap by generating a general tool which structures and integrates all the individual aspects of unbundling. Such a tool doesn't exist yet.

1.4.2 Practical relevance

The goal of this research is to develop a decision supporting tool concerning situations and circumstances in which unbundling can be considered an option. This tool should support Rijkswaterstaat to determine whether unbundling could be one of the solutions to solve specific traffic issues, before any infrastructural improvement plan is designed and estimated. Instead of investigating every specific situation separately, this tool serves as a guide in order to find out if unbundling can be an option or beneficial measure in a much more structured and faster way.

1.4.3 Social relevance

As mentioned earlier, the national government's ambition is the realisation of reliable and smooth travel times over entire door to door journeys (Rijksoverheid, 2004). The goal is to increase reliability and decrease travel times. Unbundling is one of the measures that may be applied in order to achieve this goal.

When the right measure is chosen and the goal is achieved, the decreased travel times are a major benefit for road users which result in social benefits. These benefits may exceed the social costs in many situations (Ministerie van Infrastructuur en Milieu, 2012) which make this topic also socially relevant.

1.5 Research questions

Two main goals can be appointed for this study. On the one hand, the situations in which unbundling can be considered an option and on the other hand, circumstances under which unbundling can be deemed beneficial. Consequently, the following research question can be specified:

'To what extend can unbundling of traffic flows be considered as a potential solution in solving bottlenecks on motorways and are there (any) circumstances in which unbundling can be deemed societally beneficial?'

A series of sub research questions have been defined to guide the research and to be able to answer the main research question:

1. What is meant by unbundling?
2. In which situations can unbundling be applied?
3. How can costs and benefits of an unbundling project be determined?
4. What performance indicators are needed in order to analyse a road network?
5. Which standard road designs (archetypes) can be defined?
6. Which model can be used for simulating both the archetypes and a real-life case?
7. Which circumstances that may influence the performance of unbundled networks can be defined?
8. Is there a relation between the circumstances and the performance of the unbundling measure?
9. Can the found results be verified by an actual study case?

1.6 Scope

Figure 1-1 on the next page shows how the subject is scoped in this study. As mentioned in Section 1.1 there are various ways to separate traffic flows and to realise unbundling. The static physical way of separation is considered and for the purpose of this study, the most relevant type is the separation of through and local traffic on motorways. Reasons for this choice are discussed in Section 2.1.3. With a static way of unbundling is meant that a fixed amount of lanes is available for each traffic flow.

Moreover, this study focusses on unbundled situations near and around urban areas, because the highest distribution of local traffic is available there. Commissioned by the Ministry of Infrastructure and the Environment, Rijkswaterstaat owns and develops the national motorway network. Since this study is conducted on behalf of Rijkswaterstaat, the focus during the study is on the national motorway network (main road network). Based on literature a decision tree (Figure 2-5, p.17), in which the unbundling of situations is an alternative, is built in which three situations could be determined: because of policy reasons, safety reasons and/or because of capacity problems. In Section 2.2.3 the choice for the focus on capacity problems is explained in more detail.

Unbundling in practice, is in this study understood as static separation by the presence of a parallel road, which has to be a continuous road. Therefore it must be possible to drive with a constant speed on this parallel road, without any disruptions, as for instance roundabouts or intersections. The parallel carriageway should begin and end at the same motorway (carriageway).

Finally, the simulations that are executed in order to find out if unbundling can be deemed beneficial under specific circumstances, are limited to only one type of road design (archetype) due to time constraints.

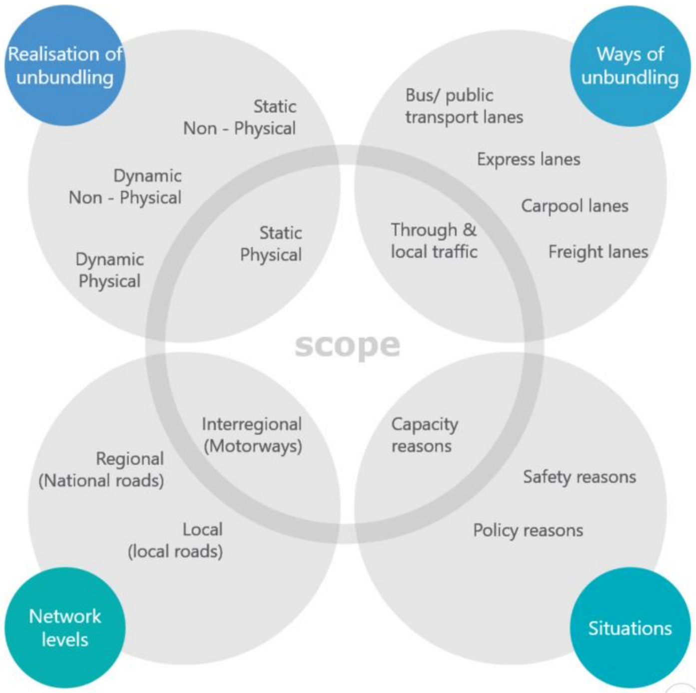


Figure 1-1. Scope

1.7 Methodology

The first four sub questions are answered by literature review. Literature on unbundling of traffic flows has been obtained through Google Scholar, TU Delft repository and Rijkswaterstaat. This literature has been scanned to identify what is meant with unbundling and in which situations unbundling can applied (captured in a decision tree). Besides, literature on cost-benefit analysis for infrastructure projects has been obtained through Rijkswaterstaat and literature on road network performance indicators has been obtained through TU Delft repository and Rijkswaterstaat. The performance indicators and the cost-benefits analysis are used to evaluate the network alternatives and if unbundling can be deemed societally beneficial under the defined circumstances.

The fifth research question has been answered through defining different areas in the Netherlands for which all possible motorway road designs have been determined. The areas include a rural area, a radial area and an urban area. This approach is used because the focus in this study is on urban areas. Therefore, it was needed to know what motorway road designs exist. In order to determine all the possible road designs in each area in which unbundling could be applied, is looked to all already unbundled situation in the Netherlands.

In order to answer the sixth sub question, a list of criteria was determined and all simulations models that are currently used in the Netherlands and internationally were listed. The model that met all the criteria was chosen. Besides, the model had to be able to provide the defined performance indicators as output.

The seventh sub question has been answered through defining different distributions of through and local traffic in the network. Unbundling, as considered in this study, is used for separating through and local traffic in order to mainly improve the traffic handling. Therefore, the distribution of through and local traffic should have the highest impact on the performance of an unbundled network.

For answering the eighth and ninth sub questions, simulations have been used. For one of the archetypes, different alternatives are determined which are tested under the two determined circumstances. Because the simulations of the archetype are purely hypothetical and only fictitious data was used in these simulations, actual data was used in order to verify the archetype simulation results. In agreement with an expert, the A4 near Leiden is chosen as the actual case. All the simulations are evaluated by the performance indicators and by cost-benefits analysis.

The aforementioned has been used to answer the main research question.

1.8 Report outline

The report structured into seven chapters, as shown in Figure 1-2. Each block represents one chapter and shows by the smaller numbers in each chapter-block, which sub research questions are answered in which chapter.

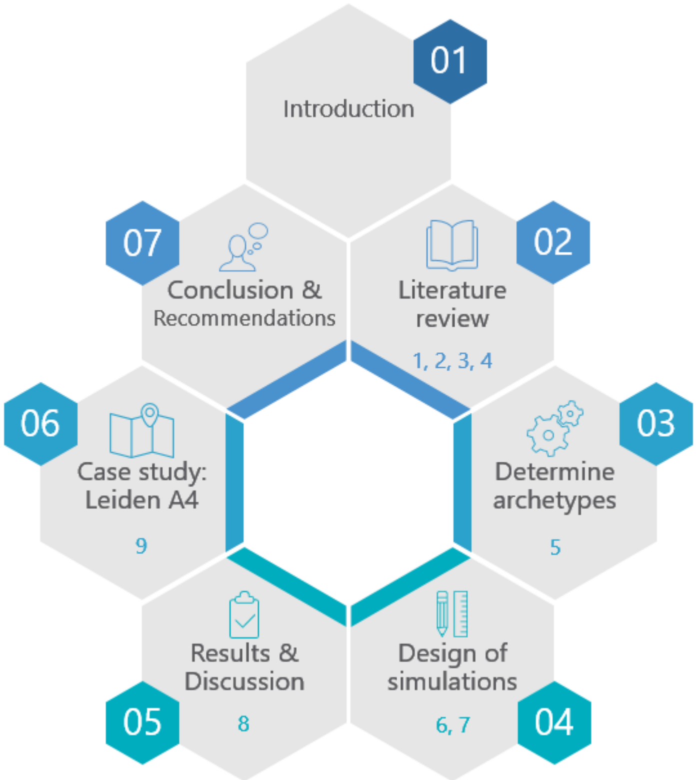


Figure 1-2. Visualisation structure of the report

Six main chapters, split in two parts, are considered in this study. The first part includes only 1 chapter; the literature review. This part covers and answers the first part of the research question.

Chapter two covers the literature review and in this chapter the first four sub research questions are answered. After the literature review it is clear what is meant with 'unbundling', in which situations unbundling can be applied (captured in a decision tree), how a cost-benefit analysis should be executed when applying unbundling and finally, what the performance indicators are for analysing a road network. These last mentioned indicators are also needed in order to choose a simulation program, which provides these indicators as output.

The second part addresses whether unbundling can be deemed beneficial under certain circumstances. Because the aim of this study is to create a guide, that explains in which situations and under which circumstances unbundling can be deemed beneficial, a generic approach is needed in order to cover all possible road designs in the Netherlands. Therefore, archetypes (standard road designs) are determined. The unbundling measure is tested within these archetypes, under several circumstances, by simulations, in order to find out if there is a relation between the performance and the circumstances. The results of these simulations will be verified by an actual case.

Chapter three discussed how the archetypes are determined. In order to create a guide that explains under which circumstances unbundling can be deemed beneficial, standard road designs are determined. Archetypes is the term that refers to these standard road designs in this study. In this chapter, sub research question five is answered.

Chapter four describes how the simulations are setup. Therefore, the simulation program that will be used during the simulations is chosen and the circumstances under which unbundling will be tested, are determined. Moreover, all the simulation inputs, cost-benefit analysis inputs, and alternatives are discussed. In this chapter, sub research questions six and seven are answered.

Chapter five shows and discusses the results of the simulations. The results are discussed based on the network performance indicators and the cost-benefit analysis. Besides, the conclusions that can be drawn from these results are discussed. Sub research question eight is answered in this chapter.

In **Chapter six** a case study of the A4 near Leiden is executed. This is done in order to verify the found results of the simulations of the standardised situations. Sub research question nine is answered in this chapter.

Chapter seven concludes this study. It draws conclusions on if unbundling can be deemed societally beneficial under certain circumstances. In this chapter the main research question is answered and future recommendations are given.

2 Literature review

This chapter will structure the available information (e.g. google scholar, TU Delft repository and Rijkswaterstaat) on unbundling and determine guidelines in which situations unbundling can be applied.

Section 2.1 explains what unbundling is and how the subject is scoped for this study. With this explanation sub-question one is answered. Secondly, Section 2.2 answers the second sub-question by structuring information and generating the general tool (i.e. decision tree) on in which situations unbundling can be applied. In order to find out under which circumstances unbundling might be a beneficial measure, cost-benefit analysis (CBA) and network performance indicators are used to evaluate the alternatives (Section 2.3). With these results sub-questions three and four will be answered.

2.1 Unbundling

Unbundling, also known as separation of traffic flows, can be divided into two aspects. First, the decision on which two traffic flows should be separated and, secondly, infrastructural designs on how to realise the separation of traffic flows. Section 2.1.1 describes which traffic flows are eligible for separation. The ways of how unbundling can be realised are discussed in Section 2.1.2, the ‘how’ concerns the infrastructural road design (geometric). Moreover, how the topic is scoped is explained in Section 2.1.3. Section 2.1.4 explains some terms, related to unbundling, that are used throughout this report.

2.1.1 Types of unbundling

Many types of unbundling, separation of traffic flows, are known. A very common example of unbundling in the Netherlands is the separation of cyclists from other traffic by bicycle paths. Bicycle paths are separated from other road(s) by, for example, a road verge, a crash barrier or just a line on the pavement. This type of separation improves safety for cyclists (Methorst, et al., 2014). Cyclists and motorized vehicles are the two *traffic flows* in this example.

Commissioned by the Ministry of Infrastructure and the Environment, Rijkswaterstaat owns and develops the national motorway network. Since this study is conducted on behalf of Rijkswaterstaat, the focus during the study is on the national motorway network (main road network). Therefore, only the five types of unbundling that appear in motorway networks will be explained hereafter.

Firstly, the most common type of unbundling on motorways in the Netherlands is the separation of through and local traffic[1]. This means that traffic which enters or leaves the motorway, known as local traffic, is separated from trough going traffic. In this way through going traffic is not

[1] Appendix A1 shows the list of all unbundled situations in the Netherlands and its type of separation.

hampered by this entering and exiting traffic, which reduces turbulence and decreases the amount of dangerous situations (Gelder, 2016; Van der Velden, 2015; Kijk in de Vegte, et al., 2012).

Two other types of unbundling on motorways include bus, or the more general public transport, lanes and freight lanes. Public transport operates according to a schedule which should be operated in a reliable and punctual manner. In order to meet these requirements and free busses from traffic interferences, public transport can be provided with their own lane (Eichler & Daganzo, 2006).

Most of the time, economic reasons are the motivation for realisation of freight lanes. In this way freight traffic does not suffer from delay. Because the vehicle hours lost by freight traffic are valued higher than vehicle hours lost by other traffic, freeing freight traffic from delays has more impact on lowering the overall costs for delay. This will be explained in more detail in Section 2.1.3. Besides, the presence of freight lanes can stimulate the economy (Haak, 2010).

The fourth and the fifth types of unbundling on motorways are not present in the Netherlands but they are common around the globe, including the United Stated. These types are mentioned in this research for completeness. Express Lanes (EL) can be considered the fourth type of unbundling. These lanes are also known as High Occupancy Toll Lanes (Davis, 2011). As described by Newmark (2014); *"High-Occupancy Toll (HOT) lanes allow motorists who do not want to face possible freeway congestion to purchase access to a parallel and uncongested toll way. Vehicles that meet an occupancy threshold may access HOT lanes at no cost."* The main reason to separate in this way is to manage traffic congestion.

Fifthly, Carpool lanes are defined by Cassidy, et al. (2010) as follows: *"Carpool lanes are deployed on urban freeways for the exclusive use of vehicles that carry more than a predetermined number of occupants."* The predetermined number of occupants differs per country. The purpose of these carpool lanes is to prioritize cars containing at least two people and increase transport efficiency. Additionally, these lanes are constructed in order to try and encourage more people to carpool.

Concluding this section, unbundling can in general be defined as follows: separation of disparate traffic (traffic flows) which all ask for different handling qualities (speed, travel time, etc.). These handling qualities can be expressed in the Level of Service, this term will be explained in more detail in Section 2.2.

2.1.2 Unbundling in practice

Which traffic flows can be separated are discussed in the previous section. In order to actually separate these traffic flows, road designs have to be adapted. Generally, there are two ways to realise the separation of traffic flows: physical and non-physical (Van der Velden, 2015). Both ways to realise separation of traffic flows can be divided further into two types.

First of all, physical separation means that traffic flows, represented by different roads, are physically separated by, for example, a concrete barrier. Therefore it is not possible to switch between the roads or lanes. The two types of physical separation are vertical and horizontal separation. Horizontal separation means that the separated roads or lanes are located on the same level, next to each other, as shown in Figure 2-1a (p.11). When separation has been applied vertically, the separated carriageways are located on different levels above each other (Kwakernaak, 2002) (Figure 2-1b).

The second way to realise separation of traffic flows is non-physical separation, which means that different carriageways are separated by, for example, road marks, lines on the pavement and signage. Although this is not the intention, in such situations it is possible to switch roads or lanes. The first type of non-physical separation is static separation, which means that always the same amount of lanes is reserved for a specific flow or direction as shown in Figure 2-1c. The second type is dynamic separation, which means that the amount of lanes on a carriageway is variable per flow or direction (Soekroella, 2011). This means that for example on a road with four lanes, 3 lanes can be used for direction A and 1 for direction B (3x1). But, the four lanes can also be divided in two lanes for direction A and two for direction B (2x2). In this context dynamic means that there is no physical separation, the traffic flows are divided in 3x1 or 2x2 lanes by flexible signage, for example, matrix signs (Figure 2-1d). As can be derived, non-physical separation is always a form of horizontal separation.

Figure 2-1. Types of traffic flow separation; horizontal (Watts, 2013), vertical (Schnabel, 2015), static (van Reeken, 2010), dynamic (SWARCO, 2015)

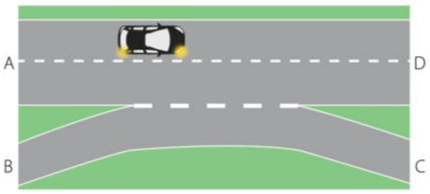
2.1.3 Scoping for this study

This section explains how the subject is scoped and which aspects are taken into account in this study. Besides, it is explained what is understood with the implementation of static physical separation.

As argued in Section 2.1.1, the focus of this study is on the national motorway network in the Netherlands. Unbundling in practice is in this study understood as static separation by the presence of a parallel road which has to be a continuous road. Therefore, it must be possible to drive with a constant speed on this parallel road, without any disruptions (e.g. roundabouts or intersections). The parallel carriageway should begin and end at the same motorway.

Moreover, in case unbundling is applied in/through an intersection of two motorways, this is considered a typical design to connect two motorways. Although the focus in this study is not on this type of unbundling, they are a form of unbundling as well.

The most common type of unbundling on motorways in the Netherlands, is separation of through and local traffic by physical static separation (Appendix A). Which traffic is considered as through and/or local traffic is shown in Figure 2-2 (p.12). Furthermore, the documents of The Ministry of Infrastructure and the Environment (Rijksoverheid, 2004; Ministerie van Infrastructuur en Milieu, 2012) explicitly refer to the separation of through and local traffic. And since they also state that unbundling should be considered during the exploration phases of infrastructural projects on solving bottlenecks on motorways, unbundling is described as the separation of through and local traffic within Rijkswaterstaat as well (Rijkswaterstaat, 2015).



Origen – Destination	Type of traffic
A – D	Through traffic
A – C	Local traffic
B – D	Local traffic
B – C	Local traffic

Figure 2-2. Definition of through and local traffic

Hence, this type of unbundling is also of most interest for Rijkswaterstaat. This can be explained with an example. Generally, the effects of congestion are measured in vehicle-loss-hours, which is then used to calculate the costs of congestion. This can be done by multiplying the vehicle-loss-hours[2], which represent delay, expressed in hours, and the costs per vehicle expressed in €/hour. However, not all uses of time are equal and, therefore, the costs per vehicle, also known as Value of Time (VoT), depend upon the purpose of the journey and are valued as shown in Table 2-1. As can be seen, the time of freight traffic is valued the most. Thus, travel time reduction of five minutes yields a higher benefit for trucks than for passenger cars. Besides, only car (commuting) and freight traffic will be considered in this study.

Furthermore, the benefits of unbundling can also be expressed in monetary terms. As freight traffic has the highest VoT, it is preferable to unbundle, and create separate infrastructure for freight traffic. Most of the time, however, freight is through traffic. If only freight traffic was unbundled, the benefits would be gained only for freight flows. This is based on the assumption that travel times for the other traffic remain the same, when applying freight lanes. On the other hand, when all through traffic is unbundled from local traffic, benefits might be gained for other types of traffic flows as well.

Table 2-1. Values of Time (VoT) for different traffic purposes for 2020 (Ministerie van Infrastructuur en Milieu, 2012)

Traffic	*Value of Time (€/hour)*
Freight	46,54
Commuting	9,53
Business	29,36
Remaining	7,73

2.1.4 Terminology related to unbundling

In order to prevent lack of clarity, this section explains which terms are related to unbundling and provides definitions of these terms.

A motorway exists of one or more carriageways, each of them represents a direction. Carriageways consists of one or more lanes. A visualisation is shown in Figure 2-3 (p.13). This figure also shows that a weaving movement is a movement in which two vehicles cross each other's paths.

[2] Note that one car waiting in a traffic jam for half an hour results in the same vehicle-loss-hours as 6 cars delayed for five minutes.

As shown in Figure 2-4 (p.14), within the Netherlands carriageways can be distinguished by the next four types (Rijkswaterstaat & Ministerie van Verkeer en Waterstaat, 2007):

1. **Main carriageway** (*Dutch: hoofdrijbaan*) - Lane intended for (fast) through traffic. A main carriageway takes care of continuity of the most important, mainly straight through, traffic flows.
2. **Collector/distributor carriageway** (*Dutch: rangeerbaan*) - Located at a node or connection, parallel to the main lane, starting and ending on the same carriageway. This parallel carriageway, also referred to as collector-distributor lane (C-D lane), "collects" traffic exiting the motorway and "distributes" the entering traffic back onto the motorway.
3. **Parallel carriageway** (also called local-express lane) (*Dutch: parallelbaan*) - A collector/distributor lane which covers two or more nodes and/or connections, with the same aim as the original collector/distributor lane.
4. **Connection carriageway** (*Dutch: verbindingsweg*) - Carriageway which is not one of the three types mentioned before, which provides the connection between two carriageways in an intersection or not-converging roads. On- and off ramps are examples of this type of carriageway.

Not only carriageways can be divided in different types as also lanes have different functions. The first one is the 'normal' lane which is always open to traffic under normal conditions. The second lane to be distinguished is the emergency lane which is meant for emergency services in time of accidents or other disruptions. This way, emergency services will not be hindered by other traffic. Lastly, there is the rush-hour lane. In order to provide more capacity on a carriageway and prevent congestion, this lane can be opened during rush hours, or during other periods of increased traffic.

In some situations the emergency lane is used as rush-hour lane or the other way around. This means in times of increased traffic, there is no emergency lane available.

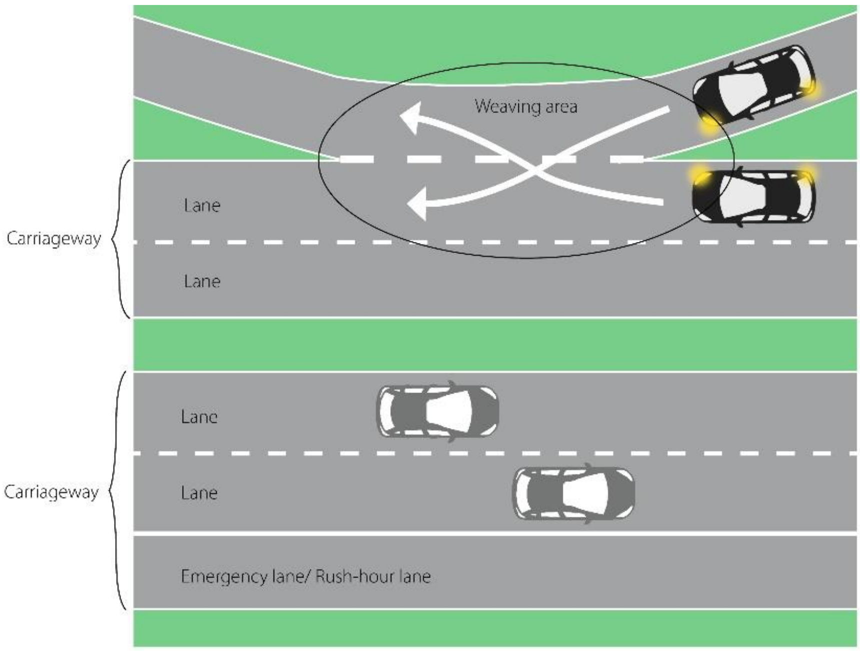


Figure 2-3. Terminology motorways

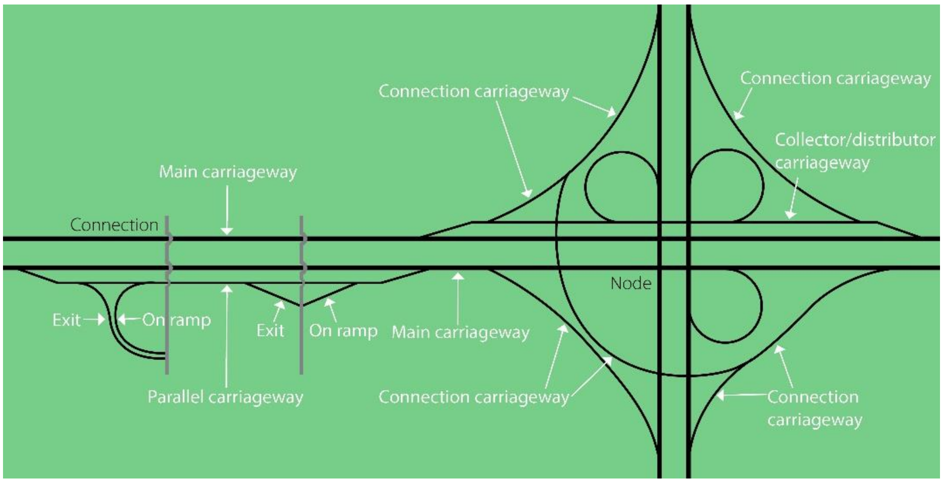


Figure 2-4. Different carriageways on motorways (Rijkswaterstaat & Ministerie van Verkeer en Waterstaat, 2007)

2.2 Situations for applying unbundling

The previous section explained what is meant by unbundling. This section gives a review of current literature on unbundling with the aim to distract in which situations unbundling can be applied. As mentioned before, all reports address merely one way of unbundling without ever mentioning the overarching concept, with the consequence that they mention different reasons and situations in which to apply unbundling. This makes it unclear when to apply unbundling. In this section, all this information will be structured in a decision tree, which guides a user in which situations unbundling can be applied. A decision tree is described in literature as (Utgoff, 1989): *'[…] a representation of a decision procedure for determining the class of a given instance. Each node of the tree specifies either a class name or a specific test that partitions the space of instances at the node according to the possible outcomes of the test'*. In this research the decision tree is used to structure the situations in which unbundling can be applied. Instead of investigating every specific situation separate, this tool serves as a guide in order to find out if unbundling can be an option or beneficial measure in a structured and fast way.

When this section refers to 'two groups of road users', any kind of the road users distinguished in Section 2.1 can be meant, as well as cyclist or pedestrians. This section discusses seven researches.

Firstly, Kijk in de Vegte, et al. (2012) compares unbundled situations, in which through and local traffic is separated, and not-unbundled situations in the Netherlands in order to investigate the effectiveness of unbundled road networks in practice. The main reason for applying unbundling mentioned in this study is to free through going traffic of turbulence. Besides, with the transfer of merging and exiting movements to the parallel road, the movements take place at lower speeds, which decreases the chance of serious accidents.

Another research on unbundling has been conducted by Van der Velden (2015). This study focussed on the relation between unbundling of through and local traffic and signage. According this study there are two reasons for applying unbundling. First, unbundling is mainly applied in order to reduce the amount of weaving movements, and therefore also the weaving areas, in order to prioritise through going traffic. High share of freight traffic is the other reason for applying unbundling. In unbundled situations, freight traffic is divided over the two roads, with the advantages that remaining traffic has more space and that the appearance of convoys decrease.

Thirdly, *'Handboek Capaciteitswaarden Infastructuur Autosnelwegen'* (Grontmij, 2015) is the source for capacity values of motorways and its backgrounds, which is essential data for Rijkswaterstaat. According this capacity manual the main reason for applying unbundling is to prioritise through traffic, which means that through traffic is not hampered by the movements of merging and exiting traffic. Although they are not mentioned in the document, there are more reasons/situations in which unbundling can be applied.

In *'Nota mobiliteit'* (Rijksoverheid, 2004), the spatial policy, as laid down in National Spatial Strategy, is elaborated and it describes the transport policy. Due to this document, the physical separation of traffic flows can contribute to a better through-flow. Unbundling can be a solution, especially during peak hours, when a relatively large amount of long distance traffic merges with local traffic that uses the motorway as a ring road. Another situation in which unbundling can be a solution is when large amounts of freight traffic make it hard for passenger cars to merge onto or exit the motorway. Road extension will not always solve the problems related to convoys of freight traffic.

Soekroella (2011) investigates the possibility to separate freeway traffic using dynamic lane assignment and he mentions two reasons for separating traffic flows. In order to guarantee a high quality of traffic flow for special users, separation of traffic flows is proposed by separating economically important users from other traffic (DHV & AVV, 1994 cited in Soekroella, 2011, p.8). The second reason to apply separation of traffic flows is mainly focused on maintaining the original function of the motorway network (DHV, 1999 cited in Soekroella, 2011, p.8).

Haak (2010) did a feasibility study to the traffic- and financial effects of applying freight lanes. In the interests of the transport sector of the Netherlands, by the increase of the amount of freight traffic, congestion costs are raising drastically. This means that the reliability of travel times and the competitive position of the Netherlands deteriorate.

Finally, the research executed by Kwakernaak (2002) concerns physical, vertical, unbundling on the main road network. The main reason for applying vertical unbundling, is the lack of available space. The reasons mentioned for applying unbundling in general are: in order to solve capacity problems and in order to create the opportunity to give the main road network its original function back.

All of the individual reasons for applying unbundling discussed in the aforementioned researches may be categorized under one of the following three situations: policy-, safety- or capacity reasons. Table 2-2 (p.16) shows how the individual reasons as identified in the literature have been categorized. Below the table a short explanation is given for each situation.

Table 2-2. Main reasons for applying unbundling by several researches

Source/research / Situations	(Kijk in de Vegte, et al., 2012)	(Van der Velden, 2015)	(Grontmij, 2015)	(Rijksoverheid, 2004)	(Soekroella, 2011)	(Haak, 2010)	(Kwakernaak, 2002)
Policy reasons						x	x
Safety reasons	x	x					
Capacity reasons	x	x	x	x	x	x	x

1. **Policy reasons -** Unbundling can be applied due to policy reasons which include, for instance, the separation of economically important users and increasing transport efficiency. In these situations, unbundling is considered as the main instrument in order to reach the goal. The main decision is which traffic flows to separate.
2. **Safety as nature of the problem -** Safety is expressed in the number of accidents, casualties or deaths and is related to differences in velocity. Applying unbundling is to prevent any of those accidents or deaths. Building bicycle paths is a very specific example of applying unbundling for safety reasons.
3. **Capacity as nature of the problem** - Some researches describe it as solving capacity problems while others call it contributing to a better through-flow. Transportation Research Board (2000), however, describes this as the Level of Service (LoS) with the following definition: *"[…] a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comforts and convenience".* Problems of this nature can be described as; traffic flows are not getting the LoS they ask for or they should get. In order to provide (one or more) traffic flows with the LoS asked for, redistribution can be the solution. Therefore, capacity problems refer to the redistribution of capacity, not necessarily to solving the capacity problem itself.

The three identified situations in which unbundling can be applied serve as input for building the decision tree (Figure 2-5, p.17) regarding the situations in which unbundling might be applied. Each of the situations will be explained in more detail in the following sections with respect to the questions in the decision tree.

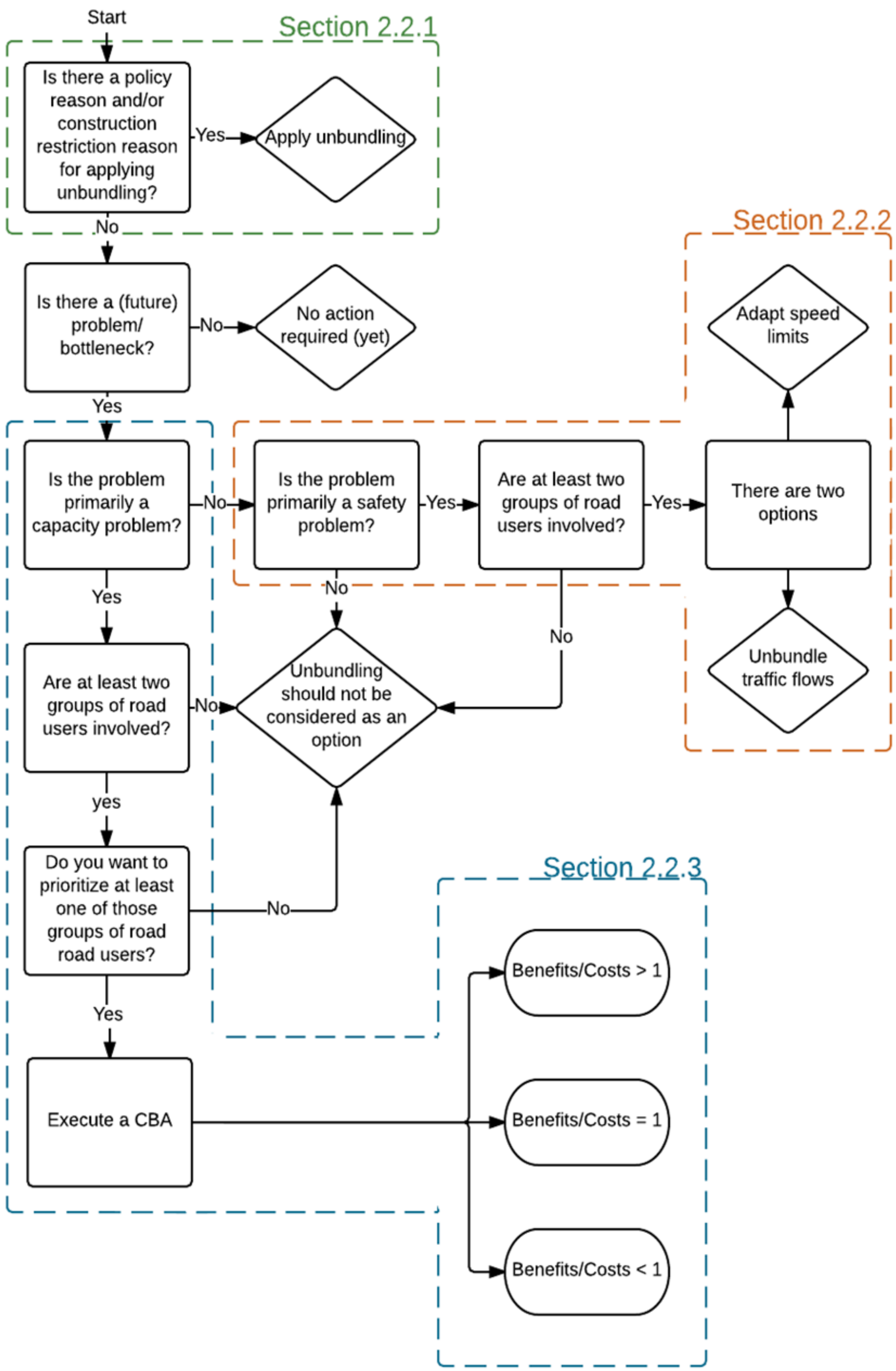


Figure 2-5. Decision tree, in which situations unbundling can be applied (green = policy reasons, orange = safety as nature of the problem, blue = capacity as nature of the problem).

2.2.1 Policy reasons

"Is there a policy reason and/or construction restriction reason for applying unbundling?" is the first question to be answered in the decision tree (Figure 2-5, p.17) as they do not prioritise the improvement of through-flows or Level of Service. Instead, policy makers have goals, such as separation of economically important users, for which making through flows better is merely the only instrument to realise the goal.

There are three main policy reasons to be distinguished:

1. **Separation of economically important users** – Separation of economically important users can be chosen to apply in order to stimulate the economy or to provide a better competitive position for the Netherlands (Haak, 2010). Therefore, a high quality of traffic flow (LoS) can be guaranteed for these special users. These special users are usually known as freight or business traffic, as shown in Table 2-1 (p.12) they have the highest Value of Time (VoT) (Ministerie van Infrastructuur en Milieu, 2016a), which makes them the most valuable. An example is prioritising freight traffic near the port of Rotterdam (Soekroella, 2011). Prioritising traffic with high values on locations where they are most present, results in the highest benefits. As already explained in Section 2.1.1, prioritizing high valued traffic leads to less social costs, or gains higher benefits, in case of congestion.
2. **Transport efficiency** – Improving transport policy can be another policy reason to apply unbundling. Transport efficiency can mean several things (Litman, 2013), but comes always down to highest possible speeds, least possible travel time, highest vehicle occupancy or least travel distances. Therefore, stimulation of travelling together by prioritizing car-poolers and/or public transport in or outside cities, could help to transport as much as people using a minimum of means.
3. **Zone planning and construction limits –** At some locations, government has determined very strict zoning plans. The zoning plans state, for instance, that roads should be eliminated from the surface in order to have 'undisturbed landscape'. Therefore, practically, tunnels must be built. Due to construction limits and safety reasons, a maximum of four lanes can be accommodated in one tunnel tube (Walhout, 2016). In case more than four lanes are needed in order to provide for the capacity, several tunnels are needed. Hence, a decision has to be made on how to distribute the traffic. The same holds for bridges. Besides, lack of space can also be a reason to prioritise specific road users.

In these three situations, unbundling is merely considered the only instrument to realise the goal. The only decision which remains, is which traffic flows to separate.

If none of the three reasons are applicable, *"Is there a (future) problem/bottleneck?"*, is the next question to be answered (Figure 2-5, p.17). A problem concerns (future) bottlenecks or congestion. When no (future) problem is observed/detected, it does not make sense to make any infrastructural changes (yet). With the detection of a problem, the nature of the problem needs to be determined. The problem is either primarily capacity based or primarily safety based. With this subdivision, the problem can also be a combined capacity and safety problem. For instance, problems at weaving areas might be considered as both a capacity and a safety problem. When this occurs, choose the *primarily* nature of the problem. Both of the safety and capacity nature of the problems are discussed in the next two following sections. If the nature of the problem is not capacity or safety, unbundling should not be considered as an option during the project as shown in Figure 2-5 (p.17).

2.2.2 Safety reasons

If the answer to *"Is the problem primarily a safety problem?"* is positive, unbundling might be a suitable measure to apply. In this context, safety is defined as number of accidents, casualties or deaths. There are two main safety reasons to distinguish:

1. **Difference in speed** - With regards to speed: *'Effective speed restrictions are maybe the most important of all regulations in favour of traffic safety. To some degree, they protect all participants in traffic situations by allowing for more reaction time and reducing the damaging force of collisions.'* (Zeitler, 1996). By lowering the speeds limit or make the difference between two speeds limit smaller, leads to more homogeneity. Lowering the speed limit is, however, not preferable in each situation. Thereby, road users are normally not willing to drive slower, especially not on motorways. However, decreasing the differences in speed between road users could make significant difference. For example in the local road network, on a road which has bike lanes at the side, lowering maximum speed of passing vehicles could make a big difference in terms of accidents.
2. **Vulnerability** - Also stated by Zeitler (1996)*: 'No doubt, traffic separation has had a positive impact on the accident and death rate of human beings. The notable decrease of accident and death rates since the early 70s is at least partly due to improvements of the road infrastructure by establishing more lines, cycle paths, motorways, pedestrian zones etc.'*. Besides, Snelder (2010) mentions that it is proven that the time loss as a result of incidents can be reduced by almost 30% by making a physical distinction according to functions (interregional traffic, urban/regional traffic, and urban traffic). Instead of adapting the speeds limit in the previous example, the bicycle lane can also be changed into a separated bicycle path. In terms of safety, unbundling on motorways is usually applied in order to decrease the amount of weaving areas.

"Are two groups of road users involved?" is the next question to be answered when safety is primarily the nature of the problem. As the word itself says, separation is the process of sorting or distinguishing into different components, groups, or categories based on inequalities between these components, groups, or categories (The free dictionary, 2016). Separation of traffic can only take place based on differences in traffic. These differences or characteristics include speed, distance, purpose, vulnerability or weight of the vehicle. In case no distinction can be made between road users, unbundling should not be considered as an option.

2.2.3 Capacity reasons

In situations where traffic demand is nearing or exceeding capacity limits or if there is unreliability of, for example, travel times, capacity utilization improvement – and road innovation (construction of new roads), measures can be put into practice (Ministerie van Infrastructuur en Milieu, 2012).

Capacity problems can be caused by weaving areas. Because of the merging and exiting traffic, there is a lot of turbulence. Therefore, capacity in these areas is lower (Grontmij, 2015). When unbundling is applied, weaving traffic is separated from remaining traffic and decreases the capacity problems.

If the answer to the question *"Is the problem primarily a capacity problem?"* is yes, unbundling might be applied as one of these measures. As already explained at the beginning of this section, the Level of Service can be used to describe this problems nature. At the base of possible impaired LoS, lays in the existence of network levels. This will be explained hereafter.

Road networks can be designated as hierarchical transport networks in which different network levels are distinguished. Previous research shows that these levels can be defined in several ways. This study uses the classification of hierarchy for private transport networks set by Van Nes (2002) which is focused on the network hierarchy within the Netherlands.

As stated by Van Nes (2002): *'Each road network level connects cities of a specific type and connects these cities with cities of the next higher level'.* This concept is shown in Figure 2-6. Besides, each of the network levels has its own transport function in terms of serving specific types of settlements or specific travel distances, also known as the Level of Service (LoS). Therefore, each level is characterized by road spacing, access spacing and speed (Van Nes, 2002).

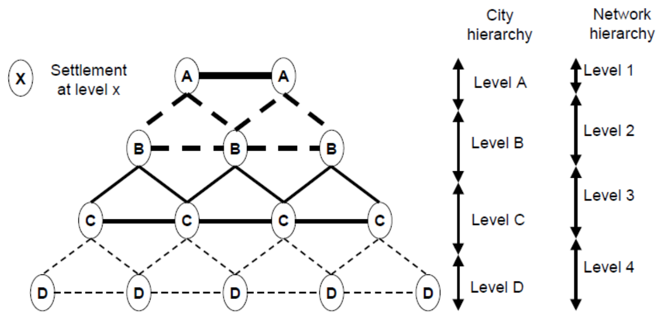


Figure 2-6. Road network structure according Schönharting & Pischner (1983 cited in Van Nes, 2002, p.88)

These characteristics of the different levels are related to each other. For example, network level C is a higher level than level D (Figure 2-6) and the speed limit in level C is 60 km/h and in level D 30 km/h. A factor (60/30=) 2 for speed can be distinguished between the levels. These factors are referred to as scale-factors. Scale-factors are used to define relationships between the characteristics of the network levels.). Scale-factor 3 for road spacing is based on findings of De Jong (1988A cited in Van Nes, 2002, p.101) and De Jong & Paasman (1998 cited in Van Nes, 2002, p.101). The scale-factors for access spacing and speed are determined by Van Nes (2002) as follows: *'The access spacing is based on the scale-factor 3 for road spacing. The speed is determined using the maximum speed for the national motorway network and the scale-factor 1.67 for speed'.*

Based on these scale-factors, Van Nes (2002) introduces the classification of road network levels as shown in Table 2-3 (p.21). The table is not completed for the national and international levels because those levels do not exist (yet). This means that the Dutch road network exists of three levels; local, regional and interregional. The interregional network level is the highest level in the Netherlands and serves 40 main urban areas, which includes cities with more than 70.000 inhabitants (Van Nes, 2002). Besides, if higher levels would exist, due to the scale-factors the network speed of the national level would be 170-200 km/h and for the international level even higher. However, this is not possible in the Netherlands at the moment. Moreover, speed limits have changed in the Netherlands over time. Table 2-4 (p.22) shows the adapted current network levels and their characteristics in the Netherlands.

Van Nes (2002) states that a hierarchical network is only successful when each network level is predominantly used by the category of travellers that it was meant to serve. This means the local traffic should use the local network, the regional traffic should use the regional network and the interregional traffic should use the interregional network. If this is not the case, at least two categories of travellers are using the same infrastructure (Ministerie van Verkeer en Waterstaat, 2008). What can happen is that the Level of Service of the higher network is not met anymore, and therefore, the different categories of travellers will negatively influence each other. In some situations in the Netherlands this occurs and two main reasons can be distinguished for the overlap in use of infrastructure.

First of all, the motorway system might be too attractive. When motorway networks grow denser, these roads become more attractive to short-distance traffic. Local traffic experiences the relatively high quality of these motorways and the amount of short distance trips increase on the motorway network (Van Nes, 2002; Kwakernaak, 2002). Therefore, congestions occurs earlier than expected. Providing more capacity by regular road extensions (adding lanes), can stimulate this phenomena and attract even more traffic. Therefore regular road extension is not always a good solution.

Secondly, networks are sometimes designed in a way which combines functions of the regional roads and the national roads on the same infrastructure (Van Nes, 2002). This is, for instance, what happened in the development of the national motorway system around Amsterdam. The development of a regional network was skipped in favour of developing a motorway network (Immers, et al., 2001; Hilbers, et al., 1997 cited in Van Nes, 2002).

Unbundling can be chosen to apply to separate the through and local traffic again. However, instead of prioritising all through going traffic, it can also be decided that only freight traffic is prioritised when a substantial part of the traffic is freight traffic, if this is more cost effective.

Table 2-3. Classification of road network levels (Van Nes, 2002)

Network level	*Spatial level*	*Road spacing [km]*	*Access spacing [km]*	*Speed [km/h]*
Urban				
Street	Neighbourhood	1	0,3	20
Arterial	District	3	1	35
Expressway	'City'	10	3	55
Interurban				
Local	Village	3	1	35-40
Regional	Town	10	3	60-70
Interregional	City	30	10	100-120
National	Agglomeration	-	-	-
International	Metropolis	-	-	-

Table 2-4. Adapted classification of road network levels from table 'Classification of road network levels' (Van Nes, 2002)

Network level	*Spatial level*	*Road spacing [km]*	*Access spacing [km]*	*Speed [km/h]*	*Roads*
Local	Village	3	1	30-50	Local road
Regional	Town	10	3	60-80	National road
Interregional	City	30	10	100-130	Motorway

When the fundamental issue of the problem is established as primarily a capacity problem, the next question to be answered is: *"Are two groups of road users involved?"* For this question, the same explanation (separation of traffic can only take place based on differences in traffic) holds as discussed in the previous section.

If two groups of road users are involved, the next question to be answered is: *"Do you want to prioritize at least one of those groups of road users?"* As explained in this section, the through going traffic can be hampered by local traffic which is merging onto- and exiting the motorway. The main reason for applying unbundling then is to give the through going traffic back its Level of Service. This does not mean that the situation becomes better for local traffic as well. Although, it is possible that the unbundling measure is beneficial for both traffic flows.

As shown in Figure 2-5 (p.17), the next action is to conduct a cost-benefit analysis (CBA) which is done in order to find out if the social benefits outweigh the social costs. Generally, CBA is not included in the decision tree for policy and safety reasons. This is because when unbundling is applied due to policy reasons, applying unbundling becomes the only option and, therefore, conducting CBA, as a decision tool, will make no difference. However, CBA can be executed for policy and safety reasons in order to find out the costs and benefits of the measure rather than using it as a decision tool. When CBA turns out negative, unbundling can still be applied in order to safe 'that one life', in terms of safety. Thereby, based on the fact that the biggest problems in terms of safety, are located in the local and regional levels of the road network (IBM Cognos PowerPlay Studyio, 2016), the safety reasons for applying unbundling are considered less relevant in this study.

Moreover, in the case of capacity problems, it is possible that applying unbundling results in high travel time gains with even higher constructions costs. Consequently, when costs are higher than the benefits gained by the measure, it is more likely to apply another measure. How the CBA is executed and which effects are taken into account during this study, will be discussed in Section 2.3.1. The focus of this study is on the capacity nature of the problem. However, safety is one of the indicators of how a network is performing and will be included in the cost-benefits analysis.

2.3 Network analysis methods

Two methods are used to analyse the results of the simulations later in Chapter 5. These methods include the cost benefit analysis and network performance indicators.

2.3.1 Cost benefit analysis

Since 2000, it has been required in the Netherlands to execute a Cost-benefit analysis (CBA), in accordance with *'Overview of the Effects of Infrastructure (OEI)'* (Eijgenraam, et al., 2000) for infrastructural projects of national interest (Rijkswaterstaat, 2012). The guidance document of Eijgenraam et al. (2000), on the evaluation of infrastructure projects, is a widely endorsed set of guidelines on preparing a CBA for transport infrastructure project in the Netherlands. Since its publication in 2000, it has been developed and expanded, a new guidance document has been made (available) and serves as the general guide on social cost-benefit analysis, (Romijn & Renes, 2013).

The essence of a CBA is stated in this document (ibid.) as follows: *"The essence of a CBA is weighing up different project or policy alternatives by comparing their welfare effects on society as a whole: the economic and social costs and benefits calculated at the national level".* If the benefits outweigh the costs, the society benefits as a whole. However, a negative balance results in reduced social welfare, and should therefore not be implemented (ibid.). Since infrastructural projects affect markets throughout the economy, Eijgenraam, et al. (2000) states that a CBA is the most adequate method for evaluating investment in infrastructure. It must be noted that in some cases it may not be possible to value a quantified effect (Romijn & Renes, 2013). Therefore, qualitative methods can be used for valuing the effect. For instance, it can be estimated if the effect is negative or positive for a certain alternative.

In terms of traffic handling/management, it is possible that under certain circumstances unbundling is a really good measure for solving bottlenecks. However, unbundling is, in comparison with 'regular' road extension, an expensive measure to apply. This might mean that the benefits of unbundling, for instance, decreased travel times, do not outweigh the investment costs of the measure.

The execution of a CBA involves eight steps, which are shown in Figure 2-7 (p.24). This figure also shows in which sections of this report the steps are conducted.

In order to compare the alternatives, it should be determined which effects are considered during the CBA. Stated by Romijn & Renes (2013): *"A CBA stands or falls on the degree to which the effects of a measure can be determined and valued. The better that can be done, the more useful the CBA will be in supporting the decision-making".*

Three kinds of effects can be designated within a CBA and are shortly explained hereafter (ibid.):

- **Direct effects** – Effects in the market where the measure is implemented are called direct effects. In an infrastructural project, travel time savings (or losses) are an example of a direct effect, and strongly rely on traffic flows, which are determined by individual behaviour of users and operators.
- **Indirect effects** – Effects in all other markets than where the measure is implemented, are called indirect effects. For instance, for a supermarket, travel time gains of trucks which provide them with supply, may result in a more efficient staff deployment. Therefore, the

supermarket benefits indirect from the implementation of the measure. However, the opposite is possible as well.

- **External effects** – As mentioned by Eijgenraam, et al. (2000), externalities are unintended, unpriced effects on the well-being of third parties. With the exception of network effects, they generally have a negative effect. Therefore, external effect include atmospheric pollutants, noise pollution, all the effects on the ecosystems and effects on safety.

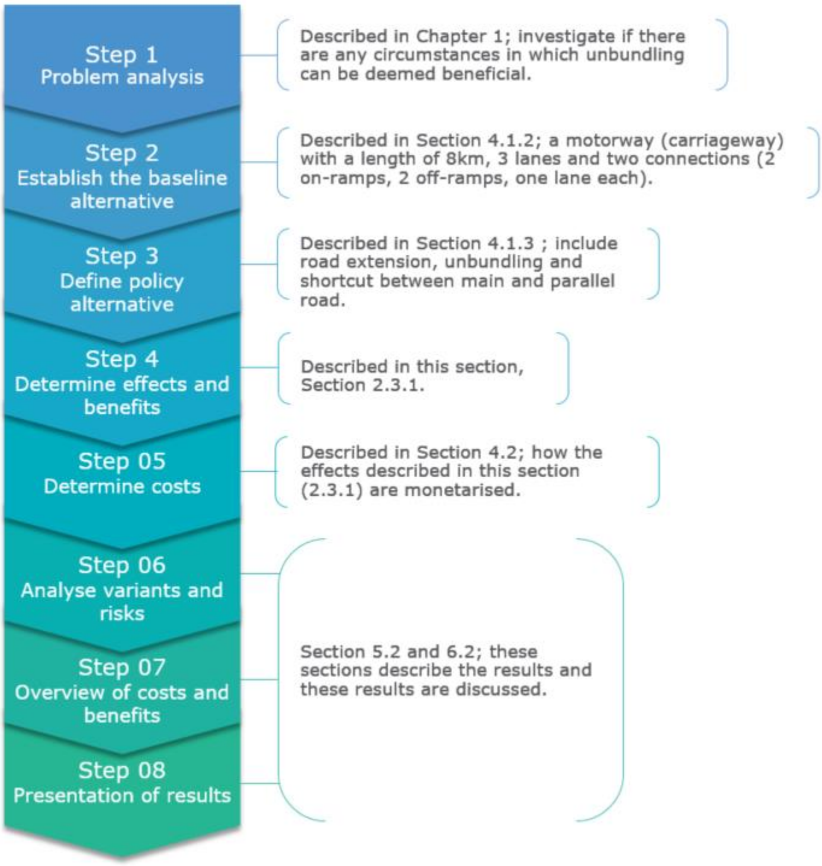


Figure 2-7. The eight steps in a CBA (Romijn & Renes, 2013)

Besides these effects, construction/investments costs is the last factor involved. These costs include preparing costs, exploitation costs, maintenance costs, purchase of land/buildings, salaries, and costs for materials, such as asphalt, concrete, crash barriers, etc. Since for a road design in which unbundling is applied, more land is needed and twice as much crash barriers, the costs for unbundling is much higher than when extending the road with more lanes.

In order to calculate the long-term effects, costs for a set amount of years in the future are estimated in a CBA. Since general prices will change over time and, costs and benefits must be corrected for this inflation, a discount rate is used. This discount rate is used in order to obtain the present values in one year by discounting all future values (Romijn & Renes, 2013). How to exactly execute a CBA, which effects to include, and how to use discount rates, is extensively explained in the 'General guidance for Cost-Benefit Analysis' (ibid.).

As can be derived from the above, conducting a good and reliable CBA is a complex process. However, it is not always necessary or useful for all stages of the decision-making process to conduct a full CBA (Romijn & Renes, 2013). Comprehensive and indices are the two types of CBAs that can be distinguished. The comprehensive CBA is the most accurate, all the steps are carried out and all the effects are identified, measure and valued (ibid.). The amount of research involved, which can make the study lengthy and costly to carry out, is a drawback of this type of CBA. The determination of effects and valuations of an indices CBA is less precise and is based on rules of thumb and index numbers in an indices CBA, which means that this type of CBA is quicker and cheaper, but also less accurate, than a comprehensive CBA (ibid.).

Since the alternatives (Section 4.1.3) considered in this study are really global (low complexity), they concern archetypes, and the amount of alternatives is quite high, the indices CBA is the most suitable type for evaluating the alternatives in this study.

It should be noted that whether the CBA is positive or not, the decision for implementing one of the alternatives or changing the road infrastructure, is still a decision of the government. Therefore, the choice implement or not can be made due to any reason.

Effects considered in this study

This section describes which effects are taken into account in this study. Section 4.2 discusses the used values and provides an extensive explanation on what is included in all the effects and how they are calculated.

The two main factors which influence the outcome of the CBA in infrastructural road design projects the most significant, are the investment costs (including maintenance) and the travel time gains (Romijn & Renes, 2013). The reason for the importance of travel time changes is that the main effect of a road extension project, or in this case an unbundling project, is usually shorter travel times. With the decrease of travel times, travel costs for the road users decrease as well. Those generalised travel costs can be seen as the price of travelling. This decrease in price leads to an increase in demand, which is expressed as an increase in the number of journeys (Romijn & Renes, 2013). The travel time gains, however, are taken into account and calculated based on the total time spent in the network and the Value of Time.

Furthermore, the externalities taken into account include safety, emissions and noise pollution. These are basically the effects, although less extensive, that are taken into account in infrastructure road projects (DECISIO, 2014a; DECISIO, 2014b).

These aforementioned factors are considered the most important during this study. A time period of 23 years (until 2040) is considered for this study. In order to monetarise all the effects, the total distance driven (veh.km) and the total time spent (veh.hour) are needed.

An overview of all effects taken into account is shown in Table 2-5 (p.26).

Table 2-5. Effects taken into account in CBA

	Effect		Monetarisation
Financial	Construction costs	Per lane	*€/km*
	Maintenance costs	Per certain distance	*€/km*
Direct	Travel time gains (VoT):	Car	*€/veh.hour*
		Freight	*€/veh.hour*
Indirect	x		
External	Air Pollution	Particulate matter	*€/kg*
		Nitrous oxides	*€/kg*
		CO_2	*€/kg*

2.3.2 Road performance indicators

In order to compare the alternatives, in chapter 5, performance indicators are needed to be determined. With the indicators can be perceived what effects the alternatives, changes in the infrastructure, have on the network performance (Grontmij, 2015). Performance of a network indicates how 'good' or 'bad' the network is exploited and is a multi-faceted indicator. Based on the performance indicators stated in the 'Capaciteitswaarden Infrastructuur Autosnelwegen' (ibid.), Table 2-6 shows the performance indicators considered in this study. Since the simulations cover 10 periods of 15 minutes (2,5 hours), the outcomes for the performance indicators will reflect these 2,5 hours.

A few of the needed indicators can also be derived from the CBA. The total distance driven (veh.km) and the total time spent (veh.hour) in the network are needed in order to calculate costs and/or benefits of the designated effect.

Besides these network performance indicators, queue length and visualisations of the queues are used in the evaluation of the alternative networks in chapter 5.

Table 2-6. The performance indicators

Performance indicator	Explanation
Amount of vehicle loss hours (total delay) *Expressed in veh*hours*	A higher total delay negatively influences the performance of the network, which leads to lower velocity and less distance travelled.
Total distance travelled *Expressed in veh*km*	The more distance travelled, the less delay and the higher the speeds.
Congestion	Visualisation.
Average speed *Expressed in km/hour*	The higher the average speed, the faster vehicles were able to drive, the more distance travelled.
Total time spent in the network (total travel time) *Expressed in veh*hours*	The less time spent in the network, the higher the speeds and the smaller travel times.

2.4 Conclusion

Section 2.1 has explained what unbundling is, what different types of unbundling exist and how the subject is scoped for this study. In this research, the type of unbundling that is considered, is the static separation of through and local traffic on motorways.

Since the reports, discussed in Section 2.2, address merely one way of unbundling without ever mentioning the overarching concept, it was unclear in which situation unbundling should be applied. All of the individual reasons for applying unbundling discussed in the researches may be categorized under one of the following three situations: policy-, safety- and/or capacity reasons. Based on these three situations in which unbundling can be applied, the decision tree is determined. It needs to be noted that this tool indicates only if unbundling is a potential measure to be considered an alternative, not if it is the best solution.

In Section 2.3 the network analysis methods, cost-benefit analysis and the performance indicators, are discussed. The effects that are taken into account in the cost-benefit analysis include: investment & maintenance costs, travel time effect, safety effect, emission effects and noise pollution effects. These are basically the effects, although less extensive in this study, that are taken into account in infrastructure road projects. The most important performance indicators are: total delay, total distance travelled, average speed, congestion and total time spent in the network. In order to find out under which circumstances unbundling might be a beneficial measure, the CBA and the performance indicators which will be used to evaluate the alternatives further on in this report (Chapter 5 & 6).

This means that the first four sub-questions have been answered.

3 Archetypes

This chapter shows how the archetypes have been generated. Archetypes (i.e. standard infrastructural road configurations) will be used to test the circumstances under which unbundling may be beneficial. What the circumstances are, will be explained in chapter 4. Since the ultimate purpose of this study is to create a manual on under which circumstances unbundling can be deemed an alternative, it is important that all possible road designs of motorways in the Netherlands are covered by the archetypes. If any circumstances are found, these can be included in the decision tree before the execution of CBA.

Section 3.1 explains how the archetypes are determined and Section 3.2 shows the actual archetypes. In Section 3.3 the motivation for the chosen archetype that will be evaluated in this study is discussed. By generating archetypes, sub-question five will be answered.

3.1 Determination of archetypes

An archetype is a common event or situation seen throughout similar works. Therefore, archetypes can be defined as standard configurations. Since the ultimate purpose of this study is to create a manual on in which situations and under which circumstances unbundling can be considered an option, there is a need for standard road configurations that cover all possible configurations in the Netherlands. There are many ways to determine archetypes and many characteristics can be distinguished when designing a road/carriageway (no road is the same):

- Amount of lanes
- Width of the lanes
- Presence of hard shoulder
- Amount of connections
- Length of on- and off-ramps
- Distance between ramps
- Amount of lanes on ramps
- Presence of weaving areas
- Length of the weaving areas
- Maximum speed limits
- Intersecting motorways (nodes)
- Amount of intersecting motorways
- Location (on a hill, in a curve etc.)
- Where it is geographically located

Besides, there are discontinuities that affect the performances which include merging, exiting, end of lane, an extra lane, etc. Moreover, the weather has an impact on the performance of the network as well. However, when taking into account all these characteristics, there are too many possibilities and many simulations should be executed (very time consuming). Therefore, a selection is made of characteristics that are taken into account in order to determine archetypes. Discontinuities are left out, as well as weather conditions.

Since the focus in this study is on motorway networks in the Netherlands and the separation of through and local traffic (Section 2.1.3), only three main characteristics are taken into account.

First of all, the geographical location makes a difference in the distribution of through and local traffic. Due to the presence of network levels, explained in Section 2.2.3, and because of the difference in distribution of through and local traffic between these levels, a geographical location based method is used to define the archetypes. In urban areas the connections (on- and off-ramps) are situated more closely together than in rural areas, which makes it easier for local traffic to make use of the motorway network. Therefore, it can be assumed that the share of local traffic in urban areas is substantially higher than in rural areas. Since most local traffic is expected in urban areas, it is assumed this will have a bigger negative impact as well, which makes these areas the most interesting areas in terms of this study. The defined areas, which are related to the network levels, are (Figure 3-1):

- Urban area (city).
- Radial area (near city); between urban and rural areas.
- Rural area; between radial areas.

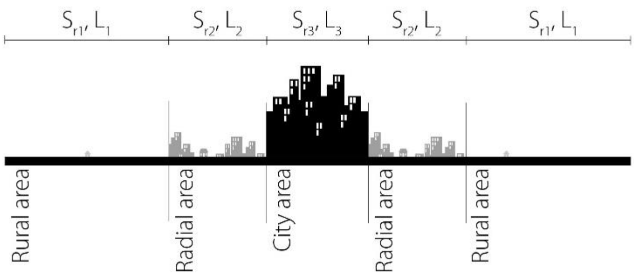


Figure 3-1. Archetype areas

Urban areas (cities), are in the Netherlands defined as cities with 70.000, or more, inhabitants (Van Nes, 2002). Figure 3-2 (p.31) shows how the areas are distributed over the Netherlands. Moreover, the figure also shows where the already unbundled situation in the Netherlands are located.

Secondly, the intersecting motorways characteristic is taken into account which directly leads to the last characteristic; the amount of intersecting motorways. Usually in city areas, motorways intersect more often than in rural areas and/or end more often near a city. These intersections can have a serious impact on the handling of through and local traffic, especially because of turning, merging and exiting traffic.

3.2 The archetypes

The numbers in Figure 3-2 (p.31) show the already unbundled situations in the Netherlands (Appendix A1) and where they are located. Based on the already unbundled situation in the Netherlands, nine archetypes, which cover all possible road designs in the Netherlands, have been determined and are shown in Figure 3-3. Only the generalised layout (standard configuration) of the motorways serves are archetype, connections (on- and off ramps) are not included in the archetypes. Some archetypes are added for completeness. Moreover, the archetypes are categorised under one of the following three areas: urban, radial or rural.

Appendix A2 shows how the already unbundled situations are linked to the archetypes.

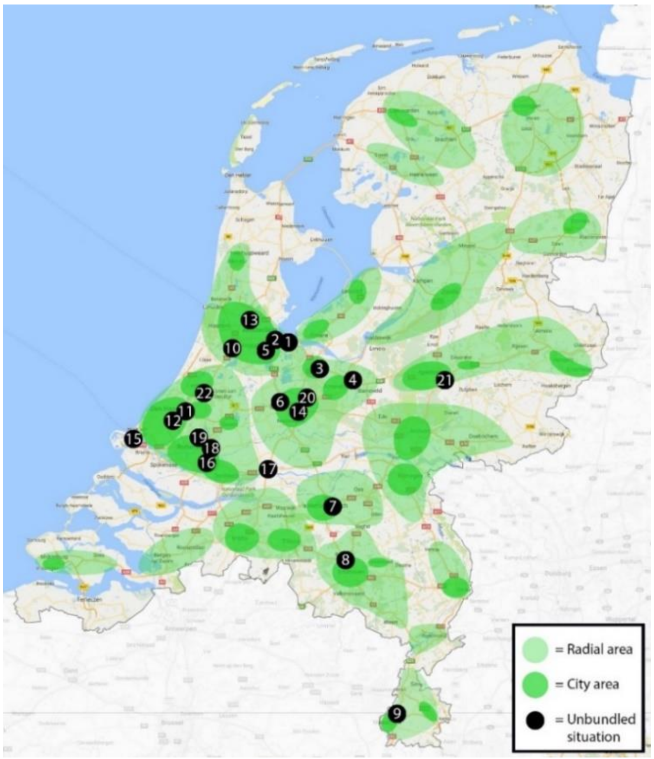


Figure 3-2. Considered areas and locations of already unbundled situations in the Netherlands[3]

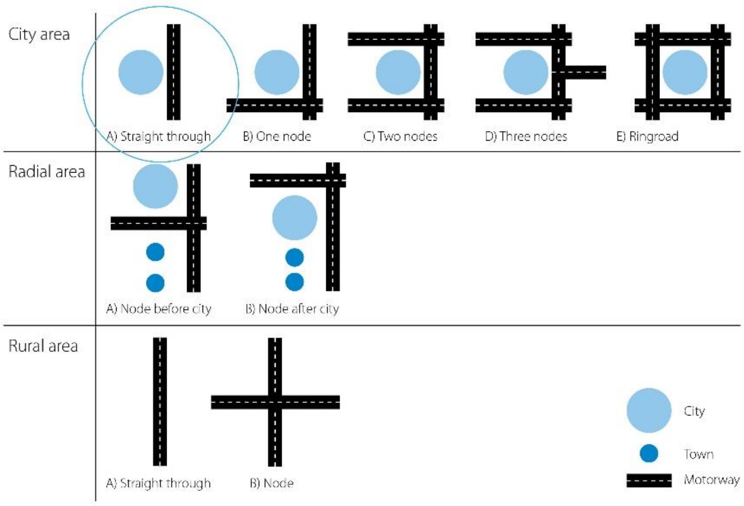


Figure 3-3. The archetypes classified by area type

[3] The list with the unbundled situation in the Netherlands can be found in Appendix A.

3.3 Choice of archetype

As shown in Figure 3-2 (p.31) and Appendix A2, most of the already unbundled situations are located in urban areas. This implies, as assumed earlier, that most of the problems concerning through and local traffic occur in urban areas. Therefore, the focus of this study is narrowed down to this area. There are two main reasons for choosing archetype A (straight through) of the city area.

First, due to time constraints, only one archetype is examined in detail in order to evaluate the circumstances in which (if any), unbundling can be deemed beneficial. What the circumstances are, is explained in Section 4.1.4. Since archetype A is the least complex archetype (least time consuming), this archetype is chosen to start with.

Secondly, all other archetypes are an extension to this archetype. This research is the first step towards defining guidelines on under which circumstances unbundling can always be deemed beneficial (or not). Therefore, it is most logical to start evaluating the most simple archetype alternatives and make it not too complex.

Therefore, Archetype A, straight through, of the city area is picked to examine extensively in this study.

3.4 Conclusion

This chapter described which and how archetypes (i.e. standard infrastructural road configurations) are determined. These archetypes are needed in order to test the circumstances under which (if any), unbundling can be deemed societally beneficial (chapter 5 and 6). The considered circumstances are defined in chapter 4.

Based on the already unbundled situation in the Netherlands, nine archetypes, which cover all possible road designs in the Netherlands, have been determined in Section 3.2. Moreover, the archetypes are categorised under one of the following three areas: urban, radial or rural. Since most of the unbundled situations are located in urban areas, this study focusses on this area. Due to time constraints, only archetype A, straight through, is chosen to test the unbundling measure and the circumstances in order to find out if there is a relation between the performance and the circumstances. With this, the fifth sub-question has been answered.

4 Design of simulations

The aim of this chapter is to provide explanation on how the set-up of the simulations is executed (which values are used and which aspects are taken into account). Simulations are needed in order to find out if there is a relation between the circumstances and the performance of unbundling measure. In the previous chapter one archetype is chosen to test this with/on.

Section 4.1 discusses which simulation model to use for the simulations. Moreover, explanation is given on how the base case and the alternatives infrastructures are characterised and is shown which circumstances are considered. Section 4.2 explains how cost-benefits analysis is executed and which values are used. By explaining the design of the simulations and evaluation methods, sub-questions 6 and 7 will be answered.

4.1 The simulations

This section provides information on the choice of simulation program, how the base case and alternative infrastructures are determined and which circumstances are considered.

4.1.1 Choice of simulation model

Since each model is a simplification of reality, models give no exact values for new/future situations (Hoogendoorn, et al., 2007). However, the strength of models primarily lays in the systematic comparison of variants (ex-ante studies) (ibid.). In order to find out, if unbundling can be deemed beneficial under any of the circumstances that will be determined in Section 4.1.4, a simulation model needs to be chosen.

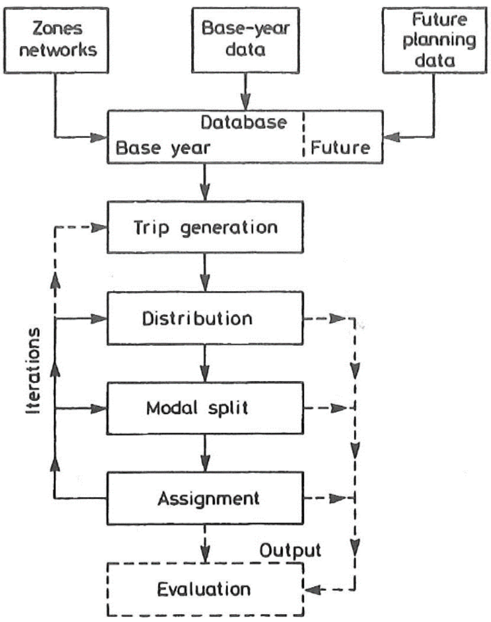


Figure 4-1. The classic four-stage transport model (de Dios Ortúzar & Willumsen, 2011)

Generally, simulation models can be divided in (four) main sub-models (Figure 4-1, p.33):

1. **Trip generation** - In this model the amount of departures and arrivals (amount of trips) (movements) per zone is generated.
2. **Trip distribution** - This model divides the calculated departures over the calculated arrivals. This results in and Origin-Destination matrix (OD-matrix) per purpose per time of the day.
3. **Modal split** - The model split model allocates the trips in the OD-matrix to different modes (car, train, bike, etc.).
4. **Assignment** – the last stage requires the model that 'assigns' traffic to the network and determines the traffic conditions on each road section and describes the driven speed. This depends on other road users on the same road section, capacity of the road section, the geometry of road design, etc.

In this study the first three stages are replaced by a given OD-matrix (Section 4.1.4). Therefore, it must be possible to add the OD-matrix and the capacity (of each link) as input in the simulation model.

How traffic is assigned to a network strongly depends on the manner the model deals with the dimensions of time and space (Hoogendoorn, et al., 2007). Therefore, the choice between a dynamic or static model has to be made. For this particular study, a dynamic model is preferred. Reasons for static models being inadequate are the following:

1. **Occurrence of congestion affects the on-trip route choice of (through going) travellers.** Changes in route choice after departure, can only be captured by dynamic models.
2. **Static models do not consider congestion itself, only travel times.** Therefore, the physical location, and therefore the spillback, of the congestion is not considered. Dynamic models allow queuing and position of the queue in the network. In this study it is important to take spillback effects into account, because in case of unbundling, through going traffic can choose between two routes.
3. **Traffic flows exceed link capacities in static models.** Dynamic models on the contrary, indicate the capacity of their links based on a realistic physical maximum flow.

Therefore, the use of dynamic modelling is recommended for the purposes of this study as they account for spillback effects as well as en-route decision-making.

Moreover, since only passenger cars (commuting traffic) and freight traffic are considered in this study, the model must be able to simulate these two user classes. Besides, the model should be able to simulate motorways. Additionally, it should be possible to obtain the performance indicators, as discussed in Section 2.3.2, from the output.

Another criteria concerns the detail level of the model. Three main detail levels can be distinguished (Calvert, et al., 2016; Hoogendoorn, et al., 2007):

- **Microscopic** – such a model describes the behaviour of individual road users and the interaction between them. One can predict individual speeds, lane usage and car-following distances at any time at any place in the network (Calvert, et al., 2016). In comparison to the other two detail levels, these models have the highest level of detail[4] but on the other hand also the highest calculation time.

- **Mesoscopic** – is used for a range of models that use groups of vehicles as starting point for the traffic flow condition calculations, while individual vehicles are moved over the network applying the calculated speeds of the groups they belong to (ibid.). However, movement of groups of vehicles is based on macroscopic relations.
- **Macroscopic** - describes the behaviour of traffic flows in general. A macroscopic model is a mathematical model that formulates the relationship between aggregate traffic flow characteristics of a traffic stream, like density, flow, mean speed, etc. The method of modelling traffic flow at a macroscopic level originated under an assumption that traffic flows are comparable to fluid flows (ibid.).

In this study a small network is considered and the main interest is in traffic flows. Besides, all the network performance indicators (Section 2.3.2), can be derived from a macroscopic model. Therefore, a macroscopic level is adequate. Table 4-1 shows the models that are currently used in the Netherlands and internationally (Calvert, et al., 2016) and if they use macroscopic simulation. One of the models that use macroscopic simulation will be chosen to use in this study.

Table 4-1. Current models used in the Netherlands and internationally (Calvert, et al., 2016)

	TRANSIMS	MARPLE	Cube Voyager	PTV VISUM	EMME	TransModeler	INDY	DynaMIT	VISSIM	Paramics	CORSIM	NRM	LMS	Omnitrans	AIMSUN	ALBATROSS	FOSIM
Macro simulation		✓	✓	✓	✓	✓	✓							✓	✓		

There is one more important criteria which considers the access to the simulation models. Access to the simulation models must be obtained without paying for it or without using the trial version. Table 4-2 (p.36) shows the macroscopic simulation models and shows if they meet this and the other criteria defined in this section.

As can be seen from Table 4-2 (p.36), of all models, only OmniTRANS and MARPLE meet all the criteria. However, OmniTRANS is not a model, but a modelling environment in which actual models can run /be included. Other models can use OmniTRANS to model. MARPLE can also model within this environment, but since quite a lot of simulations need to be done (Section 4.1.4), it is preferable to use MAPRLE without OmniTRANS. Therefore, MARPLE is chosen to execute the simulations with.

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[4] Note that using a microscopic model, with its high level of detail, does not automatically lead to a better prediction of the situation.

MARPLE is an abbreviation of "Model for Assignment and Regional Policy Evaluation" (Taale, 2008), and assigns traffic dynamically. MARPLE is fast and simple model that can simulate route choice. For each OD-pair the routes are determined (shortest routes, in distance or travel time) and the traffic is assigned to the routes by initial allocation (Taale, 2016).

Travel times on the links are calculated using travel time functions, which are based on the saturation level (I/C ratio) (ibid). Therefore, the traffic flow on a link depends on the travel times and the capacity of the link. Besides, the model takes the available space and the spillback of congestion into account.

Table 4-2. Choice of simulation model (state-of-the-art)

	OmniTRANS	AIMSUN	MARPLE	Cube Voyager	PTV VISUM	EMME	TransModeler	INDY
Input of capacity and OD matrix	✓	?	✓	?	?	?	?	?
Dynamic (en-trip route choice)	✓	✓	✓	?	✓	x	✓	✓
Simulation of different user classes	✓	?	✓	?	✓	✓	✓	✓
Motorway simulation	✓	✓	✓	?	✓	✓	✓	✓
Input infrastructure	✓	✓	✓	?	✓	✓	?	✓
Subjective criteria								
Access to the model	✓	x	✓	x	x	x	x	x

Two input files are needed for MARPLE. First, a file with general parameters. The second file contains a description of the network and also contains the OD-matrix. Subsequently, the simulation follows in order to determine the traffic flows and the corresponding indicators (flows, speeds, travel times, network indicators, etc.) (ibid.). The output consist of the following data (ibid.):

- Flows, speeds, standard deviation of the speeds and density of each link;
- Travel time and the delay for each OD-pair and route;
- Travel times, delays and speeds for each specified part of the network (traject).

And, the network indicators for the whole network and per network type:

- Amount of vehicles;
- Distance covered;
- Time spent in the network;
- Average speed;
- Delay.

These output data and indicators match with all the needed performance indicators (for this study) as determined in Section 2.3.2. The calculation time mainly depends on the amount of routes (and thus OD-pairs), the amount of links in the network and amount of time steps of the simulation. All these amounts are quite low for the simulations in this study, which makes this the most suitable tool for this study.

As mentioned in Section 2.1.3, static separation is considered in this study. For the simulation model it does not matter if the separation is physical or non-physical, the traffic is simulated in a 'static' way anyway, it does not matter to the simulation model how the infrastructure looks. It does not change anything on the simulation (or the way it is simulated). However, it does make a difference for the investment/construction costs, which will be captured in the CBA.

4.1.2 The base case

As determined in chapter 3, archetype A of the urban area is taken into account for this study. The characteristics of the base case are based on either established design guidelines (Grontmij, 2015; Rijkswaterstaat, 2015) or on the most common manner the concerned characteristic is applied in the Netherlands. A more detailed reasoning is provided in Appendix B1.

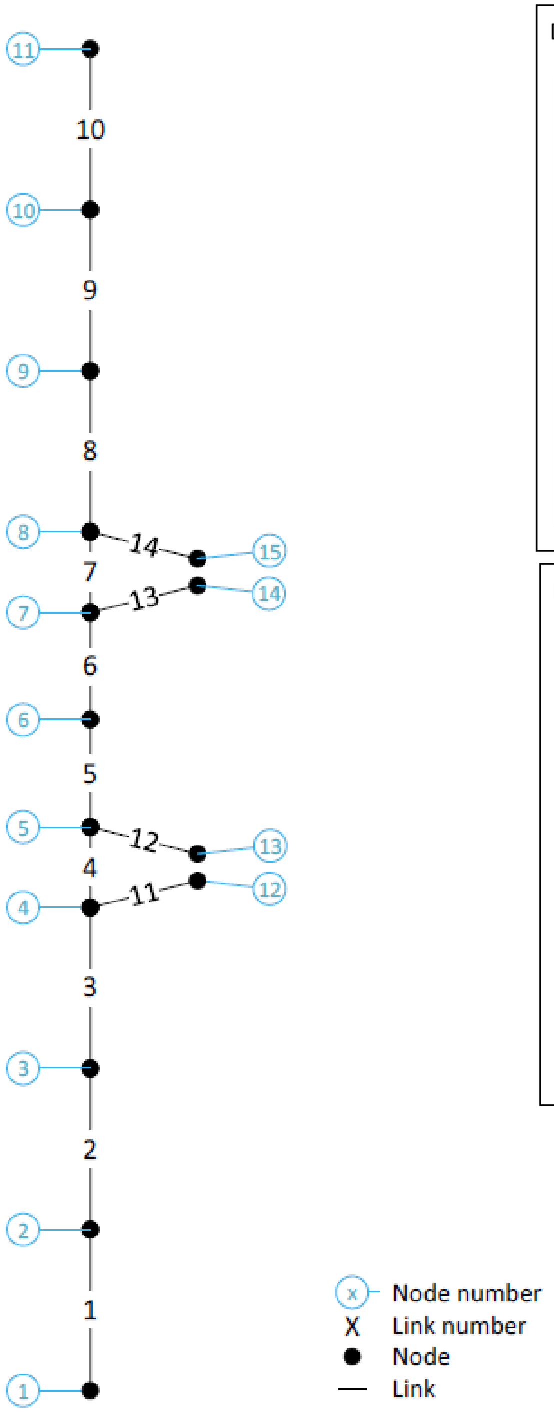
The base case is considered a three lane carriageway with a length of 9 km and a maximum speed of 120 km/h. Two connections are included, which means two on-ramps and two off-ramps, all of them exist of one lane. Due to Rijkswaterstaat (2015), the distance between an exit and an on-ramp should at least be 150m at a design speed of 120 km/h. However, the simulations will be executed with fixed time steps of 10s, which means that congestion is not visible in the output on this link. This is because the travelled distance in one time step becomes 333m, which is longer than the link. Therefore the length of those links is adjusted to 350m. The distance between the first on-ramp and the second exit should at least be 750m (Rijkswaterstaat, 2015) and is set to 1500m. The length of the exit and on-ramp links is considered 500m, the remaining links have a length of 1000m. Figure 4-2 (p.38) shows the input characteristics of the considered base case network. The capacity of each lane is equal to the values shown in Table 4-4 (p.38). Capacities are defined based on the share of available freight traffic (Grontmij, 2015), which is also input for the simulation model. Assumed is the average of 15% freight traffic which decreases a bit during rush hours (Grontmij, 2015). Table 4-3 shows the considered shares for commuters and freight traffic for each period of time. As can be seen, the simulations exist of ten time periods, of which period exists of 15 minutes each. Therefore, each simulation represents 2,5 hours. Although the origin-destination are represented by different numbers in the unbundled alternatives, these percentages are equal for all simulations.

Table 4-3. Freight share considered during the simulations (%)

Origin - destination	Time period	1	2	3	4	5	6	7	8	9	10	11	12
1-11	Commuters	85	90	90	85	85	85	85	85	85	85	85	85
	Freight	15	10	10	15	15	15	15	15	15	15	15	15
1-12	Commuters	95	95	95	95	95	95	95	95	95	95	95	95
	Freight	5	5	5	5	5	5	5	5	5	5	5	5
1-14	Commuters	95	95	95	95	95	95	95	95	95	95	95	95
	Freight	5	5	5	5	5	5	5	5	5	5	5	5
13-11	Commuters	95	95	95	95	95	95	95	95	95	95	95	95
	Freight	5	5	5	5	5	5	5	5	5	5	5	5
13-14	Commuters	100	100	100	100	100	100	100	100	100	100	100	100
	Freight	0	0	0	0	0	0	0	0	0	0	0	0
15-11	Commuters	95	95	95	95	95	95	95	95	95	95	95	95
	Freight	5	5	5	5	5	5	5	5	5	5	5	5

Table 4-4. Capacity motorways (with 15% freight traffic) (Grontmij, 2015)

Road section	Capacity (veh/hr)
1 lane	1.900, length > 1.500m 2.100, length < 1.500m
2 lanes	4.300
3 lanes	6.200
4 lanes	8.200



Data Base Case

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	120	3	6200
2	1000	120	3	6200
3	1400	120	3	6200
4	350	120	3	6200
5	750	120	3	6200
6	750	120	3	6200
7	350	120	3	6200
8	1400	120	3	6200
9	1000	120	3	6200
10	1000	120	3	6200
11	500	80	1	2100
12	500	80	1	2100
13	500	80	1	2100
14	500	80	1	2100

Data Road Extension

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	120	4	8200
2	1000	120	4	8200
3	1400	120	4	8200
4	350	120	4	8200
5	750	120	4	8200
6	750	120	4	8200
7	350	120	4	8200
8	1400	120	4	8200
9	1000	120	4	8200
10	1000	120	4	8200
11	500	80	1	2100
12	500	80	1	2100
13	500	80	1	2100
14	500	80	1	2100

Length of the routes

Origin	Destination	Length route (km)
1	11	9
1	12	3.09
1	14	5.75
13	12	5.75
13	14	2.5
15	12	3.9

Figure 4-2. Base case & road extension alternative infrastructure characteristics

4.1.3 The alternatives

In order to test the performance of unbundled situations, several alternatives are determined. Another logical measure to apply when 'capacity problems' occur, is the construction of extra lane (road extension), which is considered the most regular measure to apply. Figure 4-3 shows the considered/determined alternatives.

The first alternative is road extension, in which the base case is provided with an extra lane. Therefore, the road extension alternative consists of four lanes. The characteristics for the extended alternative are shown in Figure 4-2 (p.38).

Then both the base case and the road extension are used as base for unbundled alternatives. In case of the extended alternative there are two options of dividing the four lanes over the main carriageway and the parallel road. For all unbundled situations it is taken into account that for through going traffic the route via the main carriageway and the route via the parallel road are nearly equal. Assumed is that the maximum speed restriction on the main carriageway is 120 km/h, on the parallel road 100 km/h and on the ramps the speeds restriction is set to 80 km/h. The characteristics for all unbundled alternatives are shown in Figure 4-4 (p.40).

Finally, there is an unbundled alternative with a shortcut between the main carriageway and the parallel road. This alternative is added in order to see what happens in terms of robustness. Figure 4-5 (p.40) shows the characteristics for the alternative has the shortcut included. Each of the alternatives will be tested under the circumstances determined in the following Section 4.1.4. A more throughout reasoning for the characteristics is provided in Appendix B2.

Since alternatives can only be compared when they have initially the same amount of lanes and in order to not compare separate issues, the networks with initially three lanes are compared and the networks with initially four lanes are compared separately for each circumstance. Therefore, the base case will be compared to the unbundled 2-1 and the extended alternative and the extended alternative will be compared to all other unbundled alternatives. This means that the extended alternative actually serves as a base case as well.

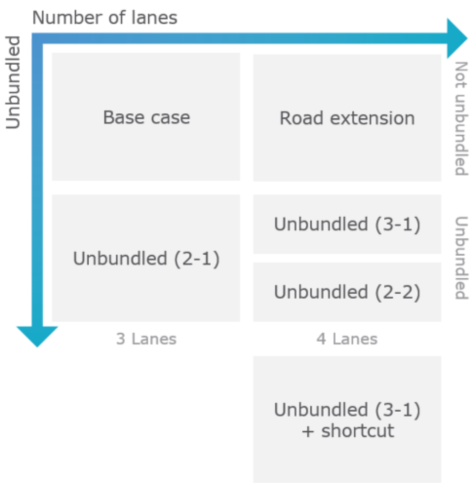
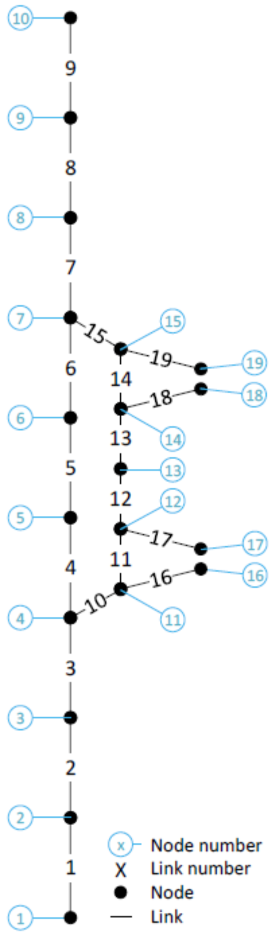


Figure 4-3. The alternatives



Length of the routes

Origin	Destination	Length route (km)
1	10 (MC)	9
1	10 (PR)	9.05
1	16	3.95
1	18	5.8
17	10	5.75
17	18	2.5
19	10	3.9

Data Unbundled 2-1

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	120	3	6200
2	1000	120	3	6200
3	1000	120	3	6200
4	1000	120	2	4300
5	1000	120	2	4300
6	1000	120	2	4300
7	1000	120	3	6200
8	1000	120	3	6200
9	1000	120	3	6200
10	450	100	1	2100
11	350	100	1	2100
12	750	100	1	2100
13	750	100	1	2100
14	350	100	1	2100
15	900	100	1	2100
16	500	80	1	2100
17	500	80	1	2100
18	500	80	1	2100
19	500	80	1	2100

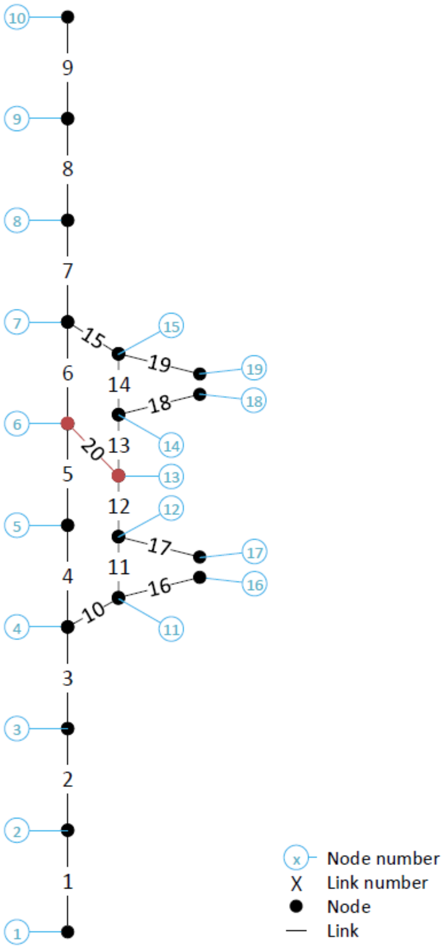
Data Unbundled 3-1

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	120	4	8200
2	1000	120	4	8200
3	1000	120	4	8200
4	1000	120	3	6200
5	1000	120	3	6200
6	1000	120	3	6200
7	1000	120	4	8200
8	1000	120	4	8200
9	1000	120	4	8200
10	450	100	1	2100
11	350	100	1	2100
12	750	100	1	2100
13	750	100	1	2100
14	350	100	1	2100
15	900	100	1	2100
16	500	80	1	2100
17	500	80	1	2100
18	500	80	1	2100
19	500	80	1	2100

Data Unbundled 2-2

Link	Length (m)	Speed (km/h)	Nr of lanes	Capacity (veh/hr
1	1000	120	4	8200
2	1000	120	4	8200
3	1000	120	4	8200
4	1000	120	2	4300
5	1000	120	2	4300
6	1000	120	2	4300
7	1000	120	4	8200
8	1000	120	4	8200
9	1000	120	4	8200
10	450	100	2	4300
11	350	100	2	4300
12	750	100	2	4300
13	750	100	2	4300
14	350	100	2	4300
15	900	100	2	4300
16	500	80	1	2100
17	500	80	1	2100
18	500	80	1	2100
19	500	80	1	2100

Figure 4-4. Network characteristics for all unbundled alternatives



Data Unbundled 3-1 + Shortcut

Link	Length (m)	Speed (km/h)	Nr of lanes	Capacity (veh/hr
1	1000	120	4	8200
2	1000	120	4	8200
3	1000	120	4	8200
4	1000	120	3	6200
5	1000	120	3	6200
6	1000	120	3	6200
7	1000	120	4	8200
8	1000	120	4	8200
9	1000	120	4	8200
10	450	100	1	2100
11	350	100	1	2100
12	750	100	1	2100
13	750	100	1	2100
14	350	100	1	2100
15	900	100	1	2100
16	500	80	1	2100
17	500	80	1	2100
18	500	80	1	2100
19	500	80	1	2100
20	200	100	1	2100

Length of the routes

Origin	Destination	Length route (km)
1	10 (MC)	9
1	10 (PR)	9.05
1	10 (SC)	9.4
1	16	3.95
1	18	5.8
17	10	5.75
17	10 (SC)	6.1
17	18	2.5
19	10	3.9

Figure 4-5. Network characteristics for the unbundled situation with shortcut

4.1.4 The circumstances

The circumstances are defined as the distribution of through and local traffic, and the (total) traffic demand. Both of them are explained in more detail hereafter.

Distribution of through- and local traffic

In Section 2.1.3 a definition for through and local traffic is given. Through and local traffic are, however, defined differently when the distribution is concerned. Although represented by different numbers (nodes) in the figures with characteristics, all alternatives include six OD-pairs. The distributions, however, only concern the distribution of traffic that enters the network at node 1 here (van Loon, 2016; Rijkswaterstaat & Goudappel Coffeng, 2015). Which means that, in the base case, only OD-pairs 1-12 and 1-14 are considered local traffic and only OD-pair 1-11 as through traffic. The other three OD-pairs are considered 'background traffic' and stay the same throughout the simulations for each distribution of through- and local traffic.

There are six different distributions of through and local traffic considered in this study:

- 50% through traffic - 50% local traffic
- 60% through traffic - 40% local traffic

- 70% through traffic - 30% local traffic
- 80% through traffic - 20% local traffic
- 90% through traffic - 10% local traffic
- 100% through traffic - 0% local traffic

Since each distribution will be tested on each of the alternatives, already 6*6=36 simulations are needed to be executed.

Traffic demand

Three circumstances considering the amount, are determined:

- Initially the demand is determined for the base case in such a way that congestion occurs. How this is done, is explained hereafter. This demand is referred to with 0.
- In order to take traffic growth into account, the previous determined demand is increased with 10%. This demand is referred to with +10%.
- The same is done for 20%.

Together with the 36 simulations of the distribution of through- and local traffic, this comes down to a total of 36*3=108 simulations. All the empty cells in Table 4-5 represent one of the simulations.

In order to determine the amount of traffic demand for initial input (the '0' demand), some assumptions had to be made.

The first assumption to be made, is how the local traffic is distributed over the two exits, which is a fixed distribution in this study. The determined distribution is 20% taking the first exit and 80% takes the second exit. These values are chosen based on actual traffic flows obtained from ViVA viewer (Rijkswaterstaat, 2014) and on the assumption that the second exit represents the connection to an intersecting motorway. Therefore, the distribution for the second exit is significantly higher.

Table 4-5. All the simulations

	Distribution (T/L) / Traffic demand	100-0	90-10	80-20	70-30	60-40	50-50
Base case	0						
	+10%						
	+20%						
Road extension	0						
	+10%						
	+20%						
Unbundled (2-1)	0						
	+10%						
	+20%						
Unbundled (3-1)	0						
	+10%						
	+20%						
Unbundled (2-2)	0						
	+10%						
	+20%						
Unbundled (3-1) + shortcut	0						
	+10%						
	+20%						

Secondly, in order to create a network in which congestion occurs, an initial demand and distribution for the through- and local traffic needed to be determined. Since the amount of through going traffic mainly differs between 60% and 75% in situations in the Netherlands (Kijk in de Vegte, et al., 2012), 65% is chosen as an average for this initial situation. These values will, during the simulations, be replaced by the aforementioned distributions (circumstances).

Then, an assumption should be made on how the amount of traffic demand differs over the ten considered time periods. In the second period the demand raises in order to create congestion (problem). After this period the demand decreases again. In this way, the network is able to 'recover' from the disruption. Since the demand during the simulations is static and the same for each simulation, the network needs to recover from the disruption. This allows all vehicles to depart and arrive. The total distance travelled is by definition lower in networks in which not all vehicles were able to depart and/or arrive. Besides, the total time spent in the network is probably lower as well. This gives misleading results on the performance of the network. Therefore, the alternatives cannot be compared when not all vehicles are able to depart and arrive.

Finally, the demands (between OD-pairs) themselves had to be determined. The initial value of 6100 (Figure 4-6, p.44) and the values for the 'background' traffic OD-pairs are set in such a way that (enough) congestion occurs. Figure 4-6 (p.44) shows the OD-pairs for each time period.

It is evident that for each circumstance (each distribution of through and local traffic), the amount of through and local traffic differs for each OD-matrix. Now both the alternatives and the circumstances are determined, 108 simulations need to be executed in order to test all alternatives under all circumstances. Appendix C shows, as an example, the input files for MAPRLE of the base case, a distribution of 60-40 at traffic demand 0 (Table 4-5, p.42, blue coloured cell).

Through traffic	0.65		Exit 1	Exit 2
Local traffic	0.35		0.2	0.8
Vehicles departing from origin 1:		6100		

Factor 1

Period 1	11	12	14
1	3965	427	1708
13	400	x	100
15	1000	x	x
Total			*7600*

Factor 1.1

Period 2	11	12	14
1	4361.5	469.7	1878.8
13	440	x	110
15	1100	x	x
Total			*8360*

Factor 1

Period 3	11	12	14
1	3965	427	1708
13	400	x	100
15	1000	x	x
Total			*7600*

Factor 0.95

Period 4	11	12	14
1	3766.75	405.65	1622.6
13	380	x	95
15	950	x	x
Total			*7220*

Factor 0.8

Period 5	11	12	14
1	3172	341.6	1366.4
13	320	x	80
15	800	x	x
Total			*6080*

Factor 0.65

Period 6	11	12	14
1	2577.25	277.55	1110.2
13	260	x	65
15	650	x	x
Total			*4940*

0.4

Period 7	11	12	14
1	1586	170.8	683.2
13	160	x	40
15	400	x	x
Total			*3040*

0.2

Period 8	11	12	14
1	793	85.4	341.6
13	80	x	20
15	200	x x	
Total			*1520*

0.2

Period 9	11	12	14
1	793	85.4	341.6
13	80	x	20
15	200	x	x
Total			*1520*

0.1

Period 10	11	12	14
1	396.5	42.7	170.8
13	40	x	10
15	100	x	x
Total			*760*

Figure 4-6. Determined traffic demand for initial situation with 65% through traffic and 35% local traffic (origins vertical and destinations horizontal)

4.2 Cost-benefit analysis

This section describes how the cost-benefit analysis is executed and which values are used for calculation. All the calculated costs/benefits are distributed over time with a discount rate factor of 1.4 (4%). Since only private cars and freight traffic are considered in this study, all private cars are considered commuting traffic.

All the effects determined in Section 2.3.1 are separately discussed hereafter and Appendix D shows extensive information on some of the effects. In the examples shown throughout this section, the benefits are negative and the costs are positive.

4.2.1 Investment/maintenance costs

The SSK[5] method is a very extensive method on estimating the investment and maintenance costs and is, in this study, used to calculate these costs for the alternatives. The calculation model is an Excel sheet in which both costs are determined and plotted over 100 years at the same time. The manual on the SSK-model (CROW, 2013) describes exactly how to use the method.

Since this study only considers simple infrastructure alternatives, and no specific situations, not all aspects are taken into account in these calculations. The aspects taken into account are:

- The width of the carriageway(s) and the amount of lanes on each carriageway
- Amount of lanes on the on- and off ramps
- Purchase real estate
- Purchase of properties
- Applying roads/pavement
- Applying lineation
- Applying crash barriers
- Applying street lighting
- Applying Dynamic Traffic Management system (DVM)
- Construction of overpasses / engineering structures
- All the maintenance costs for these constructions
- Taxes

Thereby, it is assumed that all roads are located at ground level (no height above or depth below ground level). This does, of course, not apply for the overpasses/ engineering constructions.

Appendix E shows, as an example, the calculated costs for the base case. Appendix E1 shows the input for a calculation, in this case for the base case. Appendix E2 show a summary of the outcome (costs) and Appendix E3 shows the extensive list of all aspects and their costs separately.

Since the alternatives with initially three lanes will be compared to the base case, the costs for these alternatives are compared to the investment and maintenance costs of the base case, which results in the costs for the alternatives. Therefore, Table 4-6 shows the costs for the alternatives in comparison to the base case. The same is done for the unbundled alternatives with initially four lanes, which are compared to the extended alternative. The investment and maintenance costs for all alternatives are summarised in Table 4-6 and already distributed over time until 2040. The calculated costs for each alternative are shown in Appendix E4.

Table 4-6. The investment and maintenance costs for the base case and all the alternatives

Initially three lanes	*Investment & Maintenance costs*	Initially four lanes	*Investment & Maintenance costs*
Base case	*Reference*	**Extended**	*Reference*
Unbundled 2-1	€ 10,730,000	**Unbundled 3-1**	€ 11,190,000
Extended	€ 6,990,000	**Unbundled 2-2**	€ 12,990,000
		Unbundled 3-1 + shortcut	€ 11,350,000

[5] 'StandaardSystematiek Kostenramingen' – this method is used by Rijkswaterstaat to estimate the investment and maintenance costs of an infrastructural project.

4.2.2 Travel times

In order to calculate the travel time effects, the total time spent (veh*hrs) is used. This total time spent is an output of MARPLE and is expressed in the total time spent (veh*hrs) for all vehicles together. However, the total time spent for cars and freight is needed separately in order to multiply the time with the right value of time. Therefore, the total time spent, together with the route flows and the distribution for car and freight traffic (Table 4-3, p.37) are used to calculate the time spent in the network for car and freight traffic separately.

By multiplying the distribution of car and freight traffic with the route flows, the amount of cars and freight vehicles per route (per time period) are calculated separately. This amount of vehicles per route is then multiplied by the route travel times, which are shown separate for cars and freight vehicles in the output of MARPLE. This results in the total hours spent in the network, distributed over passenger cars and freight vehicles, and can be used to calculate the travel time effects.

The differences in time (for car and freight separate) are, as an example, compared for the base case and an alternative. The difference in time is multiplied with the Value of Time (Table 2-1, p.12), which results in the time loss (costs) or time gains (benefits) expressed in monetary terms.

Table 4-7 shows an example of how the calculation of travel time effects will be executed. Therefore, this example concerns random values for the total time spent, of a random hour for no particular network. It only shows how to execute the calculation. The total time spent is lower for alternative X than for the base case and leads, therefore, to travel time gains, thus benefits.

Table 4-7. Example calculation of travel time effects

	Car	*Freight*
Base case (veh*hour)	800	150
Alternative X (veh*hour)	600	125
*Difference (veh*hour)*	*-200*	*-25*
VoT	€ 9.53	€ 46.54
Total	**€ - 1,906.00**	**€ - 1,163.5**

4.2.3 Safety

The effect on traffic safety concerns the change of the risks between project alternatives on the occurrence of the number of fatalities, the number of injuries and the total material damage of casualties (Rijkswaterstaat, 2012). These traffic effects are monetarised by multiplying the amount of victims and damage with the costs that relate to the severity of the injuries. The costs for each casualty are known (Wever & Rosenberg, 2012), but the estimation of the risks for the number of (each type of) incidents that will occur relies on several aspects (Iliadi, et al., 2015). One of those aspects, which plays a big role in estimating this risk, is the geometric characteristics of the road designs. Hereafter two studies concerning safety effects on motorways will be discussed.

First of all, Iliadi et al. (2015) developed a crash prediction model for weaving sections in the Netherlands. The results showed that the crash frequency of weaving sections is significantly affected by the length of the weaving section, the average annual daily traffic (AADT), the percentage of weaving cars, the number of lanes on the main motorway and the location of the weaving section relative to the interchange (if inside or outside the interchange) (ibid.). The length of the weaving area constrains the time and space in which the driver must make all required lane-changes. Besides, it influences the lane-changing intensity. However, the primary causes of crashes on weaving sections, is the lack of homogeneity in terms of driving speeds between weaving and non-weaving vehicles in the same traffic sections (ibid.). These changes and increased complexity raises the potential for conflicts and crashes. With the developed model, only the number of crashes is calculated and no different types of casualties. Besides, this study concerns weaving areas only, while the effects of unbundled structures needs to be known.

Moreover, Snelder, et al. (2016) studied how different topological and geometrical characteristics affect the risk of different types of occurring incidents. These characteristics include hard shoulders, the number of lanes, parallel road structures and weaving sections. The more lanes available, the more lane changing movements are needed in order to enter or leave the motorway, the higher the risk on incidents. Besides, if no hard shoulder is available, the probability of having accidents is also higher (ibid.). Although it is mentioned that the length of the parallel carriageway and the complexity of the weaving sections are important, the question whether or not it is advisable to split a roadway into two roadways needs to be answered on a network level and requires an additional analysis of the safety benefits and costs (ibid.). Therefore, it is not known what the effect on safety is when applying a parallel road.

However, assumptions can be made. Since it is not known what the effect of an unbundled network on safety is and no actual numbers/risks could be found to calculate with, it can be concluded that no actual risks can be estimated for an unbundled situation based on geometric characteristics and speeds. Instead, qualitative valuation is used to estimate safety effects. Based on the factors that influence safety mentioned in the two studies, it will be discussed what effects the different alternatives have on safety.

Since the length of the weaving sections, the average annual daily traffic, the percentage of weaving cars, the presence of hard shoulders and the location of the weaving areas are equal in the alternatives and the simulations, no effect on safety will be noticed for these factors. The two factors left, that do differ between the alternatives are the amount of lanes on the carriageways and the difference in speed between weaving traffic. Assumed is that the more lanes on a carriageway, the less safe the situation is. Therefore, the extended alternative is less safe than the base case.

Besides, it is assumed that the bigger the difference in speeds of weaving traffic, the less safe the situation is. In unbundled situations the weaving movements take place at the parallel road, which means that not all traffic suffers from turbulence. Therefore, unbundled situations are assumed to be more safe than not-unbundled situations. Besides, the maximum speed at the parallel road is lower than on the main carriageway. Therefore, the weaving movements take place at lower speeds (more homogeneity in terms of speed), which is assumed to be safer. Based on the two assumptions, Table 4-8 (p.48) shows what the effects of each alternative are on safety.

The unbundled 2-1 alternative is assumed to be safer than the base case, because the weaving movements take place at the parallel road existing of one lane and the maximum speed on this road is lower.

Any unbundled alternative with initially four lanes is assumed to be safer than the extended alternative. This is because the weaving movements take place at the parallel road which has less than four lanes and the maximum speeds on these roads are lower. However, the unbundled 2-2 alternative is assumed less safe than the unbundled 3-1 alternative because more lanes are involved in the weaving area (parallel road). It is also assumed that the alternative with the shortcut is less safe than the unbundled 3-1 alternative because of the extra entrance to the main carriageway. Therefore more sideways movements are possible which is assumed to be less safe.

It should be noted that the capacity in weaving areas is usually lower than the standard capacity for the amount of lanes due to turbulence. This is, however, not taken into account in the simulations.

Table 4-8. Safety effects (+=positive, -=negative)

Initially three lanes	*Safety effect*
Base case	*Reference*
Unbundled 2-1	++
Extended	-

Initially four lanes	*Safety effect*
Extended	*Reference*
Unbundled 3-1	++
Unbundled 2-2	+
Unbundled 3-1 + shortcut	+

Since the index numbers for safety are based on the total distance driven (km-effect), the use of index numbers is not applicable. No topological or geometrical characteristics are taken into account. As mentioned earlier, these characteristic do actually have a big impact on the safety effects. Besides, the infrastructural design and the vehicle types are not considered, which can have a significant impact on safety, especially when comparing different infrastructural designs.

Since the traffic demand is static and stays the same in each alternative (simulation), the only difference (km-effect) is that some routes become longer when an unbundled alternative is considered. Therefore, in each of the unbundled alternatives the total distance is expected to be higher than in any of the not-unbundled alternatives, which results in the unbundled alternatives being more unsafe than not-unbundled situations. Therefore, index numbers give a wrong impression of the effects on safety and cannot be used.

4.2.4 Emissions

Local air quality is mainly determined by the amount of nitrogen oxides and particulate matter, because the concentrations of these components are often the closest to the health damage limits (Wever & Rosenberg, 2012). Moreover, there are greenhouse gasses which indirect influence the local environment and influence climate change (ibid.). Therefore, the amount of emissions should be as low as possible.

The two main aspects that influence the amount of emissions are speed and the level of congestion. The higher the speeds, the more air polluting substances are emitted (ibid.). However, in case congestion occurs there is a high density of vehicles and due to constant accelerating and decelerating, emissions are high in comparison with a car that travels the same distance at a constant speed. Therefore, it is important to take these aspects into account. For example, in case these aspects are not taken into account and the emission effects are calculated based on the travelled distance[6], a congested network always performs equal to non-congested networks when the travelled distance stays the same.

Since there is a need to not only compare the outcomes on traffic flows, but also on emissions, the Macro Emission Module was designed to interface with MAPRLE (Klunder & Stelwagen, 2013). This module calculates emissions including varying vehicle dynamics as caused by different congestion, road or intersection types, as these are known to influence vehicle emissions significantly (ibid.).

The effects of emissions are calculated by multiplying the difference of emitted component (outcome of the Emission Module) and the costs per kilo (€/kg) per component. The costs for one kg of nitrous oxide and one kg of CO2 are given for the Netherlands in general. The costs for one kg of particulate matter are divided over metropolitan, urban and rural areas. Since the urban area is considered during this study, the costs for an urban area are used to calculate the effect of emitted particulate matter. Table 4-9 shows the costs (€/kg) per considered component. A calculation example is shown in Table 4-10.

Table 4-9. Index numbers for emissions (Ministerie van Infrastructuur en Milieu, 2016b)

	Particulate matter	*Nitrous oxides*	*CO2*
Costs (€/kg)	189	11	0,026

Table 4-10. Calculation example of emission effects

	Particulate matter (kg)	*Nitrous oxides (kg)*	*CO2 (kg)*
Base case	0.8	50.0	15800.0
Alternative X	0.9	61.8	19100.0
Difference	*-0.1*	*-11.8*	*-3300*
Total	**€ - 18.90**	**€ - 129.80**	**€ - 85.80**

4.2.5 Noise pollution

Usually, the noise effect is calculated based on the number of houses in the zone and the number of decibels produced by the traffic/road. The costs per person are applied per decibel and are €12,71 (Wever & Rosenberg, 2012). Since there is no information available on the number of houses in the noise zone or the number of decibels, noise effects are, as the safety effects, valued by qualitative analysis. Index numbers are, as for the same reasons as mentioned for safety effects, not applicable for determining noise pollution effects.

There are various factors that affect the traffic noise (Marathe, 2012):

- Size of traffic flow, as the traffic flow increases, the noise level increases.
- Speeds, higher speed also causes higher noise levels.

[6] Index numbers are available for emissions based on distance travelled.

- Acceleration, noise level increases during acceleration.
- Tyre-road surface interaction.
- Road surface condition, smooth surface generally produce less noise.
- The vehicle characteristics, some vehicles make more noise due to engine, brakes, chasis body structure, the fuel, etc.

Since the last three factors do not vary between alternatives or simulations, these factors are disregarded. The other three are taken into account when determining the noise effects and if they are positive (less noise pollution) or negative (more noise pollution).

First of all, the size of the traffic flow. When more lanes are available (comparing alternatives at the same location in each network), more vehicles can drive over the same length of the road. This results in more noise production. Therefore the extended alternative has a negative effect on noise pollution in comparison to the base case. This is the only comparison in which different amount of lanes are involved.

Secondly, higher speed causes higher noise levels. Since only alternatives will be compared with initially the same amount of lanes and the maximum speed on the parallel road is lower than on the main carriageway, it is assumed that all unbundled alternatives have a positive effect on noise pollution. Besides, the unbundled 2-2 alternative has more lanes with a lower maximum speed than the unbundled 3-1 alternative. Therefore, the unbundled 2-2 alternative has a higher positive effect on noise pollution.

Based on these two assumptions, Table 4-11 shows what the effects of each alternative are on noise pollution.

Lastly, the noise level increases during acceleration. Therefore, congestion leads to more noise pollution than in situations without congestion. Since it is not known yet in which alternatives congestion will occur, this will be discussed at the results (chapter 5). Therefore the noise effects shown in Table 4-11 can change.

Table 4-11. Noise effects based on size of traffic flow and maximum speeds (+=positive, -=negative)

Initially three lanes	*Noise effect*
Base case	*Reference*
Unbundled 2-1	+
Extended	-

Initially four lanes	*Noise effect*
Extended	*Reference*
Unbundled 3-1	+
Unbundled 2-2	++
Unbundled 3-1 + shortcut	+

4.2.6 From rush hour to yearly total

Since, except the investment and maintenance costs, all the effects will only represent 2,5 hours during morning rush hours in the simulations, all the outcomes of the simulations must be converted to the effects for a year. The considered networks represent only one carriageway of the motorway. It is assumed that in the morning congestion raises in one direction and in a less volume in the evening on the same carriageway. Therefore the effect is multiplied by 1,5 in order to calculate the effects for one day. The effect still has to be converted to a year. In order to do this, the effects are also multiplied by 250 (Snelder, et al., 2014).

4.3 Expectation on performance results

With the setup of the simulations, expectations are determined as well. The expectations are discussed for the alternatives that will be compared, as mentioned earlier in Section 4.1.3.

Therefore, it is expected that:

- The extended alternative will perform better than the base case for each distribution of through and local traffic. When problems occur in the base case, the problems should at least be less in the extended alternative because of the higher provided capacity.
- The unbundled 2-1 alternative will only perform better than the base case when the distribution of through and local traffic is 60-40 or 70-30 (or both). This is expected because the share of capacity in this alternative is 6.6 - 3.3. With a higher local traffic distribution, congestion will occur on the parallel road which will probably spillback on the main carriageway. Since not more capacity is provided in the 2-1 alternative, the change in performance can be attributed to the change in distribution of through and local traffic.
- The unbundled 3-1 alternative performs better than the extended alternative when the distribution of through and local traffic is 80-20. In this case the traffic is distributed by a share of 3-1 and matches with how the capacity is divided over the main carriageway and the parallel road. Therefore, it is expected that when in the extended alternative no congestion occurs, no congestion will occur in the unbundled 3-1 alternative either.
- The unbundled 2-2 alternative will perform better than the extended alternative and best of all alternatives with initially four lanes in case a substantial distribution of local traffic is available. Since the capacity in the unbundled 2-2 alternative is divided equally over the main carriageway and the parallel road, it is expected that the unbundled 2-2 alternative performs best when through and local traffic are distributed 50-50 or 60-40.
- It is expected that the unbundled 3-1 alternative performs equal or better than the unbundled 3-1 alternative. It is expected that the shortcut alternative will at least perform equal because when the route via the shortcut does not turn out to be more beneficial, it is expected that this route will not be used. Therefore, no traffic will take this route and the alternative performs equal to the unbundled 3-1 alternative.

Moreover, it is expected that when congestion occurs in the base case, congestion will also occur in the alternatives with initially three lanes because no more capacity is provided. The same holds for the extended alternative and the alternatives with initially four lanes. This holds for the alternatives with the same distributions of through and local traffic.

4.4 Conclusion

This chapter described the choice of the simulation model, how the simulations are designed, under which circumstances the alternatives will be tested and how the cost-benefit analysis will be executed. Therefore, sub questions 6 and 7 are answered.

The simulation model that is chosen to execute the simulations with is MARPLE, which is an abbreviation of ”Model for Assignment and Regional Policy Evaluation” and it assigns traffic dynamic. MARPLE is fast and simple model that can simulate route choice, which is the most important criteria during this study.

Besides, the archetype base case and its alternatives are determined in this chapter. The base case is defined as a main carriageway of 9 km, with three lanes, and a maximum speeds of 120 km/h. Two connections are included, which means two on-ramps and two off-ramps, all of them exits of one lane. This base case has two alternative road designs which include an extended alternative, which is provided with four lanes on the main carriageway, and an unbundled alternative. In the unbundled alternative the main carriageway has 2 lanes and the parallel road one. The maximum speeds on the parallel road is 100 km/h. The extended alternative also serves as a base case for the other three unbundled alternatives. Since the extended alternative has four lanes, there are two ways to divide the lanes over the two carriageways. The first one has three lanes on the main carriageway and one on the parallel road and the second way is with two lanes on the main carriageway and two on the parallel road. The third unbundled alternative is the same as the one with three lanes on the main carriageway but also contains a shortcut between the parallel road and the main carriageway.

There are two circumstances under which these alternatives will be tested: the distribution of through and local traffic, and the (total) traffic demand. There are six distributions of through traffic determined which starts at 50% through traffic till 100% through traffic, with steps of 10%. Besides, 20% of the local traffic take the first exit and 80% the second. There are six alternatives, six distributions of through and local traffic and three amounts of traffic demand. Therefore, 108 simulations are needed to simulate all alternatives under all circumstances.

In order to evaluate the alternatives, CBA will be executed. The investment and maintenance costs are calculated using the SSK method. The effects of travel times are calculated based on the total time spent (veh*hrs), which is an output of MARPLE, times the value of time for freight and car separate. Besides, the amount of emitted substances is also given as an output by MARPLE. The emissions are calculated including varying vehicle dynamics as caused by different congestion, road or intersection types, as these are known to influence vehicle emissions significantly. The safety and noise effects are determined qualitative, because of lacking data. Therefore, those are taken into account very roughly.

The next chapter provides the results of all simulations and the outcomes of the CBAs.

5 Simulation results

In this chapter the results of the simulations, of which the design was explained in the previous chapter, will be shown and discussed. The goal of this chapter is to bet insight into the results of the simulations and if unbundling can be deemed beneficial under the circumstances explained in Section 4.1.4. The results are expressed in the performance of the network, visualisation of congestion and the cost-benefit analysis.

Section 5.1 explains how the results are shown and discussed. In Sections 5.2 until 5.7 the results for each distribution of through and local traffic (circumstance) are discussed in terms of performance and the cost-benefit analysis. Section 5.8 addresses the results of the simulations with increased traffic demand. Section 5.9 discusses the limitations of the simulations and the cost-benefit analysis. By discussing the results, sub question eight will be answered.

5.1 Introduction

The performances between the alternatives of each distribution of through and local traffic in the +10% and +20% demand circumstances turned out to be comparable to results of the '0' demand circumstance. With the increase of total demand, the bottlenecks in each alternative remain the same, but the effects (congestion) became worse. Therefore, only the results for the '0' demand will be extensively discussed in this chapter. The results of all simulations and the discussion of the simulations of the +10% and +20% can be found in Appendix F. These will be shortly discussed in Section 5.8. Moreover, the results are for each distribution of through and local traffic expressed in the network performance (indicators), the visualisation of the location of congestion and the outcome of the cost-benefit analysis. The conclusions are drawn based on those three results. A more comprehensive explanation on each of the evaluation methods follows.

First of all, for each distribution of through and local traffic, a table with the network performance of all six alternatives will be shown. Besides, the performance of each alternative is also shown for the main carriageway and the parallel network parts separately. The main carriageway is represented by '1' and the parallel network part as well as the on- and off-ramps by '2'. This means that, since the base case and the extended alternative do not have a parallel road, only the on- and off-ramps are considered the 2nd network part in those cases. By showing the results for the network parts separately, it can be seen where delays occur. The other columns show the total distance travelled, the total time spent in the network, the total delay and the average speed. Additionally, the last columns show again the total time spent in the network and the total distance travelled, but now divided over cars and freight traffic.

Secondly, for each distribution of through and local traffic a figure which shows where congestion is located in each alternative will be shown. Since each simulation exists of 10 time periods of 15 minutes, one of the periods had to be chosen to visualise the congestion of. The congestion is worst in each 5th period of the simulations and therefore chosen to visualise. It has to be noted that there is a difference between congestion (i.e. jammed traffic) and slow-moving traffic. By slow-moving traffic is meant that the driven speed can still be 100 km/h on the main carriageway, which is not considered congestion in this study and, therefore, not shown in the figures.

Lastly, the cost-benefit analysis results. The societal costs and benefits will be shown for each comparison. Since the effects are roughly estimated, the amounts are rounded to the nearest ten thousand euros.

As mentioned before, alternatives can only be compared when they have initially the same amount of lanes. Therefore, the base case will be compared to the unbundled 2-1 and the extended alternatives and the extended alternative will be compared to all other unbundled alternatives. This means that the extended alternative actually serves as a base case as well.

Generally, since the traffic is static and the same in each simulation, an alternative (network) performs better than another one when the total distance travelled and the average speed increase while the total time spent and the total delay decrease. When the average speed increases, that means that there is less congestion (in at least one part of the network). Since no new traffic is attracted because of lower travel times (static demand), the travel times decrease and the total time spent in the network decreases as well. With this, more vehicles can pass the network in a shorter time, which means that the total distance travelled increases and the total delay decrease.

The next sections discuss these results for each distribution of through and local traffic separately.

5.2 Distribution of 50% through traffic

This section discusses the results of all the alternatives under the circumstance of 50% through traffic and 50% local traffic. Table 5-1 shows the network performances and Figure 5-1 (p.55) shows the locations of congestion in each alternative.

Table 5-1. Network performances all alternatives (distribution of 50% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	81808	1914	1274	43	1726	187	74006	7801
	1	78027	1848	1256	42				
	2	3781	65	18	58				
Unb. (2-1)	Total	81071	2506	3350	32	2276	230	73350	7721
	1	63345	2070	3100	31				
	2	17726	436	250	41				
Extended	Total	81808	1572	874	52	1412	160	74006	7801
	1	78027	1507	856	52				
	2	3781	65	18	58				
Unb. (3-1)	Total	81074	2419	2627	34	2195	224	73353	7721
	1	63348	1982	2377	32				
	2	17726	437	250	41				
Unb. (2-2)	Total	82190	1219	494	67	1108	111	74363	7828
	1	64022	590	56	109				
	2	18168	629	438	29				
Unb. (3-1)	Total	79135	2405	2961	33	2180	225	71600	7535
& shortcut	1	62037	2012	2748	31				
	2	17098	393	213	43				

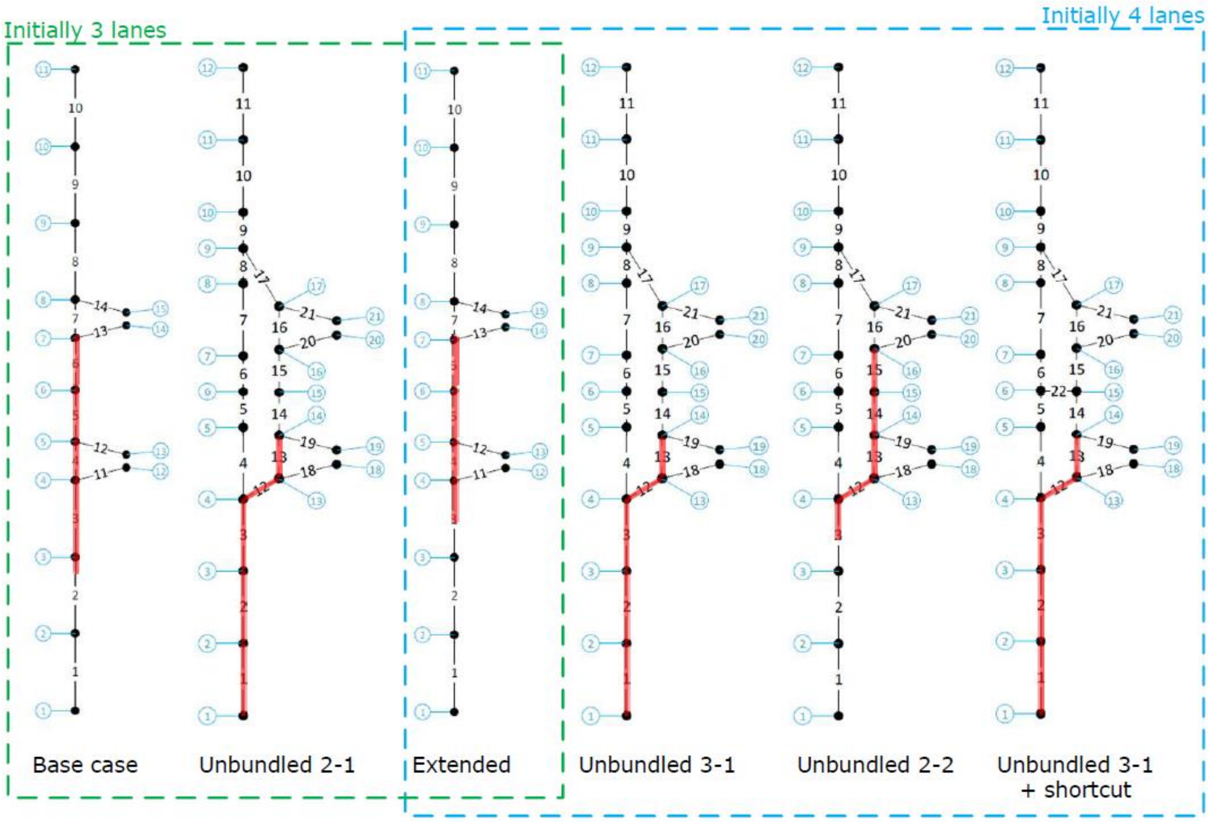


Figure 5-1. Visualisation congestion all alternatives (distribution of 50% through traffic)

5.2.1 Alternatives with initially three lanes

Since the distribution of through and local traffic is 50%-50%, and the capacity is not equally divided over the two roads in the unbundled 2-1 alternative, it can be expected that the unbundled 2-1 alternative performs worse than the base case. Problems were expected on the parallel road, which is confirmed by the location of the congestion (Figure 5-1). The congestion occurred because of the big share of local traffic that takes the second exit and the traffic that want to access the motorway via the first on-ramp. Apparently, the parallel road, with one lane, does not provide enough capacity between the first on-ramp and the second exit to handle both of these flows.

In the base case congestion occurred because of the high amount of local traffic that wants to leave the motorway at the second exit. Since this exit exists of only one lane, not enough capacity is provided to handle all the exiting traffic. Therefore, it seemed that three lanes is enough to handle the amount of traffic, but that the second exit is the bottleneck. Table 5-1 (p.54) shows how both cases performed. In the unbundled 2-1 alternative the total distance travelled is slightly lower, the total time spent is higher, the total delay is more than twice as high and the average speed is lower than in the base case. Therefore, the unbundled 2-1 alternative performs worse than the base case.

As mentioned earlier, it would be expected that the extended alternative performs, under any circumstances, better than the base case. As shown in Table 5-1 (p.54), the total distance travelled is equal for the base case and the extended alternative. The main difference is that in the extended alternative the average speed is higher and, therefore, the total time spent in the network and the total delay are lower. This should mean that less congestion occurred, which is confirmed by the location of the congestion (Figure 5-1, p.55). Therefore, the extended alternative performs, as expected, better than the base case.

5.2.2 Alternatives with initially four lanes

The extended alternative serves as the reference case in order to compare all unbundled alternatives with initially four lanes. It was expected that the unbundled 3-1 alternative performs worse than the extended alternative with a distribution of 50% through traffic and 50% local traffic, because the capacity is divided with 80% on the main carriageway and 20% on the parallel road. As shown in Table 5-1 (p.54) the total distance travelled and the average speeds are lower for the unbundled 3-1 alternative than for the extended alternative. Therefore, it is a natural consequence that the total time spent in the network is higher. In the unbundled 3-1 alternative the same problem as in the unbundled 2-1 alternative underlies to the occurrence of congestion (Figure 5-1, p.55). Since the parallel road consist of only one lane, not enough capacity is provided to handle the traffic that wants to leave the motorway at the second exit and the entering traffic at the first on-ramp together. Therefore, the unbundled 3-1 alternative performs worse than the extended alternative.

The capacity in the unbundled 2-2 alternative is divided equally over the main carriageway and the parallel road. Since the distribution of through and local traffic is equal as well, it would be expected that this alternative performs the best with this equal distribution of through and local traffic. When comparing this unbundled 2-2 alternative with the extended alternative, the total distance travelled and the average speed increased, the total times spent and the total delay decreased (Table 5-1, p.54). Therefore can be stated that the unbundled 2-2 alternative performs better than the extended alternative. However, as shown in Figure 5-1 (p.55) congestion still occurs at the parallel road and spills back on the main carriageway. In this unbundled alternative the congestion does not occur at the first on-ramp as in the unbundled 2-1 and 3-1 alternatives, but at the second exit as in the base case and the extended alternative. Apparently the parallel road provides enough capacity to handle all the traffic, but the second exit is the bottleneck now. Since this second off-ramp exists of one lane and the big amount of traffic that wants to leave the motorway there, the exit does not provide enough capacity. When providing the second exit of two lanes, probably no congestion occurs at all.

Finally, the unbundled 3-1 and shortcut was expected to perform equal or slightly better than the unbundled 3-1 alternative. This is, however, not the case. As shown in Appendix F1 this is the one and only alternative in which not all vehicles arrived. Besides, the least total distance of all alternatives is travelled. Therefore this alternative performs worst of all alternatives. In the unbundled 3-1 alternative the same problems occur as in the unbundled 2-1 (and unbundled 3-1) alternative(s), which means the congestion spills back onto the main carriageway and blocks the access for a period of time. Apparently the problems in this alternative are even worse than in the other two alternatives. This can be explained by the route choice of through going traffic. Through going traffic has three routes to choose from: one via the main carriageway, one via the parallel road and one via the parallel road and the shortcut. In relation to the unbundled 3-1 alternative less vehicles choose to travel via the main carriageway, which explains the bigger effect of congestion (Appendix F1).

Overall it can be derived from the performances that the main capacity problems for the unbundled 2-1, the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives occur on the parallel road at the first on-ramp. Since the parallel road consist of only one lane, not enough capacity is provided to handle the traffic that wants to leave the motorway at the second exit and the entering traffic at the first on-ramp together. This has to with the amount of traffic that enters the motorway at the first on-ramp, by changing this amount, the results could be different. In the base case, the extended 2-2 and the extended alternatives, problems occurred because the second off-ramp exists of only one lane (bottleneck).

However, based on the performances and the location of congestion the extended alternative performs best when having initially three lanes and the unbundled 2-2 alternative performs best with initially four lanes.

5.2.3 Cost-benefit analysis

As discussed in the previous section, the unbundled 2-1 performs worse and the extended alternative performs better than the base case. This is also reflected in the outcome of the cost-benefit analysis (Table 5-2, p.58). The extended alternative has a societal benefit of approximately 15 million euros while the unbundled 2-1 alternative results in nearly 52 million societal costs. The only benefits in the unbundled 2-1 alternative are for safety and noise. Since in all of the alternatives congestion occurs, the effect on noise pollution is assumed to be equal. Therefore, the effects are the same as shown in Table 4-11 (p.50). Nevertheless, the extended alternative is the best option when comparing the alternatives with initially three lanes and taking into account both the performance and the cost-benefit analysis.

In the alternatives with initially four lanes, as explained in the previous section, the unbundled 2-2 alternative performed best and the other two unbundled alternatives performed worse than the extended alternative. This is also reflected in the cost-benefit analysis (Table 5-2, p.58). When implementing the unbundled 2-2 alternative, this leads roughly to a societal benefit of 16,7 million euros. Travel times gains and the emissions lead to benefits. The benefits for emitted components can be explained by the less total delay and therefore less congestion.

The unbundled 3-1 alternative scores, with its 71 million euros of societal costs, a bit worse than the unbundled 3-1 and shortcut alternative. The alternative with the shortcut has lower costs due to less time spent in the network than in the unbundled 3-1 alternative. This is because not all vehicles were able to arrive in the alternative with the shortcut, which leads to slightly less time spent in the network and therefore slightly lower costs. Therefore, the unbundled 3-1 alternative with shortcut can be excluded as an option anyway.

Concluding, the results of the performances and the cost-benefit analysis are in line with each other. The best performing alternative with initially three lanes, is the extended alternative. Moreover, the best performing alternative with initially four lanes is the unbundled 2-2 alternative.

Table 5-2. Cost-benefit analysis results (distribution of 50% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 29,190,000	€ -
Freight	€ 11,120,000	€ -
Emissions	€ -	€ -
PM	€ 190,000	€ -
Nox	€ 800,000	€ -
CO2	€ 290,000	€ -
Safety	++	
Noise	+	
	€ 52,300,000	€ -
Total	€ -52,300,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 16,710,000
Freight	€ -	€ 6,960,000
Emissions	€ -	€ -
PM	€ 150,000	€ -
Nox	€ 710,000	€ -
CO2	€ 480,000	€ -
Safety	-	
Noise	-	
	€ 8,330,000	€ 23,670,000
Total	€ -	€ 15,340,000

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 41,570,000	€ -
Freight	€ 16,540,000	€ -
Emissions	€ -	€ -
PM	€ 320,000	€ -
Nox	€ 1,170,000	€ -
CO2	€ 450,000	€ -
Safety	++	
Noise	+	
	€ 71,240,000	€ -
Total	€ -71,240,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 16,150,000
Freight	€ -	€ 12,650,000
Emissions	€ -	€ -
PM	€ -	€ 100,000
Nox	€ -	€ 560,000
CO2	€ -	€ 260,000
Safety	+	
Noise	++	
	€ 12,990,000	€ 29,720,000
Total	€ -	€ 16,730,000

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 40,810,000	€ -
Freight	€ 16,690,000	€ -
Emissions	€ -	€ -
PM	€ 300,000	€ -
Nox	€ 1,050,000	€ -
CO2	€ 390,000	€ -
Safety	+	
Noise	+	
	€ 70,580,000	€ -
Total	€ -70,580,000	€ -

5.3 Distribution of 60% through traffic

This section discusses the results of all alternatives under the circumstances of 60% through traffic and 40% local traffic. Table 5-3 (p.59) shows the network performances and Figure 5-2 (p.60) shows the locations of congestion in each alternative.

5.3.1 Alternatives with initially three lanes

When comparing the unbundled 2-1 alternative and the base case, it would be expected that the unbundled alternative performs slightly worse. This is expected because of the distribution between the through and local traffic of 60-40. In the base case no congestion occurred, while in the unbundled 2-1 alternative quite some congestion occurred and therefore a high total delay (Figure 5-2 & Appendix F2). Besides, because of the congestion, the total times spent is almost three times as high and the average speed is significantly lower than in the base case (Table 5-3, p.59). The congestion in the unbundled 2-1 alternative occurs at the parallel road at the first on-ramp. Therefore, the capacity on the parallel road is not sufficient for the traffic that wants to leave the motorway at the second exit and the entering traffic at the first on-ramp together. It can be stated that, as expected, the unbundled 2-1 alternative performs worse than the base case.

As expected the extended alternative performs better than the base. As shown in Table 5-3 (p.59) the total time spent and the total delay are lower in the extended alternative. Besides, the average speed is higher in the extended alternative while the total distance travelled remains the same for both cases. In both cases no congestion occurred, but the difference in performance can be explained by slow-moving traffic (Appendix F2). In the base case there is short period in which the traffic drives a little slower than the maximum speed. This explained the slightly higher times spent in the network and higher total delay in the base case. It can be stated that the extended alternative performs better than the base case.

Table 5-3. Network performances all alternatives (distribution of 60% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	85452	849	181	101	752	97	76719	8733
	1	82171	804	177	102				
	2	3281	45	4	73				
Unb. (2-1)	Total	85795	2221	1784	39	1995	226	77037	8758
	1	69630	1856	1588	38				
	2	16166	366	196	44				
Extended	Total	85452	781	56	109	684	97	76719	8733
	1	82171	736	51	112				
	2	3281	45	4	72				
Unb. (3-1)	Total	85799	2064	1320	42	1851	213	77040	8759
	1	69648	1698	1124	41				
	2	16151	366	196	44				
Unb. (2-2)	Total	85829	808	49	106	711	97	77065	8764
	1	64930	552	11	118				
	2	20899	256	38	82				
Unb. (3-1) & shortcut	Total	85989	2207	1621	39	1979	228	77213	8776
	1	69875	1847	1429	38				
	2	16113	361	191	45				

5.3.1 Alternatives with initially four lanes

In this section all alternatives with initially four lanes are compared. As mentioned earlier, in the extended alternative no congestion occurred. Therefore the unbundled 3-1 alternative performs already worse, because congestion does occur in this alternative (Figure 5-2, p.60). This congestion is reflected in high total time spent, the high total delay and the low average speed of the unbundled 3-1 alternative in comparison with the extended alternative (Table 5-3). The same problem as in the unbundled 2-1 alternative underlies to the occurrence of congestion in the unbundled 3-1 alternative (Figure 5-2, p.60). The problem is that the parallel road does not provide enough capacity to handle the traffic that wants to leave the motorway at the second exit and the entering traffic at the first on-ramp together. Therefore, the unbundled 3-1 alternative performs worse than the extended alternative.

In both the extended and unbundled 2-2 alternatives no congestion occurred (Figure 5-2, p.60). The unbundled 2-2 alternative resulted in a slightly higher total distance travelled and slightly higher total times spent in the network than the extended alternative. This can be explained by the available routes for through traffic. Through traffic can choose the route via the main carriageway or the route via the parallel road. The route via the parallel road, on which the maximum speed is 100 km/h instead of 120 km/h on the main carriageway, is slightly longer than the route via the main carriageway. This explains the slightly higher distance travelled and the slightly higher total time spent in the network. Besides, the lower average speed can be explained by the lower maximum speed on the parallel road. Appendix F2shows that in the extended alternative traffic drives slower than the maximum speed for a short time and therefore the delay is slightly higher. This is not the case for the unbundled 2-2 alternative and therefore this alternative performs better than the extended alternative.

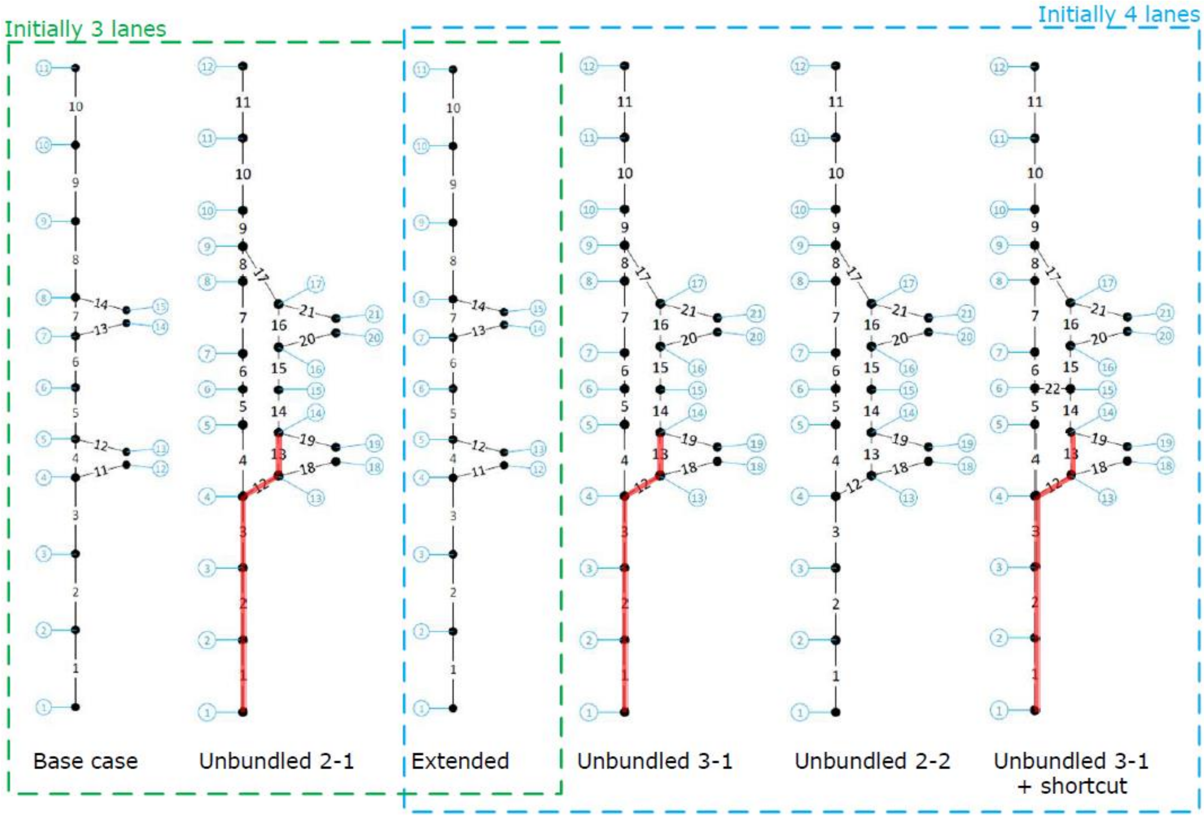


Figure 5-2. Visualisation congestion all alternatives (distribution of 60% through traffic)

It is expected that the unbundled 3-1 with shortcut alternative performs equal or better than the unbundled 3-1 alternative. As shown in Table 5-3 (p.59) this expectation did not come true. The total distance travelled, the total time spent in the network and the total delay are higher for the alternative with shortcut (Table 5-3, p.59). Therefore, less delay (congestion) occurred in the unbundled 3-1 alternative (Appendix F2). The through going traffic is divided over three routes in the alternative with the shortcut as opposed to two routes in the unbundled 3-1 alternative without shortcut. The only explanation for the worse performance of the alternative with shortcut is that less vehicles take the route via the main carriageway than in the unbundled 3-1 alternative (Appendix F2). Therefore, more traffic goes via the parallel road. Overall, the unbundled 3-1 and shortcut alternative performs worse than the extended alternative.

Since no congestion occurred at the base case, unbundled 2-2 and the extended alternative it can be concluded that with the decreased distribution of local traffic the second off-ramp with lane does provide enough capacity now. The problems, location of congestion, for the other alternatives remained the same as for the distribution of 50% through traffic.

Concluding, for a distribution of 60% through traffic and 40% local traffic, the extended alternative performs best when having initially three lanes and the unbundled 2-2 alternative performs best in cases with initially four lanes. The same results were obtained with a distribution of 50% through traffic and 50% local traffic.

5.3.2 Cost-benefit analysis

As derived from the performances of the extended and unbundled 2-1 alternatives, only the extended alternative performed better than the base case. The cost-benefit analysis shows for both alternatives a negative outcome (Table 5-4). The slightly decreased travel times of the extended alternative do not outweigh the costs for investment & maintenance and the emissions. The amount of emissions increased for the extended alternative because of higher driven speeds (less delay/congestion). Since congestion occurred in the unbundled 2-1 alternative, the noise effect is more negative than initially determined in Table 4-11 (p.50). The implementation of the unbundled 2-1 alternative leads to even more societal costs than the extended alternative. In this alternative there are no benefits at all.

Table 5-4. Cost-benefit analysis results (distribution of 60% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 66,010,000	€ -
Freight	€ 33,380,000	€ -
Emissions	€ -	€ -
PM	€ 500,000	€ -
Nox	€ 2,460,000	€ -
CO2	€ 1,030,000	€ -
Safety	++	
Noise	0	
	€ 114,110,000	€ -
Total	€ -114,110,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 3,600,000
Freight	€ -	€ 40,000
Emissions	€ -	€ -
PM	€ 130,000	€ -
Nox	€ 700,000	€ -
CO2	€ 480,000	€ -
Safety	-	
Noise	-	
	€ 8,310,000	€ 3,640,000
Total	€ -4,670,000	€ -

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 61,940,000	€ -
Freight	€ 30,020,000	€ -
Emissions	€ -	€ -
PM	€ 640,000	€ -
Nox	€ 2,830,000	€ -
CO2	€ 1,190,000	€ -
Safety	++	
Noise	0	
	€ 107,810,000	€ -
Total	€ -107,810,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ 1,400,000	€ -
Freight	€ 10,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 10,000
Nox	€ -	€ 200,000
CO2	€ -	€ 90,000
Safety	+	
Noise	++	
	€ 14,400,000	€ 300,000
Total	€ -14,100,000	€ -

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 68,780,000	€ -
Freight	€ 33,870,000	€ -
Emissions	€ -	€ -
PM	€ 620,000	€ -
Nox	€ 2,620,000	€ -
CO2	€ 1,110,000	€ -
Safety	+	
Noise	0	
	€ 118,350,000	€ -
Total	€ -118,350,000	€ -

For the alternatives with initially four lanes, only the unbundled 2-2 alternative performed better than the extended alternative (previous section). Although the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives lead to substantial higher societal costs than the unbundled 2-2 alternative, none of the alternatives leads to societal benefits. This is because in none of the alternatives the travel times are lower than in the extended alternative and lead, therefore, only to societal costs. The only benefits are for emissions in the unbundled 2-2 alternative. In this alternative the maximum speed is lower on a part of the network (parallel road), which leads to an decrease of emission. Besides, congestion occurred in the unbundled 3-1 and unbundled 3-1 with shortcut alternatives and therefore the noise effects are more negative than initially determined in Table 4-11 (p.50).

When looking at the performances only, the extended alternative performs best when having initially three lanes and the unbundled 2-2 alternative performs best with initially four lanes. But, when taking into account the CBAs as well, it is better to do ‘nothing’.

5.4 Distribution of 70% through traffic

This section discusses the results of all alternatives under the circumstances of 70% through traffic and 30% local traffic. Table 5-5 shows the network performances and Figure 5-3 (p.63) shows the locations of congestion in each alternative.

Table 5-5. Network performances all alternatives (distribution of 70% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	89103	938	242	95	825	113	79438	9665
	1	86322	903	241	96				
	2	2781	35	0	79				
Unb. (2-1)	Total	89371	1291	572	69	1146	145	79684	9687
	1	74646	1007	443	74				
	2	14726	284	130	52				
Extended	Total	89103	772	18	115	668	104	79438	9665
	1	86322	737	17	117				
	2	2781	35	1	79				
Unb. (3-1)	Total	89375	1158	382	77	1023	135	79687	9687
	1	74665	877	254	85				
	2	14709	281	127	52				
Unb. (2-2)	Total	89483	806	18	111	701	105	79781	9701
	1	68273	581	13	117				
	2	21210	224	5	95				
Unb. (3-1) & shortcut	Total	89635	1463	685	61	1295	167	79921	9714
	1	75368	1171	543	64				
	2	14267	291	142	49				

5.4.1 Alternatives with initially three lanes

As can be seen from Figure 5-3 (p.63), a little congestion occurred near the first on-ramp in the base case. This can be explained by the main carriageway not providing enough capacity during a small period of time due to the entering amount of traffic at the first on-ramp. In comparison with the previous distribution of through and local traffic, there is 10% less local traffic. Therefore, less vehicles leave the motorway at the first exit. This problem remains in the unbundled 2-1 alternative, but then this problem is moved to the parallel road. Even though the distribution of local traffic is 30%, the parallel road still does not provide enough capacity between the first on-ramp and the second exit to handle the traffic. In the unbundled 2-1 alternative the congestion spills back on the main carriageway which causes delay for all routes and therefore higher total time spent in the network, a higher total delay and a lower average speed than in the base case (Table 5-5). Therefore the unbundled 2-1 alternative performs worse than the base case.

As expected the extended alternative performs better than the base case and no congestion occurred (Figure 5-3). As shown in Table 5-5 (p.62) the total delay is neglectable and the average speed almost reaches the maximum speed in the extended alternative. Since the average speed is higher than in the base case, but the total distance travelled remained the same, the total time spent in the network decreased for the extended alternative. Therefore, the extended alternative performs better than the base case.

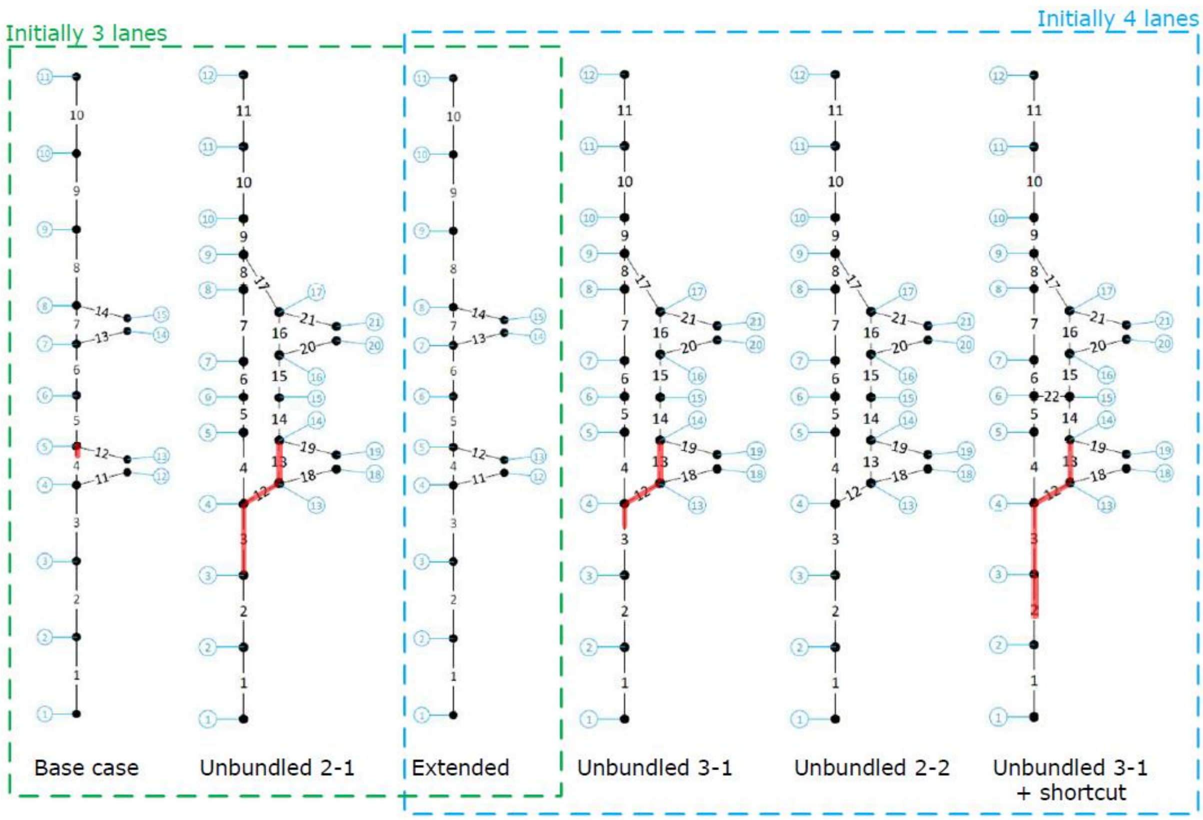


Figure 5-3. Visualisation congestion all alternatives (distribution of 70% through traffic)

5.4.2 Alternatives with initially four lanes

Since they all have initially four lanes, the extended alternative will be compared with the unbundled 3-1, the unbundled 2-2 and the unbundled 3-1 with shortcut alternatives. As mentioned before, no congestion occurred in the extended alternative. In the unbundled 3-1 alternative, however, congestion occurred near the first on-ramp on the parallel road and spills back on the main carriageway for a period of time (Figure 5-3). Therefore, more time is spent in the network and the total delay is higher for the unbundled 3-1 alternative than for the extended alternative (Table 5-5, p.62

Table 5-5. Another consequence of the congestion is a lower average speed. Therefore, the unbundled 3-1 alternative performs worse than the extended alternative.

In the unbundled 2-2 alternative no congestion occurred. The slightly higher distance travelled and higher total time spent in the unbundled alternative than in the extended alternative can be explained by the presence of the parallel road. In the unbundled alternative the through going traffic can choose a route via the main carriageway or a route via the parallel road. Since the route via the parallel road is slightly longer and the maximum on the parallel road is 100 km/h instead of 120 km/h on the main carriageway, this explains the differences in total distance travelled and total time spent and the slightly lower average speed for the unbundled 2-2 alternative. In the extended alternative the second network part only exists of the on- and off-ramps, while the same network part in the unbundled 2-2 alternative exists of the on- and off-ramps and the parallel road, on which the maximum speed is 100 km/h instead of 80 km/h on the on- and off-ramps. This explains the lower average speed for the second network part in the extended alternative. Since no congestion occurred in neither of the extended or unbundled 2-2 alternatives, but since the extended alternative has a slightly lower total time spent in the network, the unbundled 2-2 alternative performs worse than the extended alternative.

The unbundled 3-1 with shortcut alternative performs worst of all alternatives with its highest time spent in the network, the highest amount of total delay and the lowest average speeds (Table 5-5, p.62). Besides, most congestion occurred in this alternative (Figure 5-3, p.63). For the through traffic three routes, of which two via the parallel road, are available (Appendix F3).

In comparison with the previous distributions of through traffic (50% and 60%), less congestion occurred in the unbundled 2-1, unbundled 3-1 and unbundled 3-1 with shortcut alternatives. This can be explained by the less amount of local traffic that wants to exit the motorway. However, congestion occurred because the parallel road does still not provide enough capacity to handle the entering traffic at the first on-ramp. More capacity between the first on-ramp and second off-ramp can solve this problem.

Summarising, for a distribution of 70% through traffic and 30% local traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

5.4.3 Cost-benefit analysis

As discussed in the previous section the extended alternative performed better than the base case and the unbundled 2-1 alternative performed much worse than the base case. This is also reflected in the cost-benefit analysis results (Table 5-6, p.65). Since the unbundled 2-1 alternative performed much worse than the base case, there are no societal benefits at all. In the extended alternative the travel time gains outweigh the costs for investment & maintenance and the emissions. The amount of emission increased in the extended alternative due to higher driven speeds.

As shown in Table 5-6 (p.65) none of the alternatives with initially four lanes leads to societal benefits. The amount of costs correspond to the performances. The unbundled 3-1 with shortcut alternative performed worst, the unbundled 3-1 performed less worse and the unbundled 2-2 performed quite well. Since in none of the three alternatives the total time spent in the network was lower than in the extended alternative, there are only societal costs for travel times (Table 5-6, p.65). Since congestion occurred in the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives, this has a negative influence on the noise pollution effect.

Table 5-6. Cost-benefit analysis results (distribution of 70% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 17,040,000	€ -
Freight	€ 8,300,000	€ -
Emissions	€ -	€ -
PM	€ 530,000	€ -
Nox	€ 2,780,000	€ -
CO2	€ 1,260,000	€ -
Safety	++	
Noise	+	
	€ 40,640,000	€ -
Total	€ -40,640,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 8,370,000
Freight	€ -	€ 2,150,000
Emissions	€ -	€ -
PM	€ 170,000	€ -
Nox	€ 840,000	€ -
CO2	€ 630,000	€ -
Safety	-	
Noise	-	
	€ 8,630,000	€ 10,520,000
Total	€ -	€ 1,890,000

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 18,840,000	€ -
Freight	€ 8,080,000	€ -
Emissions	€ -	€ -
PM	€ 590,000	€ -
Nox	€ 2,830,000	€ -
CO2	€ 1,170,000	€ -
Safety	++	
Noise	0	
	€ 42,700,000	€ -
Total	€ -42,700,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ 1,750,000	€ -
Freight	€ 210,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 10,000
Nox	€ -	€ 230,000
CO2	€ -	€ 120,000
Safety	+	
Noise	++	
	€ 14,950,000	€ 370,000
Total	€ -14,580,000	€ -

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 33,330,000	€ -
Freight	€ 16,350,000	€ -
Emissions	€ -	€ -
PM	€ 600,000	€ -
Nox	€ 2,770,000	€ -
CO2	€ 1,140,000	€ -
Safety	+	
Noise	0	
	€ 65,540,000	€ -
Total	€ -65,540,000	€ -

In the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives congestion occurred. Therefore it makes sense that these alternatives lead to societal costs only. However, no congestion occurred in the unbundled 2-2 alternative. But, since the total time spent in the network is slightly higher than in the extended alternative due to the slightly longer route via the parallel road, only emission effects lead to societal benefits. This can be explained by the lower driven speed in the unbundled 2-2 alternative in comparison with the extended alternative.

Concluding, the extended alternative performs overall the best. None of the unbundled alternatives performs better than the extended alternative or leads to societal benefits.

5.5 Distribution of 80% through traffic

This section discusses the results of all alternatives under the circumstances of 80% through traffic and 20% local traffic. Table 5-7 (p.67) shows the network performances and Figure 5-4 (p.67) shows the locations of congestion in each alternative.

5.5.1 Alternatives with initially three lanes

As shown in Figure 5-3 (p.63) and Figure 5-4 (p.67) more congestion occurred in the base case with a distribution of 80% through traffic in comparison with the base case and a distribution of 70% through traffic. This is a logical consequence of the reduced amount of local traffic leaving the motorway at the first exit. Since the distribution of through traffic is 80% now, less local traffic is presence that uses the parallel road. This low distribution of local traffic still leads to congestion in the unbundled 2-1 alternative on the parallel road only. Therefore, the through going traffic that takes the route via the main carriageway is less hindered than in the base case. Besides, as shown in Table 5-7 more distance is travelled and the total delay is lower in the unbundled 2-1 alternative than in the base case. Moreover, the total time spent and the average speed remain nearly the same. Therefore, the unbundled 2-1 alternative performs better/equal to the base case.

As shown in Table 5-7 the total distance travelled for the base case and the extended alternative are equal. However, the total times spent and the total delay decreased significantly in the extended alternative. This implies that the average speed increased, which is true (Table 5-7). Besides, no congestion occurred in the extended alternative (Figure 5-4, p.67). Therefore, the extended alternative performs much better than the base case, and the unbundled 2-1 alternative.

Table 5-7. Network performances all alternatives (distribution of 80% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	92748	1124	399	83	988	135	82150	10598
	1	90466	1095	399	83				
	2	2281	29	0	79				
Unb. (2-1)	Total	93016	1126	378	83	993	133	82392	10624
	1	78211	879	285	89				
	2	14805	247	93	60				
Extended	Total	92748	804	22	115	690	114	82150	10598
	1	90466	775	21	117				
	2	2281	29	0	79				
Unb. (3-1)	Total	93018	879	74	106	761	118	82394	10624
	1	78154	668	17	117				
	2	14864	211	57	70				
Unb. (2-2)	Total	93101	835	20	111	720	115	82466	10635
	1	72843	623	16	117				
	2	20257	212	4	95				
Unb. (3-1) & shortcut	Total	93364	912	105	102	791	121	82700	10664
	1	79460	684	22	116				
	2	13904	228	83	61				

5.5.1 Alternatives with initially four lanes

Since the distribution of through and local traffic is 80%-20%, which is equal to a ratio of 3-1, it was expected that the unbundled 3-1 alternative would perform good. When comparing the extended alternative and the unbundled 3-1 alternative, it turns out that the extended alternative performs better. The total delay is higher and the average speed is lower for the unbundled 3-1 alternative (Table 5-7). The delay in the unbundled 3-1 alternative is caused by little congestion on the parallel road (Figure 5-4, p.67), which is reflected in the total delay and average speed of the second network part. The congestion occurred near the first on-ramp, which indicates that the parallel road does not provide enough capacity to handle the entering traffic.

In the unbundled 2-2 alternative no congestion occurred and the total distance travelled is higher than in the extended alternative. Besides, the total times spent is higher and the total delay and average speeds are lower than in the extended alternative (Table 5-7). This can again be explained by the slightly longer routes via the parallel route for the through traffic, but also for local traffic that leaves the motorway. Since the maximum speed on the parallel road is lower than on the main carriageway, the route via the parallel road for through traffic takes longer and it takes longer to reach an exit for local traffic. This explains why more distance is travelled and why more time is spent in the network. Besides, the maximum speed on the parallel road is lower than on the main carriageway, which explains the lower average speed for the unbundled 2-2 alternative. Overall, it can be stated that the extended alternative performs slightly better.

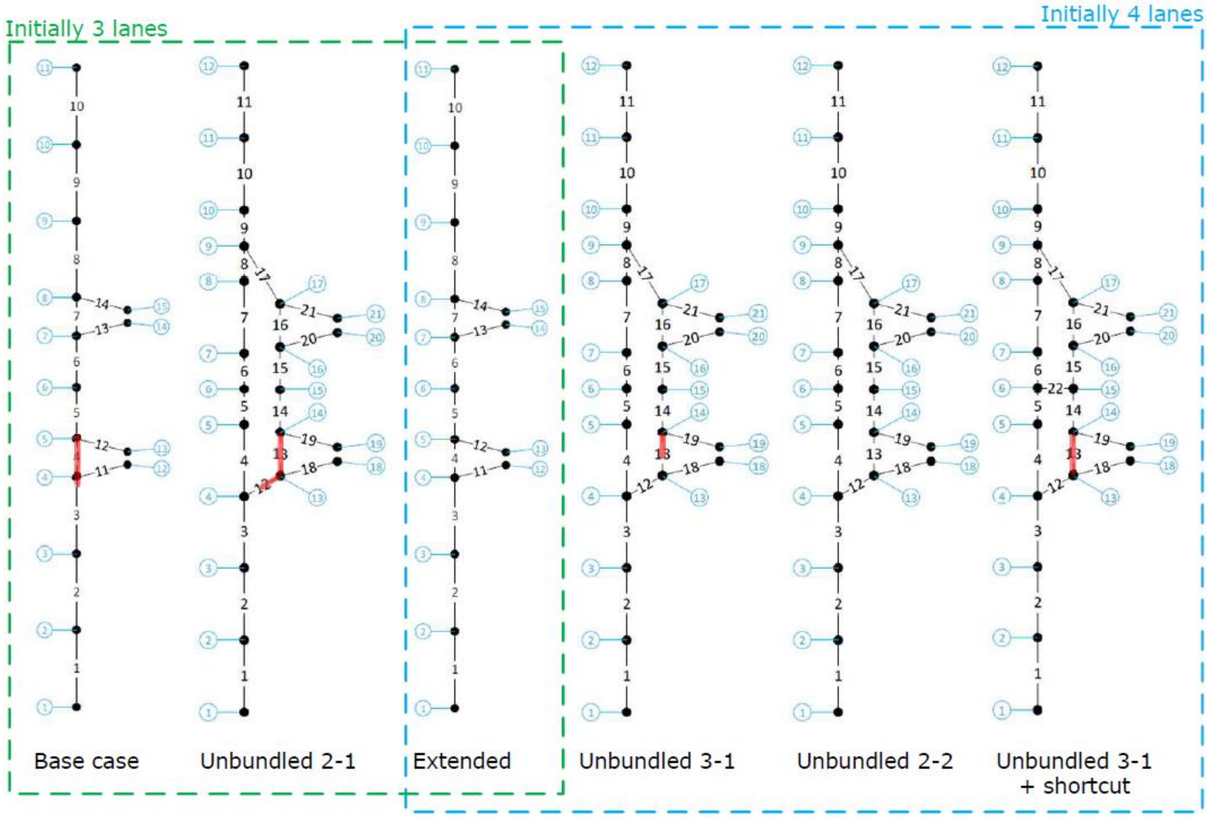


Figure 5-4. Visualisation congestion all alternatives (distribution of 80% through traffic)

As shown in Figure 5-4 congestion occurred at the same location in the unbundled 3-1 with shortcut alternative as in the unbundled 3-1 alternative, but in the alternative with shortcut more congestion occurred. Since the congestion occurred on the parallel road, only the second network part of the alternative with shortcut performs worse (Table 5-7, p.65). Through going traffic, that take the route via the main carriageway, is not hindered in any of the unbundled alternatives. Since no congestion occurred in the extended alternative and the unbundled 3-1 alternative already performed worse than the extended alternative, the unbundled 3-1 with shortcut alternative performs worse than the extended alternative.

Still the same problems occurred in the unbundled 2-1, the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives as in all previous distributions of through traffic. The only difference is that the congestion does not spill back onto the main carriageway anymore. Therefore, the through traffic that takes the route via the main carriageway is not hindered anymore. However, the problems on in the base case became worse than for a distribution of 70% through traffic. Since there is more through traffic available, less traffic leaves the motorway at the first off-ramp.

Thereby, the background traffic, entering traffic at the first on-ramp, remains the same in all simulations.

Concluding, for a distribution of 80% through traffic and 20% local traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, as with a distribution of 70% through traffic, no congestion occurred in the unbundled 2-2 alternative either.

5.5.2 Cost-benefit analysis

As shown in Table 5-8 only the extended alternative leads to societal benefits of the alternatives with initially three lanes. This matches with the outcome of the performances. In the base case all vehicles are hindered while in the unbundled 2-1 alternative only the traffic that takes a route via the parallel road is hindered. Since almost all freight traffic can be considered through traffic, this explains the difference in time spent in the network between car and freight traffic (and therefore the benefits). In the extended alternative, the obtained travel gains outweigh the societal costs of the investment and emissions. The emissions lead to societal costs for the extended alternative because of higher driven speeds. Since congestion occurred in the base case and the unbundled 2-1 alternative but not in the extended alternative the effect on noise pollution is more positive for the extended alternative.

Table 5-8. Cost-benefit analysis results (distribution of 80% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 250,000	€ -
Freight	€ -	€ 650,000
Emissions	€ -	€ -
PM	€ 700,000	€ -
Nox	€ 3,230,000	€ -
CO2	€ 1,650,000	€ -
Safety	++	
Noise	+	
	€ 16,560,000	€ 650,000
Total	€ -15,910,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 15,850,000
Freight	€ -	€ 5,550,000
Emissions	€ -	€ -
PM	€ 310,000	€ -
Nox	€ 1,050,000	€ -
CO2	€ 930,000	€ -
Safety	-	
Noise	0	
	€ 9,280,000	€ 21,390,000
Total	€ -	€ 12,110,000

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 3,770,000	€ -
Freight	€ 1,120,000	€ -
Emissions	€ -	€ -
PM	€ 580,000	€ -
Nox	€ 2,990,000	€ -
CO2	€ 1,250,000	€ -
Safety	++	
Noise	+	
	€ 20,900,000	€ -
Total	€ -20,900,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ 1,630,000	€ -
Freight	€ 230,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 20,000
Nox	€ -	€ 260,000
CO2	€ -	€ 140,000
Safety	+	
Noise	++	
	€ 14,850,000	€ 410,000
Total	€ -14,440,000	€ -

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 5,340,000	€ -
Freight	€ 1,920,000	€ -
Emissions	€ -	€ -
PM	€ 530,000	€ -
Nox	€ 2,710,000	€ -
CO2	€ 1,120,000	€ -
Safety	+	
Noise	+	
	€ 22,970,000	€ -
Total	€ -22,970,000	€ -

Once again, the unbundled 3-1 alternative with shortcut leads to the highest societal costs and the unbundled 3-1 alternative scores a bit better. The unbundled 2-2 alternative leads to the least societal costs for the alternatives with initially four lanes. In none of the alternatives less time is spent in the network than in the extended alternative. Therefore, no travel time gains are obtained in any of the alternatives. Due to the congestion in the unbundled 3-1 and unbundled 3-1 with shortcut alternatives, the amount of emissions is higher in these alternatives. In the unbundled 2-2 alternative the emissions lead to societal benefits. This can be explained by the lower driven speeds in this alternative, while in both the unbundled 2-2 and extended alternatives no congestion occurred.

Overall, when taking into account the performances and the cost-benefit analysis, only the extended alternative seems to be beneficial for a distribution of 80% through traffic and 20% local traffic.

5.6 Distribution of 90% through traffic

This section discusses the results of all alternatives under the circumstances of 90% through traffic and 10% local traffic. Table 5-9 shows the network performances and Figure 5-5 (p.70) shows the locations of congestion in each alternative.

5.6.1 Alternatives with initially three lanes

As shown in Table 5-9 the base case and the unbundled 2-1 alternative perform quite the same. In the unbundled 2-1 slightly more distance is travelled, the average speed is equal and the total delay even decreased. In both cases congestion occurred (Figure 5-5, p.70). The slightly more time spent in the unbundled 2-1 alternative can be explained by the presence of the parallel road, on which a lower maximum is allowed than on the main carriageway. And the more distance travelled is because some routes, via the parallel road, become longer. Therefore, it can be said that the base case and the unbundled 2-1 alternative perform equal.

Table 5-9. Network performances all alternatives (distribution of 90% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	96399	1847	1093	52	1619	227	84867	11532
	1	94617	1824	1093	52				
	2	1782	22	0	80				
Unb. (2-1)	Total	96640	1853	1079	52	1627	226	85081	11559
	1	83487	1553	915	54				
	2	13154	300	164	44				
Extended	Total	96399	841	30	115	717	124	84867	11532
	1	94617	818	30	116				
	2	1782	22	0	80				
Unb. (3-1)	Total	96618	903	71	107	774	128	85061	11556
	1	83514	721	25	116				
	2	13104	181	46	72				
Unb. (2-2)	Total	96725	871	28	111	746	125	85155	11570
	1	77402	669	24	116				
	2	19323	201	4	96				
Unb. (3-1) & shortcut	Total	97119	918	82	106	788	130	85502	11617
	1	83507	722	26	116				
	2	13612	196	55	69				

As expected the extended alternative performs better than the base case (Table 5-9). As for all other distributions of through and local traffic, the same distance in travelled in the base case and the extended alternative. However, in the extended alternative significant less time is spent in the network, there is almost no delay and the average speeds reach the maximum allowed speeds. Besides, no congestion occurred in the extended alternative (Figure 5-5, p.70). Therefore, the extended alternative performs way better than the base case.

5.6.1 Alternatives with initially four lanes

Unlike the extended alternative, congestion does occur in the unbundled 3-1 alternative. The congestion occurred on the parallel road at the second on-ramp (Figure 5-5), which causes more delays and reduced speeds on the parallel road (second road network). The total delay is even lower on the main carriageway in the unbundled 3-1 alternative. Nevertheless, the extended alternative performs better than the unbundled 3-1 alternative.

As in the extended alternative, no congestion occurred in the unbundled 2-2 alternative either (Figure 5-5). The extended and the unbundled 2-2 alternative perform quite the same. Slightly more distance is travelled, more time is spent in the network and the average speed is higher for the network parts in the unbundled alternative (Table 5-9, p.69). Besides, the delay in this unbundled alternative is lower than in the extended alternative. The differences in performance can again be explained by the presence of the parallel road, on which the maximum speed is lower than on the main carriageway and some routes become longer. When only looking at the numbers, the extended alternative performs better.

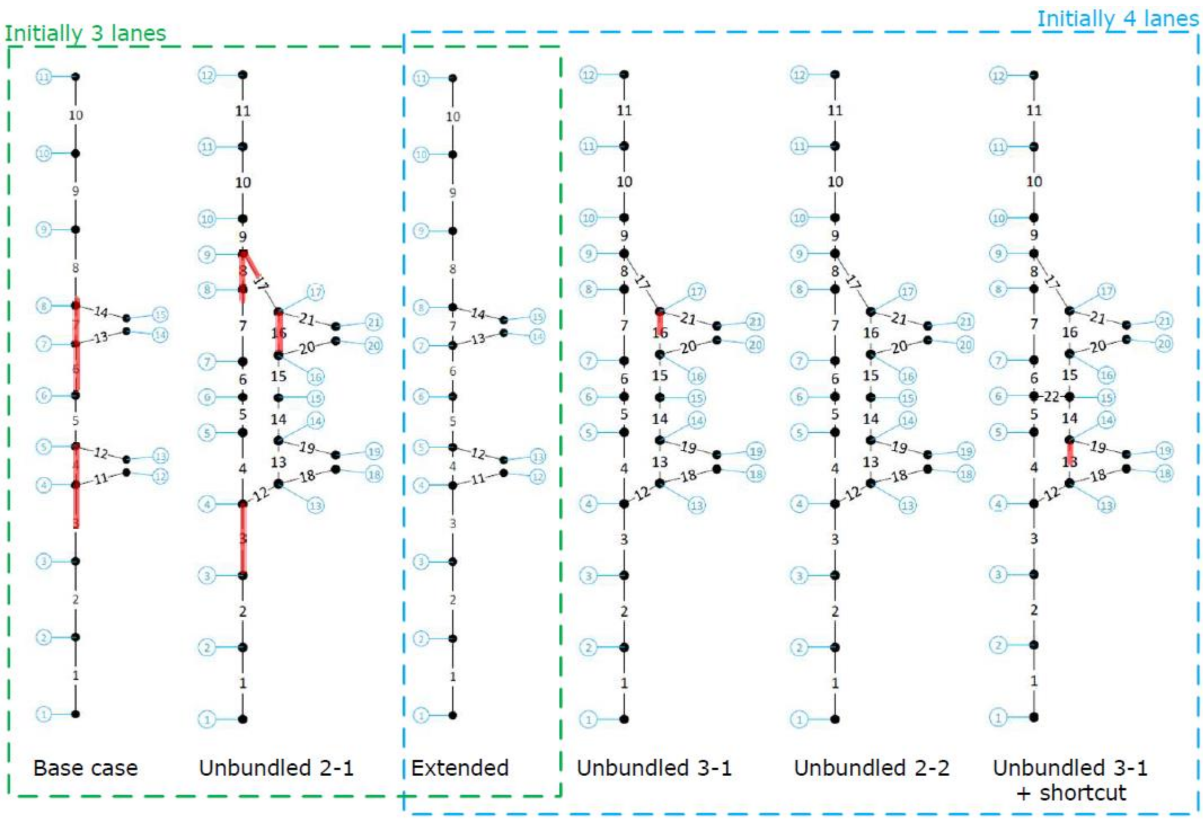


Figure 5-5. Visualisation congestion all alternatives (distribution of 90% through traffic)

The final alternative to compare with the extended alternative is the unbundled 3-1 alternative with shortcut. In the alternative with shortcut, more distance is travelled, more time is spent in the network, the total delay is higher and the average speed is lower than in the extended alternative (Table 5-9, p.69). In the extended alternative no congestion occurred, while in the unbundled 3-1 alternative with shortcut congestion occurred near the first on-ramp (Figure 5-5, p.70). Therefore the extended alternative performs better than the unbundled 3-1 with shortcut alternative.

It was expected that the unbundled 3-1 with shortcut alternative performs equal or better than the unbundled 3-1 alternative. With the this distribution of 90% through traffic, they perform quite equal. The main cause for the difference in performance is because of the differences on the second network part. In the alternative without shortcut the congestion occurs at the second on-ramp, while in the alternative with shortcut congestion occurs at the first on-ramp (Figure 5-5, p.70). This implies that in the unbundled alternative with shortcut more vehicles take a route via the parallel road. since an amount of vehicles also take the route via the shortcut, the problems at the second on-ramp are rectified. Therefore problems occur earlier in on the parallel road in this alternative with shortcut.

In all alternatives congestion occurred, except in the extended and the unbundled 2-2 alternative. Since only 10% of the traffic that entered the network in node 1 leaves the motorway, congestion occurred at the on-ramps in the base case. The main carriageway cannot handle this amount of traffic. The problems that occurred due to congestion for the distribution of 90% through traffic are expected to be higher for the distribution of 100% through traffic.

As the distributions of 70% and 80% through traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

5.6.2 Cost-benefit analysis

Table 5-10 (p.72) shows the results of the cost-benefit analysis. As in line with the performances results, the extended alternative leads to high societal benefits and the unbundled 2-1 alternative leads to societal costs. The benefits that are obtained by travel time gains outweigh the investment & maintenance and emission costs in the extended alternative. In the base case congestion occurred and in the extended alternative not. Apparently the higher speeds in the extended alternative caused more emissions than the jammed traffic in the base case.

As for all previous distributions of through and local traffic, except the distribution of 50% through and local traffic, the unbundled 3-1 alternative with shortcut leads to the highest societal costs and the unbundled 3-1 alternative scores a bit better. Moreover, the unbundled 2-2 alternative leads to the least societal costs for the alternatives in networks with initially four lanes. Again, in none of the alternatives less time is spent in the network than in the extended alternative and no travel time gains are obtained in any of the alternatives. Due to the congestion in the unbundled 3-1 and unbundled 3-1 with shortcut alternatives, the amount of emissions is higher in these alternatives. In the unbundled 2-2 alternative the emissions lead to societal benefits. This can be explained by the lower driven speeds in this alternative than in the extended alternative, while in both alternatives no congestion occurred.

As well as for the distributions of 70% and 80% through traffic, only the extended alternative seems to be beneficial for 90% through going traffic when taking into account the performances and the cost-benefit analysis.

Table 5-10. Cost-benefit analysis results (distribution of 90% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 400,000	€ -
Freight	€ -	€ 340,000
Emissions	€ -	€ -
PM	€ 670,000	€ -
Nox	€ 2,440,000	€ -
CO2	€ 1,470,000	€ -
Safety	++	
Noise	+	
	€ 15,710,000	€ 340,000
Total	€ -15,370,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 47,930,000
Freight	€ -	€ 26,780,000
Emissions	€ -	€ -
PM	€ 290,000	€ -
Nox	€ 230,000	€ -
CO2	€ 770,000	€ -
Safety	-	
Noise	0	
	€ 8,280,000	€ 74,710,000
Total	€ -	€ 66,430,000

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 3,080,000	€ -
Freight	€ 1,090,000	€ -
Emissions	€ -	€ -
PM	€ 660,000	€ -
Nox	€ 3,500,000	€ -
CO2	€ 1,500,000	€ -
Safety	++	
Noise	+	
	€ 21,020,000	€ -
Total	€ -21,020,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ 1,540,000	€ -
Freight	€ 250,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 40,000
Nox	€ -	€ 390,000
CO2	€ -	€ 230,000
Safety	+	
Noise	++	
	€ 14,780,000	€ 660,000
Total	€ -14,120,000	€ -

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 3,770,000	€ -
Freight	€ 1,650,000	€ -
Emissions	€ -	€ -
PM	€ 620,000	€ -
Nox	€ 3,300,000	€ -
CO2	€ 1,410,000	€ -
Safety	+	
Noise	+	
	€ 22,100,000	€ -
Total	€ -22,100,000	€ -

5.7 Distribution of 100% through traffic

Finally, this section discusses the results of all alternatives under the circumstances of 100% through traffic and 0% local traffic. Table 5-11 (p.73) shows the network performances and Figure 5-6 (p.74) shows the locations of congestion in each alternative.

5.7.1 Alternatives with initially three lanes

As shown in Table 5-11 the base case and the unbundled 2-1 alternative perform quite equal. The total time spent, total delay and the average speed are the same. The total distance travelled is higher for the unbundled 2-1 alternative, which can be explained by the presence of the parallel road. In the unbundled 2-1 alternative more distance is travelled because the routes via the parallel road are slightly longer than the same routes in the base case. In both cases a lot of congestion occurred and the main carriageway is blocked for a period of time (Figure 5-6, p.74). It can be stated that the base case and the unbundled 2-1 alternative perform equal.

In both the extended alternative and the base case the same total distance is travelled. However, in the extended alternative no congestion occurred. Therefore, the total times spent in the network and the total delay are significantly lower (Table 5-11). Moreover, the average speed is much higher in the extended alternative and no congestion occurred (Figure 5-6, p.74). Therefore, the extended alternative performs much better than the base case.

Table 5-11. Network performances all alternatives (distribution of 100% through traffic)

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
						Car	Freight	Car	Freight
Base case	Total	100045	2649	1867	38	2311	338	87579	12466
	1	98762	2632	1867	38				
	2	1282	16	0	80				
Unb. (2-1)	Total	100220	2651	1859	38	2311	340	87731	12489
	1	88412	2320	1650	38				
	2	11808	330	209	36				
Extended	Total	100045	898	59	111	763	135	87579	12466
	1	98762	882	59	112				
	2	1282	16	0	80				
Unb. (3-1)	Total	100202	966	110	104	827	139	87715	12487
	1	89303	803	59	111				
	2	10899	164	51	67				
Unb. (2-2)	Total	100346	926	56	108	791	136	87841	12505
	1	81854	732	50	112				
	2	18493	195	6	95				
Unb. (3-1) & shortcut	Total	106098	1196	292	89	1032	164	93130	12967
	1	95233	992	198	96				
	2	10865	204	94	53				

5.7.1 Alternatives with initially four lanes

In the unbundled 3-1 alternative some congestion occurred on the parallel road at the second on-ramp (Figure 5-6, p.74). In the extended alternative no congestion occurred, which explains why the total time spent and the total delay are higher for the unbundled 3-1 alternative. That the congestion only occurred on the parallel road is reflected in the performances of the sub-network parts. The performances of the first network parts are quite the same for the extended and unbundled 3-1 alternatives. And again, because this is an unbundled alternative, some routes are slightly longer than in not unbundled alternatives. Although, the extended alternative performs a little better than the unbundled 3-1 alternative.

In the unbundled 2-2 alternative, as in the extended alternative, no congestion occurred (Figure 5-6 & Figure 5-5 p.74). It would be expected that since no congestion occurred in the extended alternative, no congestion occurs in this alternative either. The total delay in the unbundled 2-2 alternative decreased in comparison with the extended alternative (Table 5-11, p.73). However, the total distance travelled and the total time spent increased. Besides, the average speeds in the sub-network parts are equal or higher in the unbundled alternative. Only because some routes are longer via the parallel road and the lower speed on the parallel road, the total distance and total time spent are higher for the unbundled 2-2 alternative compared to the extended alternative. When looking solely to the amounts, the extended alternative performs better than the unbundled 2-2 alternative.

The last alternative to discuss is the unbundled 3-1 with shortcut alternative. In comparison with the extended alternative, the total time spent in the network is much higher, the total delay increased and the average speed is lower for the unbundled 3-1 alternative (Table 5-11, p.73). Therefore, the unbundled 3-1 alternative performs worse than the extended alternative.

Moreover, when comparing the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives, there is a similar relation, as with the distribution of 90% through traffic. In the alternative without shortcut the congestion occurs at the second on-ramp, while in the alternative with shortcut congestion occurs at the first on-ramp (Figure 5-6 & Figure 5-5 p.74). This implies that in the unbundled alternative with shortcut more vehicles take a route via the parallel road and the shortcut. Therefore problems occur earlier in on the parallel road in this alternative.

As expected the problems that occurred with a distribution of 90% through traffic, became worse. However, still no congestion occurred in the extended and unbundled 2-2 alternatives. Like the distributions of 70%, 80% and 90% through traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

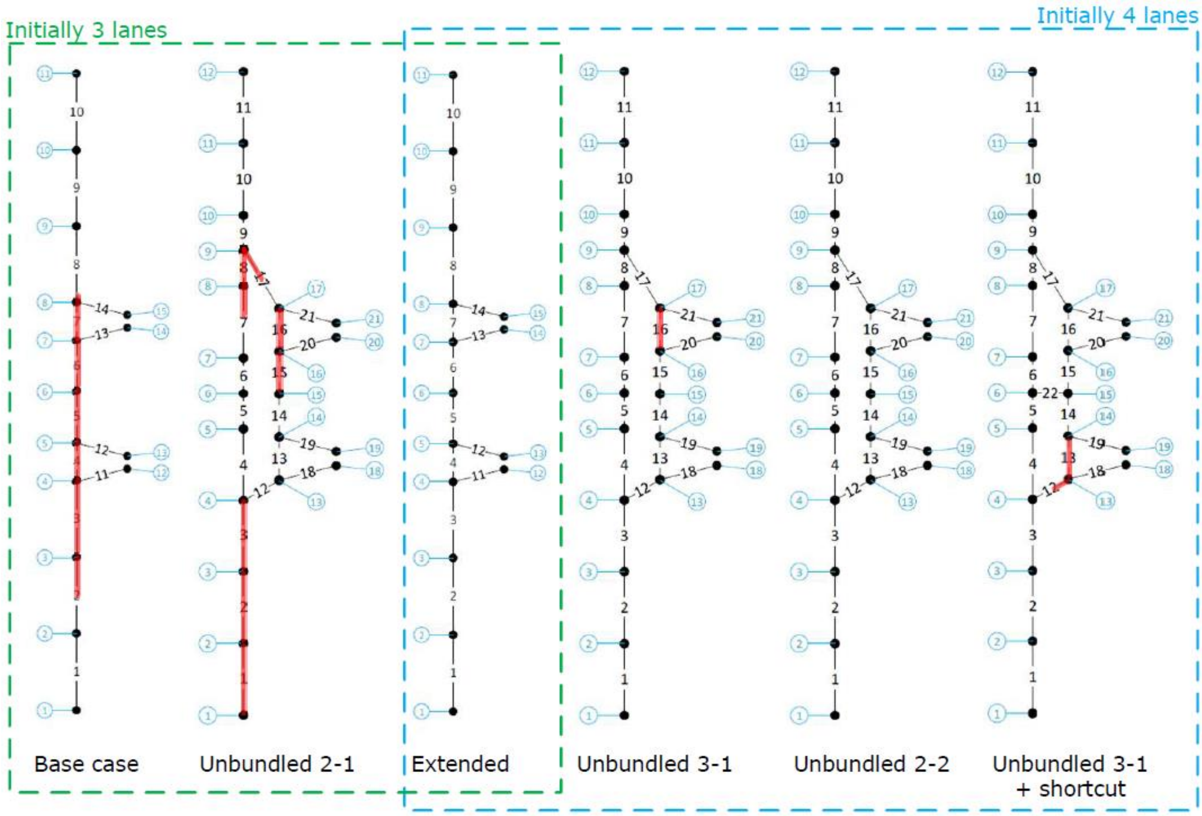


Figure 5-6. Visualisation congestion all alternatives (distribution of 100% through traffic)

5.7.2 Cost-benefit analysis

As shown in Table 5-12 (p.75) the only alternative that leads to societal benefits is the extended alternative. The extended alternative leads to high societal benefits and the unbundled 2-1 alternative leads to societal costs. This is in line with the results of the performances. The benefits that are obtained by travel time gains outweigh the investment & maintenance and emission costs in the extended alternative. In the base case congestion occurred and in the extended alternative not.

As for all previous distributions of through and local traffic, except the distribution of 50% through and local traffic, the unbundled 3-1 alternative with shortcut leads to the highest societal costs and the unbundled 3-1 alternative scores a bit better. Moreover, the unbundled 2-2 alternative leads to the least societal costs for the alternatives with initially four lanes. Again, in none of the alternatives less time is spent in the network than in the extended alternative and no travel time gains are obtained in any of the alternatives. Due to the congestion in the unbundled 3-1 and unbundled 3-1 with shortcut alternatives, the amount of emissions is higher in these alternatives. In the unbundled 2-2 alternative the emissions lead to societal benefits. Since in both alternatives no congestion occurred, this can be explained by the lower driven speeds in this alternative than in the extended alternative.

As well as for the distributions of 70%, 80% and 90% through traffic, only the extended alternative seems to be beneficial for 100% through going traffic when taking into account the performances and the cost-benefit analysis.

Table 5-12. Cost-benefit analysis results (distribution of 100% through traffic)

Base case & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 10,730,000	€ -
Travel times	€ -	€ -
Car	€ 110,000	€ -
Freight	€ -	€ -
Emissions	€ -	€ -
PM	€ 480,000	€ -
Nox	€ 2,030,000	€ -
CO2	€ 1,050,000	€ -
Safety	++	
Noise	+	
	€ 14,400,000	€ -
Total	€ -14,400,000	€ -

Base case & Extended

	Costs	Benefits
Inv. & Maint.	€ 6,990,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 82,040,000
Freight	€ -	€ 53,300,000
Emissions	€ -	€ -
PM	€ 110,000	€ -
Nox	€ -	€ 580,000
CO2	€ 290,000	€ -
Safety	-	
Noise	0	
	€ 7,390,000	€ 135,920,000
Total	€ -	€ 128,530,000

Extended & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 11,190,000	€ -
Travel times	€ -	€ -
Car	€ 3,370,000	€ -
Freight	€ 1,230,000	€ -
Emissions	€ -	€ -
PM	€ 790,000	€ -
Nox	€ 4,180,000	€ -
CO2	€ 1,860,000	€ -
Safety	++	
Noise	+	
	€ 22,620,000	€ -
Total	€ -22,620,000	€ -

Extended & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 12,990,000	€ -
Travel times	€ -	€ -
Car	€ 1,450,000	€ -
Freight	€ 240,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 90,000
Nox	€ -	€ 150,000
CO2	€ -	€ 290,000
Safety	+	
Noise	++	
	€ 14,680,000	€ 540,000
Total	€ -14,140,000	€ -

Extended & Unbundled 3-1 & shortcut

	Costs	Benefits
Inv. & Maint.	€ 11,350,000	€ -
Travel times	€ -	€ -
Car	€ 14,280,000	€ -
Freight	€ 7,530,000	€ -
Emissions	€ -	€ -
PM	€ 410,000	€ -
Nox	€ 2,110,000	€ -
CO2	€ 950,000	€ -
Safety	+	
Noise	+	
	€ 36,630,000	€ -
Total	€ -36,630,000	€ -

5.8 Increase of traffic demand

The results of the circumstances of 10% and 20% traffic demand increase are discussed in Appendix F. From this it can be concluded that the performances of the alternatives come closer together when the traffic demand increases. Besides, it can be concluded that the extended and the unbundled 2-2 alternatives perform the best under increased traffic demand circumstances of and are therefore the most robust alternatives. However, this is not true for the distribution of 100% through traffic. In that situation the unbundled 3-1 alternative performs best when the traffic demand increases with 20%.

Another finding is that for a distribution of 70% through traffic almost no congestion occurs in the extended and unbundled 2-2 alternatives when traffic demand increases with 20%. These performances decrease when the distribution of through traffic gets lower or higher. Therefore, it can be stated that with a distribution of 70% through traffic, the extended and unbundled 2-2 alternatives can handle the increase of traffic demand the best. This also holds for the unbundled 2-1 alternative. the other alternatives perform best with a distribution of 80% through traffic when traffic demand increases.

The section hereafter addresses the main limitations of the simulations and the CBA.

5.9 Limitations

This section addresses the main existing limitations, both for the simulations and the cost-benefit analysis. These limiting factors have an impact on the results.

5.9.1 Limitations design & simulations

Seven main limitations are distinguished for the simulations.

First of all, the assumption of distribution of the local traffic over the first and second exit has a big impact. This is a fixed distribution in this study, 20% of the local traffic takes the first exit and 80% of the local traffic takes the second exit. Variation in this distribution can have a big impact on the results. In the unbundled 2-1, unbundled 3-1 and unbundled 3-1 with shortcut alternative, under the circumstances with distributions of 50%, 60%, 70% and 80% through traffic, congestion occurs on the parallel road at the first on-ramp. Therefore the parallel road does not provide enough capacity to handle through traffic that takes the route via the parallel road, local traffic that wants to leave the motorway at the second exit and the traffic that enters at the first on-ramp together. Since the congestion occurs after the first exit, at the first on-ramp, the problem could be less when more traffic takes the first exit (and therefore less traffic takes the second exit). Another measure that can be taken, is to provide the parallel road between the first on-ramp and the second exit with an extra lane in order to meet the capacity demand. When solving this bottleneck, it is assumed that the mentioned alternatives perform better and have more societally benefits.

Secondly, the on- and off-ramps exist of only one lane. During this study a fixed number for the number of lanes on on- and off-ramps of one is used. Therefore, the second exit becomes the bottleneck in the base case, the extended and unbundled 2-2 alternatives under the circumstance of a distribution of 50% through traffic. This congestion spills back (onto the main carriageway) and these alternatives do not perform well. Therefore, no conclusion can be drawn if unbundling is an option or not for these alternatives. When this exit would be provided with two lanes, there is a big chance that no congestion occurs anymore in those alternatives and they could be an option.

The third limitation is that only two circumstances are taken into account. Besides, only one situation is simulated (one time of the day). In order to provide a better insight in what happens under different circumstances, more simulations should be executed under more different circumstances. Therefore, simulations in which accidents, detours and bad weather occur should be simulated as well. This also gives a better insight in the robustness of the networks.

Moreover, MARPLE does not take into account the effect of shorter travel times (road design change) attracting more traffic which could be another performance indicator. If the model would take this effect into account, the amount of vehicles (departed and arrived) would be higher in the networks that performed better (obtained lower travel times) than one of the two base cases. Therefore, the total time spent in the network and the total distance travelled would be higher. This has impact on the CBA and the consumer surplus as well. When then only the total times are taken into account, this gives an distorted result. With more traffic, the total travel time can still be higher, but the individual travel time is lower. Since there are more vehicles, more travel time is gained and leads to higher benefits.

Because of the use of a macroscopic model, only total travel times are obtained. It can be questioned that if the travel times were obtained per vehicle, the unbundled 2-2 alternative would lead to higher social benefits. For example, the traffic on the main carriageway gains travel time and has a higher value of time (higher distribution of freight traffic) then the traffic on the parallel road. It is possible that the travel time gains of the traffic on the main carriageway outweigh the costs of slightly longer travel times of traffic on the parallel road. Therefore, it is important to take this into account when this effect is taken into account.

However, since the alternatives will be compared based on the amount of traffic staying the same in each alternative, lower total time spent in the network and higher distance travelled identify individual travel time gains and can be identified as performance indicators. From this, conclusions can be drawn if an unbundled situation performs better.

Fifthly, the expectation that the unbundled 3-1 with shortcut alternative would perform better or equal to the unbundled 3-1 alternative did not come true for any of the distributions. Only for the distributions of 90% and 100% through traffic, the performances came close. As can be seen in Appendix F in each of the unbundled 3-1 alternatives with shortcut, the route via the shortcut is chosen. If the shortcut is such a bad alternative, it would be expected that this route is not used in the alternative with the shortcut. This is, however, not the case. This has probably something to do with the initial assignment and the combination of the network and demand input. No good explanation can be given for the results of the unbundled 3-1 with shortcut alternative.

Moreover, the decreased capacity of weaving areas is not taken into account during the simulations. Due to the turbulence that usually occurs at weaving areas the capacity is lower than for the standard capacity for the amount of lanes available. One of the reasons for applying unbundling is that less vehicles suffer from the turbulence caused by weaving traffic. Therefore, the effect of weaving areas is underestimated in the simulations and more problems (congestion) can be expected when decreasing the capacity for weaving areas.

Lastly, as mentioned in Section 3.1 there are many characteristics that can be distinguished when designing a road. It should be investigated what influence they have on the results of this study and if they have influence on the unbundling measure.

5.9.2 Limitations cost-benefit analysis

Three main limitations are distinguished for the cost-benefit analysis.

First, only car (commuting) and freight traffic purposes are taken into account. All the car traffic is considered commuting traffic, which has a substantial lower value of time than business traffic, but a lower value of time than 'remaining' traffic. When including the business and remaining traffic as well, this will have an impact on the travel time effects, either positive or negative. This depends on the shares of the different purposes and on the distribution of through and local traffic, but also the time of the day. Therefore it is assumed that, for example, commuting traffic mainly travels in peak hours. Besides, assumed is that through traffic mainly consists of freight and business traffic. When the distribution of through traffic is 50%, there is in relation to a distribution of 80% through traffic, a smaller amount of freight traffic present in the network. Therefore, travel times gains lead to lower societal benefits.

Secondly, as explained in Section 4.2, due to lacking information, safety and noise effects are not properly taken into account in the CBA. This is actually a very serious limitation, because safety can have a much higher effect than the travel time gains (positive or negative). Therefore, this could have made a difference in the CBA results, especially for the unbundled situations. Since the unbundled situations are assumed to be safer than the not-unbundled situations, this could have led to societal benefits.

Finally, the values that are used in the CBAs are for one situation only and are not corrected over time. This means that, for example, for value of time for 2020 is considered in the CBA. Since it is expected that the values for value of time will be higher in the future, the societal benefits are probably too low in the CBA. This is not taken into account.

5.10 Conclusion

The aim of this chapter has been to find out if unbundling can be deemed societal beneficial under two defined circumstances. The circumstances under which the alternatives have been tested are the distribution of through and local traffic, and the (total) traffic demand. There are six distributions of through traffic determined which starts at 50% through traffic till 100% through traffic, with steps of 10%. The total traffic demand is increased with 10% and 20%. This results in answering the eighth sub question: *'Is there a relation between the circumstances and the performance of the unbundling measure?'*

It can be identified that only for the circumstances of 50% through traffic and 50% local traffic and the initial traffic demand unbundling can be deemed beneficial for the base case with initially four lanes. More specific, only the unbundled 2-2 alternative is societally beneficial under those circumstances.

Table 5-13 shows the for each distribution of through and local traffic, for the initially three lanes and four lanes alternative separate, which alternative turned out to be the best option based on the network performance indicators and CBA. It must be noted that the extended alternative is the base case for the alternatives with initially four lanes. Therefore, it means that when the table shows 'ext' in a column with initially four lanes, the 'base case' ('do nothing') is best option.

Table 5-13. Overview best performing alternative in terms of performance and CBA for each distribution of through and local traffic (base = base case, ext = extended alternative, 2-2 = unbundled 2-2 alternative)

Distribution T/L	50-50		60-40		70-30		80-20		90-10		100-0	
Initially nr. of lanes	3	4	3	4	3	4	3	4	3	4	3	4
Performance	Ext	2-2	Ext	2-2	Ext	Ext	Ext	Ext	Ext	Ext	Ext	Ext
CBA	Ext	2-2	Base	Ext	Ext	Ext	Ext	Ext	Ext	Ext	Ext	Ext
Together	*Ext*	*2-2*	*Base*	*Ext*	*Ext*	*Ext*	*Ext*	*Ext*	*Ext*	*Ext*	*Ext*	*Ext*

For the distribution of 70%, 80%, 90% and 100% through traffic, the results are the same. For each case with initially three lanes, it is the best option to extend the motorway with one lane. Both the results of the performance as well as the results of CBAs show this. In none of these situations any of the unbundled alternatives performed better, which is not in line with the expectations. Therefore, unbundling is not promising for these distributions.

Moreover, when only evaluating based on the performance indicators, there is one more situation in which the unbundled 2-2 alternative performed the best. This is under the circumstances of 60% through traffic and 40% local traffic and the initial traffic demand. In none of the other simulations an unbundled alternative performed better than a not-unbundled situation (extended alternative) or was societally beneficial.

Several limitations have been distinguished as well. Due to the use of static distribution of local traffic taking the first or the second exit, it is assumed that the results are underestimated because bottlenecks appeared for which was not anticipated. Secondly, the decreased capacity in weaving areas is not taken into account during the simulations. Therefore, the effect of weaving areas is underestimated in the simulations and more problems (congestion) can be expected when decreasing the capacity for weaving areas. Lastly, the safety and noise effects in the CBA are estimated very roughly and it was not possible to monetarise these effects. Therefore, this could have made a difference in the CBA results, especially for the unbundled situations. Since the unbundled situations are assumed to be safer than the not-unbundled situations, this could have led to higher societal benefits.

The alternatives are also tested for different amounts of traffic demand. It can be concluded that the performances of the alternatives come closer together when the traffic demand increases. Besides, it can be concluded that the extended and the unbundled 2-2 alternatives perform the best under increased traffic demand circumstances of and are therefore the most robust alternatives. However, this is not true for the distribution of 100% through traffic. In that situation the unbundled 3-1 alternative performs best when the traffic demand increases with 20%. The distribution of 100% through traffic is however a very unlikely distribution.

It must be noted that, these conclusion are based on the results of the simulations and CBAs only. The results of these simulations will be verified ex-ante in the next chapter by an actual case.

6 Case study: Leiden A4

This chapter aims on verifying the found results from the archetype simulations, which are discussed in chapter 5. Since the simulations of the archetype are purely hypothetical, actual data will be used in order to verify the results. For the archetype alternatives, assumptions are made on the layout and geometry of the road design and fictitious data and traffic demand are used in order to create congestion. Therefore, an actual case with actual data is used to verify the simulation results and should show the same results. In agreement with an expert, the A4 near Leiden is chosen as the actual case.

Section 6.1 explains how the simulations for the actual case are setup. Section 6.2 discusses what changes in the execution of the CBA and Section 6.3 discusses the expectations on the results. Finally, Section 6.4 addresses the results. Sub question 9 will be answered in this chapter.

6.1 Setup of simulations

This section provides information on how the actual infrastructure/ road design of the A4 near Leiden (Amsterdam-Den Haag) is translated, so it can be used as input for MARPLE, how the alternatives are designed and what the circumstances are in this actual case.

6.1.1 The actual situation

The construction of a parallel road on the motorway A4 near Leiden was finished in 2015 and the network design corresponds to the base case determined in Section 4.1.2. Therefore, the unbundled situation at the A4 near Leiden, has two connections to the parallel road as well. Figure 6-1 shows the considered infrastructure of the A4 near Leiden. As in the archetype simulations, only one direction, Amsterdam – Den Haag, is considered. In this direction the biggest problems occur (van Loon, 2016; Rijkswaterstaat & Goudappel Coffeng, 2015). As can be seen from Figure 6-1 the main carriageway has initially three lanes and is reduced to two lanes after a few hundred meters of the beginning of the parallel road. Besides, at the end of the parallel road the main carriageway merges with the parallel road and becomes three lanes again. The maximum speed on both the main carriageway and the parallel road is 100 km/h.

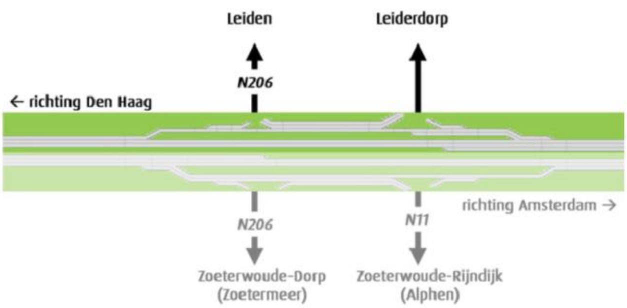
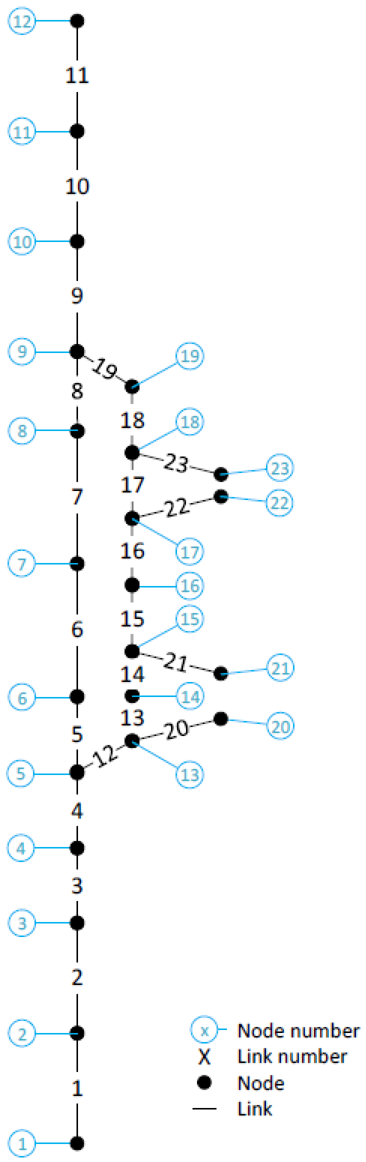


Figure 6-1. Considered infrastructure Amsterdam - Den Haag (Rijkswaterstaat & Goudappel Coffeng, 2015)

Data on the road design characteristics of the selected infrastructure is collected by Google Earth, Google Maps and Google street view. The collected data includes the number of lanes on the main carriageway and the parallel road, the number of lanes on the on- and off-ramps, the maximum speed on all roads and the lengths of the roads. The recent unbundled infrastructure at the A4 near Leiden is not yet included in google earth. Google Maps, however, does include the new road layout (in 'maps' view). Therefore, coordinates are used to transfer the actual road design of the A4 to google earth in order to measure the infrastructure. Appendix G shows which reference points are used. In order to be able to compare this case with the results of the archetypes (H6) it is important to keep the length of the network equal. Therefore, the length of the main carriageway is 9 kilometres. Figure 6-2 shows the characteristics of the actual situation of the A4 near Leiden as used during the simulation. In order to reconstruct the congestion as on the chosen day (explained in Section 6.1.3), some calibration was needed to reconstruct the congestion as in the actual case. Therefore, the capacity of some links is adapted.



Data Leiden Actual situation

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	3	6000
2	1000	100	3	6000
3	500	100	3	6000
4	500	100	4	8000
5	500	100	3	6000
6	1000	100	2	4100
7	1000	100	2	4100
8	500	100	2	4100
9	1000	100	3	6100
10	1000	100	3	6100
11	1000	100	3	6100
12	500	100	2	4100
13	250	100	2	4100
14	250	100	1	2000
15	500	100	3	6200
16	500	100	3	6200
17	350	100	1	2100
18	250	100	2	4300
19	500	100	1	2100
20	500	80	1	2100
21	500	80	2	4300
22	500	80	2	4100
23	500	80	1	2100

Length of the routes

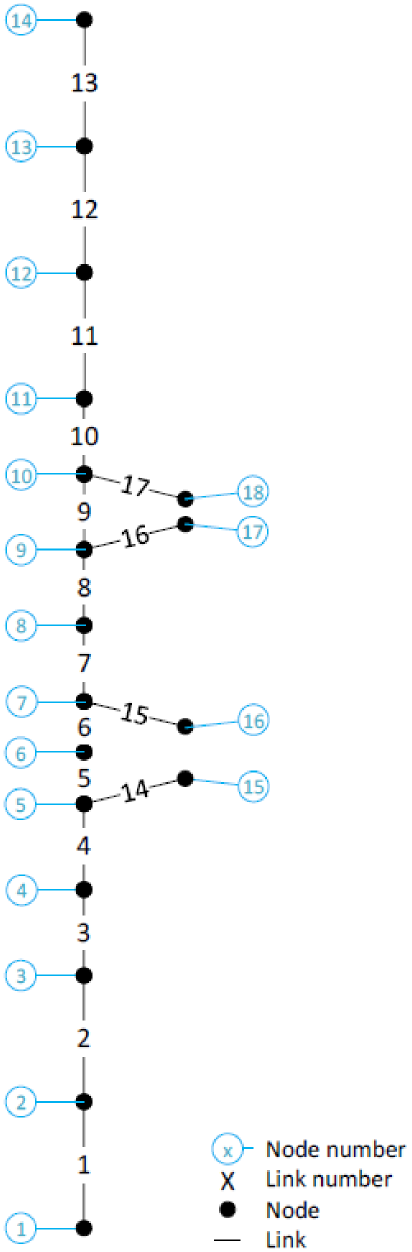
Origin	Destination	Length route (km)
1	12 (MC)	9
1	12 (PR)	9.1
1	20	4
1	22	5.5
21	12	5.6
21	22	2
23	12	4.25

Figure 6-2. Network characteristics actual situation of A4 Leiden

6.1.2 The alternatives

In order to compare the actual case with the archetypes, the archetype alternatives have to be translated to the same characteristics as the actual case. This means that the links and the length of all links remains the same and only the amount of lanes and capacity changes.

Therefore, the actual case is converted to a main carriageway of three lanes without parallel road, a main carriageway of four lanes with parallel road and four unbundled alternatives. The four unbundled alternatives correspond to the alternatives of the previous chapter. As explained before, in order to create an equivalent amount of congestion as in reality, some calibration had to take place. The same link capacities as in the actual case are applied. This is necessary in order to compare the alternatives to the actual case.



Data Leiden Base

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	3	6000
2	1000	100	3	6000
3	1000	100	3	6000
4	575	100	3	6000
5	250	100	3	6000
6	250	100	3	6000
7	500	100	4	8000
8	500	100	4	8000
9	350	100	3	6000
10	575	100	3	6000
11	1000	100	3	6000
12	1000	100	3	6000
13	1000	100	3	6000
14	500	80	1	2100
15	500	80	2	4300
16	500	80	2	4100
17	500	80	1	2100

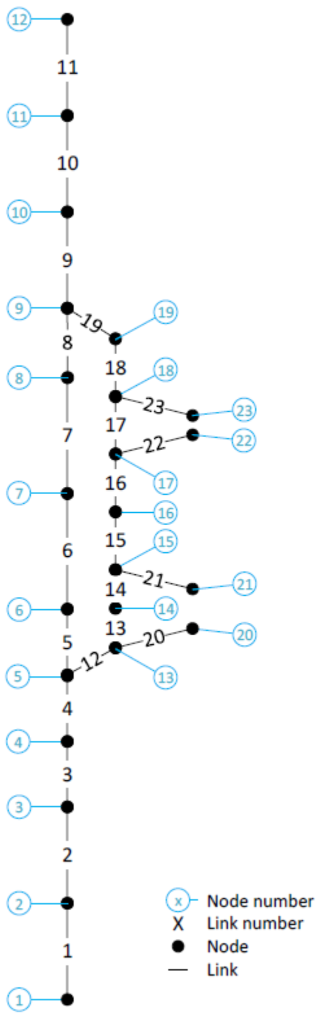
Data Leiden Extended

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	4	8000
2	1000	100	4	8000
3	1000	100	4	8000
4	575	100	4	8000
5	250	100	4	8000
6	250	100	4	8000
7	500	100	5	10100
8	500	100	5	10100
9	350	100	4	8000
10	575	100	4	8000
11	1000	100	4	8000
12	1000	100	4	8000
13	1000	100	4	8000
14	500	80	1	2100
15	500	80	2	4300
16	500	80	2	4100
17	500	80	1	2100

Length of the routes

Origin	Destination	Length route (km)
1	14	9
1	15	4.08
1	17	5.58
16	14	5.42
16	17	2
18	14	4.08

Figure 6-3. Characteristics of the base case and the extended alternative (Leiden)



Length of the routes

Origin	Destination	Length route (km)
1	12 (MC)	9
1	12 (PR)	9.1
1	20	4
1	22	5.5
21	12	5.6
21	22	2
23	12	4.25

Data Leiden Unbundled 2-1

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	3	6200
2	1000	100	3	6200
3	500	100	3	6200
4	500	100	3	6200
5	500	100	2	4300
6	1000	100	2	4300
7	1000	100	2	4300
8	500	100	2	4300
9	1000	100	3	6200
10	1000	100	3	6200
11	1000	100	3	6200
12	500	100	1	2100
13	250	100	1	2100
14	250	100	1	2100
15	500	100	1	2100
16	500	100	1	2100
17	350	100	1	2100
18	250	100	1	2100
19	500	100	1	2100
20	500	80	1	2100
21	500	80	1	2100
22	500	80	1	2100
23	500	80	1	2100

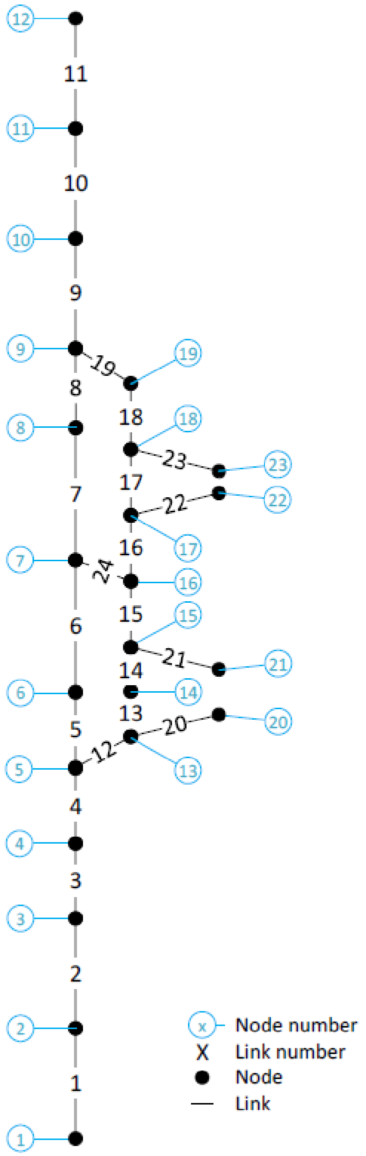
Data Leiden Unbundled 3-1

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	4	8200
2	1000	100	4	8200
3	500	100	4	8200
4	500	100	4	8200
5	500	100	3	6200
6	1000	100	3	6200
7	1000	100	3	6200
8	500	100	3	6200
9	1000	100	4	8200
10	1000	100	4	8200
11	1000	100	4	8200
12	500	100	1	2100
13	250	100	1	2100
14	250	100	1	2100
15	500	100	1	2100
16	500	100	1	2100
17	350	100	1	2100
18	250	100	1	2100
19	500	100	1	2100
20	500	80	1	2100
21	500	80	1	2100
22	500	80	1	2100
23	500	80	1	2100

Data Leiden Unbundled 2-2

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	4	8200
2	1000	100	4	8200
3	500	100	4	8200
4	500	100	4	8200
5	500	100	2	4300
6	1000	100	2	4300
7	1000	100	2	4300
8	500	100	2	4300
9	1000	100	4	8200
10	1000	100	4	8200
11	1000	100	4	8200
12	500	100	2	4300
13	250	100	2	4300
14	250	100	2	4300
15	500	100	2	4300
16	500	100	2	4300
17	350	100	2	4300
18	250	100	2	4300
19	500	100	2	4300
20	500	80	1	2100
21	500	80	1	2100
22	500	80	1	2100
23	500	80	1	2100

Figure 6-4. Network characteristics of all unbundled alternatives (Leiden)



Data Leiden Unbundled 3-1 + shortcut

Link	Length (m)	Speed (km/h)	Nr of lanes	Satflow (veh/hr)
1	1000	100	4	8200
2	1000	100	4	8200
3	500	100	4	8200
4	500	100	4	8200
5	500	100	3	6200
6	1000	100	3	6200
7	1000	100	3	6200
8	500	100	3	6200
9	1000	100	4	8200
10	1000	100	4	8200
11	1000	100	4	8200
12	500	100	1	2100
13	250	100	1	2100
14	250	100	1	2100
15	500	100	1	2100
16	500	100	1	2100
17	350	100	1	2100
18	250	100	1	2100
19	500	100	1	2100
20	500	80	1	2100
21	500	80	1	2100
22	500	80	1	2100
23	500	80	1	2100
24	200	100	1	2100

Length of the routes

Origin	Destination	Length route (km)
1	12 (MC)	9
1	12 (PR)	9.1
1	12 (SC)	9.2
1	20	5.5
1	22	5.6
21	12	5.6
21	12	5.7
21	22	2
23	12	4.25

Figure 6-5. Network characteristics for the unbundled alternative with shortcut (Leiden)

6.1.3 The circumstances / data collection

Since an actual case is considered, the circumstances, in terms of the distribution of through and local traffic and the traffic demand, are known. Data and information about the traffic demand is obtained by three sources. Therefore, seven simulations need to be executed.

First of all, a register plate investigation[7]. This investigation is executed during 5 working days in the week of 31th of August till the 4th of September 2015. Since the Tuesday, 1st of September 2015, seemed the busiest day, this day is chosen as the reference day. Besides, the morning peak hours, three hours between 07:00 AM and 10:00 AM, are considered during the simulation. Therefore, the simulations exist of 12 periods of 15 minutes. The actual traffic demand between all

[7] This register plate investigation is executed by Rijkswaterstaat and it is determined how through going traffic distributed over the main carriageway and the parallel road. This is done based on licence plate observation of passing vehicles (Rijkswaterstaat & Goudappel Coffeng, 2015).

OD pairs of Tuesday, the 1st of September 2015 between 07:00 AM and 10:00 AM can be found in Appendix H.

Secondly, the location of congestion in Google Maps is used to find out what links are congested. Google Maps includes a function that shows where congestion is located based on speeds of traffic. This can be visualised in two ways; live traffic information or typical traffic speeds. For this study the visualisation of typical traffic on a Tuesday morning is used for verification. Figure 6-6 shows what the speeds are for the A4 near Leiden on a typical Tuesday morning.

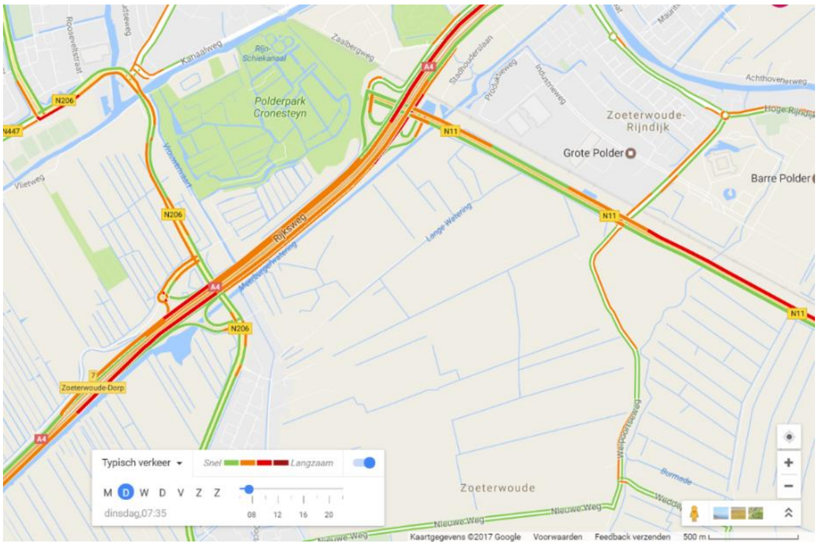


Figure 6-6. Typical traffic on Tuesday morning at the A4 near Leiden (Google Maps, 2017)

Thirdly, a speed contour plot is used to visualise the location of congestion of the main carriageway as well. MoniCa (abbreviation of MONItoring CAsco) is a system of Rijkswaterstaat that collects measurement results derived from the loop detectors on highways mainly. This data concerns, for example, velocities and intensities per minute. MoniGraph is a program that is used to process and visualise this data (Rijkswaterstaat, 2016). Figure 6-7 (p.87) shows the visualisation of the driven speeds on the 1st of September 2015 between 06:00 AM and 10:00 AM, between hectometre posts 30.1 and 36.8. In order to give a better insight in how to relate this figure to the actual situation, the parallel road start approximately at hectometre post 32.5 and ends at 36.0.

Based on this data, the actual case, A4 near Leiden, is simulated. In order to match the simulated situation with the actual case, some calibration was needed. Therefore, some link capacities and traffic demand between OD-pairs are adjusted. The traffic demand between all OD-pairs used during the simulation are shown per period in Figure 6-8. As can be seen inTable 6-1 (p.88), the average distribution between through and local traffic is 87% through traffic and 13% local traffic. The distribution for through traffic variates over the periods between 84% and 90%. Therefore, these distributions correspond the best to the distribution of 90% through traffic and 10% local traffic as defined as a circumstance for the archetype simulations. Moreover, the distribution of local traffic of the two exits is also shown in Table 6-1 (p.88). As can be seen only in the first period the distributions match with the distribution used in the archetypes simulations. The distribution of local traffic that take the first exit varies from 22% to 55%.

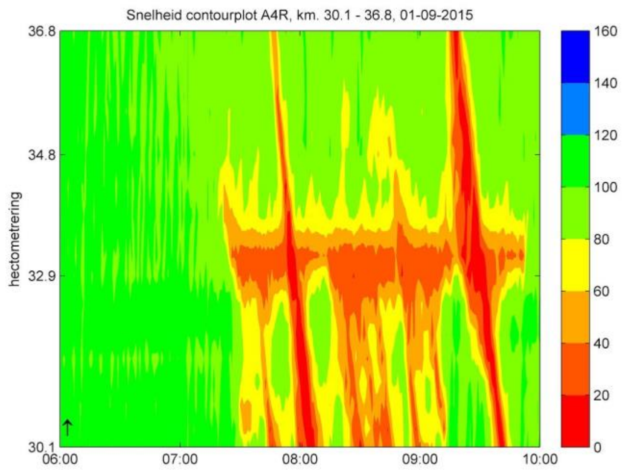


Figure 6-7. Speed contour plot main carriageway A4, 1st of September 2015, MoniGraph

Moreover, since no information is available on the type of traffic and thus shares of freight traffic, the freight traffic shares remain the same as in the archetype simulations and are shown in Table 4-3 (p.37).

Period 1	12 (14)	20 (15)	22 (17)
1	5184	152	526
21 (16)	984	x	508
23 (18)	750	x	x

Period 2	12 (14)	20 (15)	22 (17)
1	5907	222	648
21 (16)	1076	x	568
23 (18)	783	x	x

Period 3	12 (14)	20 (15)	22 (17)
1	4576	278	587
21 (16)	1008	x	588
23 (18)	870	x	x

Period 4	12 (14)	20 (15)	22 (17)
1	5230	291	503
21 (16)	972	x	480
23 (18)	770	x	x

Period 5	12 (14)	20 (15)	22 (17)
1	4244	364	432
21 (16)	884	x	580
23 (18)	703	x	x

Period 6	12 (14)	20 (15)	22 (17)
1	4216	417	360
21 (16)	852	x	520
23 (18)	863	x	x

Period 7	12 (14)	20 (15)	22 (17)
1	4347	446	360
21 (16)	872	x	612
23 (18)	712	x	x

Period 8	12 (14)	20 (15)	22 (17)
1	4450	301	337
21 (16)	740	x	508
23 (18)	611	x	x

Period 9	12 (14)	20 (15)	22 (17)
1	3846	260	296
21 (16)	544	x	485
23 (18)	601	x	x

Period 10	12 (14)	20 (15)	22 (17)
1	4959	222	315
21 (16)	514	x	490
23 (18)	593	x	x

Period 11	12 (14)	20 (15)	22 (17)
1	3736	294	269
21 (16)	414	x	498
23 (18)	463	x	x

Period 12	12 (14)	20 (15)	22 (17)
1	3319	260	215
21 (16)	405	x	459
23 (18)	432	x	x

Through traffic
Local traffic

Figure 6-8. Traffic demand OD-pairs for actual case, A4 near Leiden

Table 6-1. Distribution of through and local traffic for each period of time

	Through traffic	Local traffic	Local traffic-Exit 1	Local traffic-Exit 2
Period 1	88%	12%	22%	78%
Period 2	87%	13%	26%	74%
Period 3	84%	16%	32%	68%
Period 4	87%	13%	37%	63%
Period 5	84%	16%	46%	54%
Period 6	84%	16%	54%	46%
Period 7	84%	16%	55%	45%
Period 8	87%	13%	47%	53%
Period 9	87%	13%	47%	53%
Period 10	90%	10%	41%	59%
Period 11	87%	13%	52%	48%
Period 12	87%	13%	55%	45%
Average	**87%**	**13%**		

6.2 Cost-benefit analysis

This section describes how the costs-benefit analysis are executed and which values are used for the actual case. The way of calculating the effects stay the same and the same effects are included. The biggest change in the cost-benefit analysis are the investment & maintenance costs for the alternatives.

Investment & maintenance costs

Since the initial situation is an actual network, it has to be determined what the costs for adjustments to this network/infrastructure are. Therefore, an estimation is made on what the costs are for both the construction of 1 kilometre of main carriageway and 1 kilometre of parallel road. In order to do so, the costs for construction & maintenance for the base case and extended alternative of the archetype alternatives are compared (Section 4.2.1). The only difference between these two alternatives is that in the extended alternative one more lane is available over a length of 9 kilometres. Therefore, the difference in costs for the base case and the extended alternative is divided by 9 in order to estimate the construction costs for 1 km of main carriageway. The same is done for the parallel road with the unbundled 2-1 and unbundled 2-2 alternative.

Since no costs for removing (part of) roads are available/known, it is assumed that removing costs will be lower than the construction costs. Therefore, the construction costs are multiplied by 1/3[8] in order to estimate the costs for removing 1 kilometre (1 lane). The estimated costs for constructing and removing 1km of carriageway and parallel road are shown in Table 6-2 (p.89).

When comparing the length of the carriageways and parallel road (if available) of each alternative with the actual case, the differences in the amount of kilometres the costs for adjusting the actual case can be calculated. The complete calculations for the adjustment costs of each alternative are

[8] This is a rough estimation in order to estimate costs for removing 1 lane over 1 km of the main carriageway and the parallel road.

shown in Appendix I and the costs for each alternative are shown in Table 6-3. These costs are used in the CBA for adjustment of the actual case.

Table 6-2. Costs for constructing and removing 1km of carriageway and parallel road

	Costs for constructing	Costs for removing (km)
Main carriageway		
Base case	€ 52,504,000	
Extended	€ 59,494,000	
Difference	€ 6,990,000	
	€ 777,000	€ 259,000
Parallel road		
Unbundled 2-1	€ 63,233,000	
Unbundled 2-2	€ 72,486,000	
	€ 9,253,000	
	€ 2,606,000	€ 2,606,000

Table 6-3. Adjustment costs infrastructure in comparison to actual case

	Total
Base case	€ 7,630,000
Extended	€ 14,620,000
Unb 2-1	€ 690,000
Unb 3-1	€ 6,650,000
Unb 2-2	€ 6,750,000
Unb 3-1 +	€ 6,350,0000

Travel time

Since still only car and freight traffic are considered, the calculation of travel time effects stays the same as for the archetype alternatives. Therefore, the value of time for cars (commuting traffic) is €9,53 and for freight traffic €46,54 (Ministerie van Infrastructuur en Milieu, 2012).

Emissions

The same components are taken into account as for the archetype alternatives, because the concentrations of those components are often the closest to the health damage limits (Wever & Rosenberg, 2012). The amount of grams of emitted substances is calculated by the simulation model MARPLE. The difference between each emitted substance of the alternative and the actual case is multiplied by the costs. Therefore, one kg of emitted particulate matter costs €189, one kg of emitted nitrous oxides costs €11 and one kg of emitted CO2 costs €0,026 (Ministerie van Infrastructuur en Milieu, 2016b). The costs are the same as for the archetype because the same location is considered.

Safety & noise pollution

Since it is still not known what the effects of an unbundled network on safety are and no actual numbers/risks could be found to calculate with and no information on the number of decibels is known, the same method is used to calculate the effects of safety and noise with as for the archetype.

The safety effect is determined based on the amount of lanes on the carriageways and the difference in speed between weaving traffic. The more lanes on the carriageway and the higher the difference between weaving traffic, the less safer. The effect of the amount of lanes stays the same as for the archetype simulations. Since the maximum speed is 100 km/h on both the main carriageway and the parallel road in the actual case, this does not differ between the alternatives. Therefore, safety only depends on the amount of lanes on which the weaving movements take place. Therefore, the unbundled situations are considered safer than the not-unbundled situations.

Noise effects are determined based on the size of the traffic flow, the speeds and the acceleration. Since there are no speed differences between all the alternatives, this factor is left out for the actual case. For the other two factors are taken into account the same way as for the archetype simulations.

6.3 Expectations

As mentioned earlier, the average distribution between through and local traffic is 87% through traffic and 13% local traffic for the actual case (Table 6-1, p.88). Therefore, these distributions correspond the best to the distribution of 90% through traffic and 10% local traffic as defined as a circumstance for the archetype simulations. Therefore, it is expected that the results of this actual case will correspond to the results of the distribution of 90% through traffic in the archetype simulations, which are discussed in Section 5.6. For the alternatives with initially three lanes the extended alternative performs best and the societal benefits for this alternative outweigh the costs. For the alternatives with initially four lanes, 'the base case' (extended alternative) performs the best as well. Therefore, the unbundling measure is expected to not be societal beneficial in the actual either.

Moreover, the distribution of local traffic leaving the motorway at the first and the second off-ramps differs from the distribution used in the simulation of the archetype (Table 6-1, p.88). The distribution of local traffic taking the first exit rises over the periods. Therefore it is expected that in the base case no congestion occurs at the first on-ramp, because a higher share of traffic is leaving the motorway at first exit. Besides, it is expected that no congestion will occur in the unbundled 3-1 with shortcut alternative on the parallel road because of the same reason.

For the distribution of 90% through traffic and 10% local traffic in the archetype simulations, in all alternatives congestion occurred, except in the extended and the unbundled 2-2 alternative. This means that is expected that no congestion will occur in the not-unbundled carriageway with four lanes and the unbundled 2-2 alternative in the actual case either. Therefore, they are expected to perform better than the actual case.

For the alternatives with initially three lanes, the base case performed equal to the unbundled 2-1 in the archetype simulation and the extended performed better than the base case. Therefore, it is expected that the not-unbundled carriageway with three lanes will perform equal to the unbundled 2-1 alternative and the not-unbundled carriageway with four lanes will perform better than the alternative with three lanes. Congestion occurred in the base case archetype simulation at the two on-ramps and congestion occurred in the unbundled 2-1 alternative at the junction where the parallel road start and where the main carriageway and the parallel road merge again.

For the alternatives with initially four lanes, the extended alternative performed better than any of the other alternatives. However, in the unbundled 2-2 alternative no congestion occurred either.

The total time spent and the total distance travelled are slightly higher for this alternative, but can be explained by the presence of the parallel road. The maximum speed on this lane is 20 km/h lower than on the main carriageway and the route via the parallel road for through traffic is slightly longer than the one via the main carriageway. Since the speeds on the main carriageway and the parallel road are equal for the actual case at the A4 near Leiden, it is expected that the difference of the performance between the unbundled 2-2 and the extended alternative will be smaller.

When comparing all alternatives to the actual case, it is expected that the alternatives with initially four lanes will perform better. The actual case has initially three lanes as well, which is decreased by one lane just after the beginning of the parallel road. This is one of the main bottlenecks in this case. Therefore it is expected that any alternative with three lanes on the main carriageway (initially four lanes) will perform better. The other main bottleneck is when the main carriageway and the parallel road merge again. Since the same amount of lanes is available at the bottlenecks in the unbundled 2-1 alternative it is expected that this alternative will perform equal to the actual case.

6.4 Results

As for the result of the archetype simulations, the results are for alternative are expressed in the network performance (indicators), the visualisation of the location of congestion and the outcome of the cost-benefit analysis. The conclusions are drawn based on those three results. The tables and figure contain the same aspects as shown for the simulations of the archetype.

Therefore, a table with the network performance of the actual case and all six alternatives will be shown. Besides, the performance of each alternative is again shown for the main carriageway and the parallel network parts separately. By showing the results for the network parts separately, it can be seen in which sub network delays occur.

Secondly, the location of congestion for each alternative will be shown. Since each simulation exists of 12 time periods of 15 minutes, one of the periods had to be chosen to visualise the congestion of. The congestion is, again, the worst in each 5th period of the simulations and therefore chosen to visualise. As for the archetype simulations, it has to be noted that there is a difference between congestion (i.e. jammed traffic) and slow-moving traffic.

Lastly, the cost-benefit analysis results. The societal costs and benefits will be shown for each comparison. Since the effects are roughly estimated, the amounts are rounded to the nearest thousand euros. It is not possible to round to then thousands, because otherwise some amounts disappeared from the CBA.

Since alternatives can only be compared when they have initially the same amount of lanes and in order to not compare separate issues, the networks with initially three lanes are compared and the networks with initially four lanes are compared separately for each distribution of through and local traffic. Besides the same comparisons have to be made as for the archetypes simulations in order to verify the results of the archetype simulations. Therefore, the not-unbundled carriageway with three lanes will be compared to the unbundled 2-1 and the not-unbundled carriageway with four lanes and the not-unbundled carriageway with four lanes, will be compared to all other unbundled alternatives. Moreover, all six alternatives will be compared to the actual case in order to say something about which alternative is the option to solve the problems at the bottlenecks.

As for the archetype simulations, an alternative (network) performs better than another one when the total distance travelled and the average speed increase while the total time spent and the total delay decrease. When the average speed increases, that means that there is less congestion (in at least one part of the network). Since no new traffic is attracted because of lower travel times, the travel times decrease and the total time spent in the network decreases as well. With this, more vehicles can pass the network in a shorter time, which means that the total distance travelled increases and the total delay decrease.

6.4.1 Network performances

In this section the results of the actual case, the A4 near Leiden, will be shown and discussed. Table 6-4 (p.93) shows how the alternatives perform and in Figure 6-10 (p.94) is visualised where congestion is located in the actual case and all alternatives.

The actual situation of the A4 near Leiden is simulated as good as possible by, as explained earlier, adapting the capacity on some links and by changes in the traffic amount between OD-pairs in some of the periods. Figure 6-9 shows the speed contour plot of the actual case after simulation generated by MARPLE. In this situation the parallel road stars at 3 and ends at 6. As can be seen the bottlenecks are replicated at the same places (Figure 6-7 & Figure 6-9). Due to the congestion (and spillback) that occurs at link 5 because of the disappearance of one lane, the access to the parallel road is blocked. This causes the low average speeds and the high total delay and high total time spent in the network.

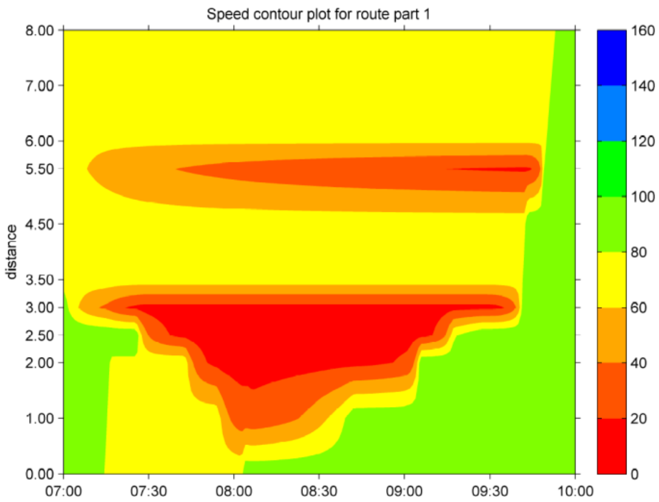


Figure 6-9. Speed contour plot simulated actual case, A4 near Leiden, MARPLE

Initially three lanes

When comparing only the three alternatives with initially three lanes, the results correspond to the results of these cases in the simulations of the archetype with a distribution of 90% through traffic. In those was expected that the not unbundled carriageway with four lanes (i.e. extended alternative) always performs better than the not unbundled carriageway with three lanes (i.e. base case). Once again, this turns out to be true.

It was also expected that the unbundled 2-1 alternative performs equal to the not-unbundled carriageway with three lanes. This turns out to be true as well. The total time spent in the network is for both alternatives the same, the total delay differs just with 10 hours and the average speed is equal as well. Therefore, the results for the alternatives with initially three lanes are in line with the results of the archetypes simulations.

However, the expectation that no congestion occurred in the base case at the first on-ramp did not come true (Figure 6-10, p.94). But, the second on-ramp is not the bottleneck anymore. Since much more traffic is entering the motorway at the second on-ramp than in the archetype simulations, this bottleneck stays and the congestion spills back throughout the network.

Table 6-4. Simulation results of all alternatives for actual case, A4 near Leiden

	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (min)		Distance travelled (km)	
						Car	Freight	Car	Freight
Actual case	Total	157984	3431	1911	46	3023	408	139160	18824
	1	136907	2773	1475	49				
	2	21077	658	435	32				
Not. Unb. 3	Total	156830	4199	2691	37	3690	510	138106	18723
	1	152008	4139	2690	37				
	2	4822	61	0	80				
Not. Unb. 4	Total	156970	1629	47	96	1422	207	138230	18740
	1	152156	1569	47	97				
	2	4815	60	0	80				
Unb. (2-1)	Total	157774	4199	2681	38	3692	507	138976	18799
	1	136806	3535	2239	39				
	2	20968	664	442	32				
Unb. (3-1)	Total	157818	1786	196	88	1569	217	139014	18805
	1	136199	1403	41	97				
	2	21620	383	155	56				
Unb. (2-2)	Total	158175	1643	49	96	1435	208	139321	18854
	1	124460	1284	39	97				
	2	33715	359	10	94				
Unb. (3-1) & shortcut	Total	158443	1725	128	92	1508	217	139559	18884
	1	131985	1360	40	97				
	2	26457	365	88	72				

Initially four lanes

Secondly, the four alternatives with initially four lanes will be compared. The not-unbundled carriageway with four lanes, has the lowest total time spent in the network and the lowest total delay. However, the unbundled 2-2 alternative has the highest speeds. The speed maximum speeds difference between the parallel road, 100 km/h, and the on- and off-ramps, 80 km/h, need to be taken into account here. The second network part of the unbundled 2-2 alternative exists of the parallel road and the on- and off-ramps, while the second network part in the not-unbundled carriageway with four lanes exists of on- and off-ramps only. Therefore the average speed of the not-unbundled alternative will never be higher than 80 km/hr.

That the unbundled 2-2 alternative performs slightly better than the not-unbundled situation, while it did not in the archetype simulations, can be explained by the maximum speed limits. Since there is no difference between the maximum speed on the main carriageway and the parallel road and the route via the parallel route is just slightly longer, the differences in travel times between the two routes become very small. This is in line with the expectations.

The unbundled 3-1 alternative performs worse than the not-unbundled carriageway with four lanes and the unbundled 2-2 alternatives. The unbundled 3-1 alternative has a higher total times pent, higher total delay and a lower average speed than both of the other two alternatives.

In the archetype simulations, the alternative with the shortcut never performed better than the unbundled 3-1 alternative. However, the problem did not occur in the actual case. Apparently, the problem was caused by an unhappy combination of the number of routes, the capacity on the links and the traffic demand.

The expectation that no congestion would occur in the unbundled 3-1 with shortcut alternative at the first on-ramp came true. The bottleneck, however, moved to the first exit, because of the increased distribution of local traffic that wants to take the first exit. This exit does, with its one lane, not provide enough capacity.

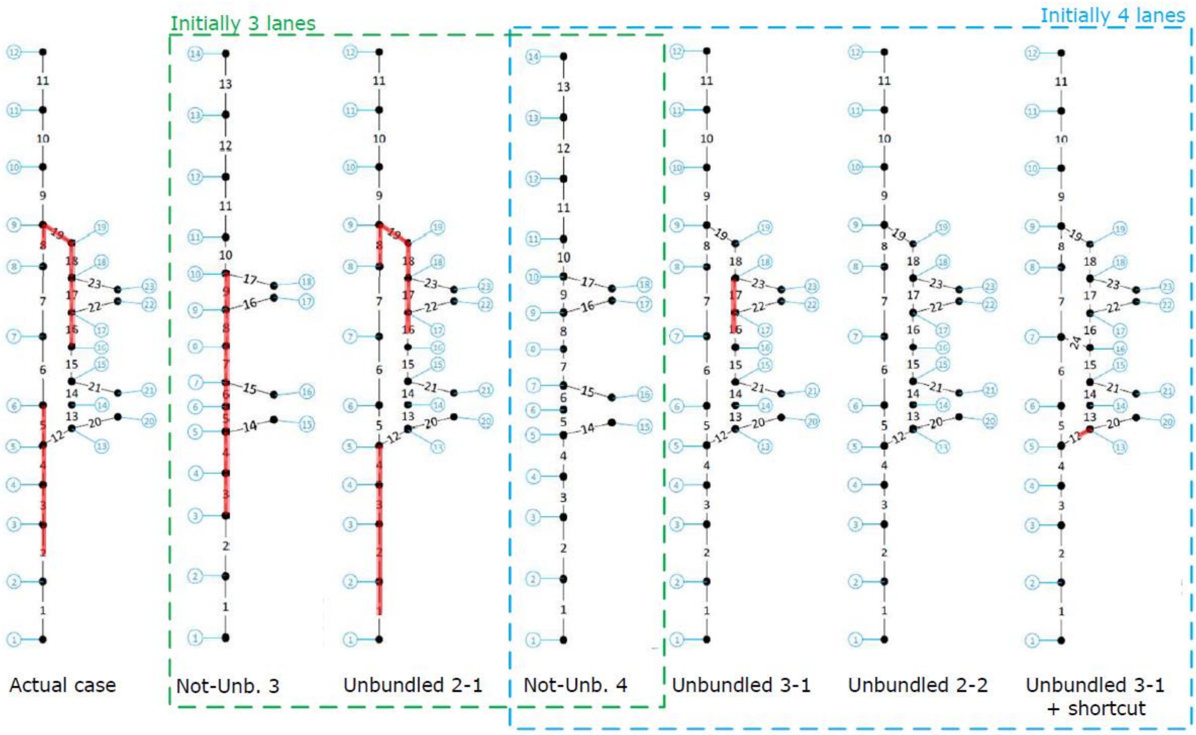


Figure 6-10. Visualisation congestion all alternatives (Actual case, A4 near Leiden)

Therefore, these results, except for the alternative with shortcut, are also in line with the results for the archetype simulations with a distribution of 90% through traffic. The not-unbundled carriageway with three lanes performed best of the alternatives with initially three lanes and the not-unbundled carriageway with four lanes and the unbundled 2-2 alternatives performed the best of the alternatives with initially four lanes.

The actual case

First the actual case will be compared to the not unbundled alternatives. As can be seen from Table 6-4 (p.93), a not unbundled infrastructure with three lanes on the carriageway does not provide enough capacity to handle traffic without any major delays. The total delay is higher than for the actual case. Therefore, the total time spent is higher as well and the average speed is lower. From this can be deduced that a not unbundled carriageway with three lanes does not perform better than the actual case.

Unlike the not unbundled carriageway with three lanes, the not unbundled carriageway with four lanes does perform much better than the actual case. Besides, no congestion occurred in this alternative. Therefore, the total delay and the total time spent in the network are low, the lowest of all alternatives. Moreover, the average speeds are (almost) equal to the maximum allowed speeds, which also indicates the absence of congestion. Therefore, the alternative consisting of a not unbundled carriageway with four lanes performs better than the actual case.

Secondly the actual case will be compared to the other alternative with initially three lanes, the unbundled 2-1 alternative. In the unbundled 2-1 alternative congestion occurred at the same locations as in the actual case (Figure 6-10, p.94), but in the alternative the congestion spills further back. Therefore, the unbundled 2-1 alternative has a higher total time spent, a higher total delay and lower average driven speeds than the actual case. It can be stated that the unbundled 2-1 alternative performs worse than the actual case.

Thirdly, all alternatives with initially four lanes will be compared to the actual case. In the unbundled 3-1 alternative the vehicles spent almost half of the time in the network (Table 6-4, p.93). Besides, the total delay is significantly lower than in the actual case as well. Moreover, congestion only occurred on the parallel road at the second on-ramp (Figure 6-10, p.94). Link 18 does not meet the capacity to accommodate the traffic that is already on the parallel road and the traffic that enters the motorway at the second on-ramp. However, the unbundled 3-1 alternative does perform better than the actual case. The biggest bottleneck that exists in the actual case, that the main carriageway goes from three to two lanes, has been removed in this alternative.

In the unbundled 2-2 alternative the vehicles spent less than half of the time in the network than the vehicles in the actual situation (Table 6-4, p.93). The total delay is low and the average speeds almost reaches the maximum allowed speed. Besides, no congestion occurred in the unbundled 2-2 alternative either (Figure 6-10, p.94). Therefore this alternative also performs better than the actual case.

As in the not-unbundled carriageway with four lanes and the unbundled 2-2, in unbundled 3-1 with shortcut no congestion occurred either (Figure 6-10, p.94). Also in this alternative the total time spent is lower, the total delay is lower and the average speed is higher than in the actual case. Therefore, the unbundled 3-1 alternative performs better than the actual case.

Since all alternatives with initially four lanes perform better than the actual case, it can be stated that more capacity is needed on the main carriageway. The not-unbundled carriageway with four lanes and the unbundled 2-2 alternatives are the best options in order to solve the bottlenecks.

6.4.2 Cost-benefit analysis

Also for the CBA the alternatives with initially three lanes and initially four lanes are compared. Besides, all six alternatives are also compared to the actual case in order to say something about which alternative is the option to solve the actual problems at the bottlenecks.

Table 6-5 shows the results of the cost-benefit analysis for the alternatives with initially three and with initially four lanes. In the cost-benefit analysis for the archetype simulations with a distribution of 90% through traffic, only the extended alternative (not-unbundled carriageway with four lanes) lead to societal benefits. This is also true for this actual case, all other alternatives lead to societal costs. In the archetype simulations the unbundled 2-2 lead to the least societal costs for the alternatives with initially four lanes. The unbundled 3-1 alternative leaded to more societal costs. This also turned out to be true for this actual case. The only difference is that the unbundled 3-1 alternative with shortcut leads to less societal costs than the unbundled 3-1 alternative without shortcut. But, due to the performance results this could be expected.

Table 6-5. Cost-benefits results

Initially three lanes

Not-unbunlded 3 lanes & Unbundled 2-1

	Costs	Benefits
Inv. & Maint.	€ 15,980,000	€ -
Travel times	€ -	€ -
Car	€ 90,000	€ -
Freight	€ -	€ 650,000
Emissions	€ -	€ -
PM	€ 430,000	€ -
Nox	€ 1,770,000	€ -
CO2	€ 840,000	€ -
Safety	++	
Noise	0	
	€ 19,110,000	€ 650,000
Total	€ -18,460,000	€ -

Not-unbunlded 3 lanes & Not-unbundled 4 lanes

	Costs	Benefits
Inv. & Maint.	€ 7,020,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 120,390,000
Freight	€ -	€ 78,500,000
Emissions	€ -	€ -
PM	€ 180,000	€ -
Nox	€ -	€ 2,090,000
CO2	€ -	€ 90,000
Safety	-	
Noise	0	
	€ 7,200,000	€ 201,080,000
Total	€ -	€ 193,880,000

Initially four lanes

Not-unbundled 4 lanes & Unbundled 3-1

	Costs	Benefits
Inv. & Maint.	€ 16,590,000	€ -
Travel times	€ -	€ -
Car	€ 7,790,000	€ -
Freight	€ 2,750,000	€ -
Emissions	€ -	€ -
PM	€ 910,000	€ -
Nox	€ 5,180,000	€ -
CO2	€ 2,230,000	€ -
Safety	++	
Noise	0	
	€ 35,450,000	€ -
Total	€ -35,450,000	€ -

Not-unbundled 4 lanes & Unbundled 2-2

	Costs	Benefits
Inv. & Maint.	€ 19,420,000	€ -
Travel times	€ -	€ -
Car	€ 650,000	€ -
Freight	€ 360,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 130,000
Nox	€ 230,000	€ -
CO2	€ -	€ 150,000
Safety	+	
Noise	++	
	€ 20,660,000	€ 270,000
Total	€ -20,390,000	€ -

Not-unbundled 4 lanes & Unbundled 3-1 & shortcu

	Costs	Benefits
Inv. & Maint.	€ 17,830,000	€ -
Travel times	€ -	€ -
Car	€ 4,580,000	€ -
Freight	€ 2,540,000	€ -
Emissions	€ -	€ -
PM	€ 210,000	€ -
Nox	€ 1,060,000	€ -
CO2	€ 500,000	€ -
Safety	+	
Noise	+	
	€ 26,720,000	€ -
Total	€ -26,720,000	€ -

Overall, the results of the cost-benefit analysis are in line with the archetype simulations in the previous chapter. Therefore, the unbundling measure is not societally beneficial for this distribution of through and local traffic. This means that with a distribution of 90% through traffic, and in this case 87%, the only alternative that leads to societal benefits is the not-unbundled carriageway with four lanes (i.e. extended alternative) when having initially three lanes. In case there are initially four lanes, none of the alternatives seems a better option.

In order to say something about which alternative is the option to solve the problems at the bottlenecks in the actual case, cost-benefits analysis are also executed for all alternatives in comparison to the actual case. Table 6-6 shows the results of these CBAs. As can be seen from the table, only for the not-unbundled carriageway with three lanes and the unbundled 2-1 alternative no travel times are gained. For all other alternatives the societal benefits that result from travel time gains, do outweigh the societal costs, and lead to high societal benefits. Therefore it can be said that, in order to solve the bottlenecks, at least three lanes must be available over the full length of the main carriageway or the parallel road should be provided with two lanes over the full length of the parallel road.

Table 6-6. Cost-benefit analysis results (actual case, A4 near Leiden)

Initially three lanes

Actual situation & Not-unbunlded 3 lanes

	Costs	Benefits
Reconstruction	€ 7,630,000	€ -
Travel times	€ -	€ -
Car	€ 35,400,000	€ -
Freight	€ 26,370,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 530,000
Nox	€ -	€ 2,240,000
CO2	€ -	€ 1,110,000
Safety	-	
Noise	0	
	€ 69,400,000	€ 4,070,000
Total	€ -65,330,000	€ -

Actual situation & Not-unbundled 4 lanes

	Costs	Benefits
Reconstruction	€ 14,620,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 84,990,000
Freight	€ -	€ 52,130,000
Emissions	€ -	€ -
PM	€ -	€ 350,000
Nox	€ -	€ 4,330,000
CO2	€ -	€ 1,190,000
Safety	-	
Noise	-	
	€ 14,620,000	€ 143,160,000
Total	€ -	€ 128,540,000

Actual situation & Unbundled 2-1

	Costs	Benefits
Reconstruction	€ 690,000	€ -
Travel times	€ -	€ -
Car	€ 35,500,000	€ -
Freight	€ 25,720,000	€ -
Emissions	€ -	€ -
PM	€ -	€ 100,000
Nox	€ -	€ 470,000
CO2	€ -	€ 270,000
Safety	0	
Noise	0	
	€ 61,910,000	€ 870,000
Total	€ -61,040,000	€ -

Initially four lanes

Actual situation & Unbundled 3-1

	Costs	Benefits
Reconstruction	€ 6,650,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 77,200,000
Freight	€ -	€ 49,380,000
Emissions	€ -	€ -
PM	€ 560,000	€ -
Nox	€ 850,000	€ -
CO2	€ 1,040,000	€ -
Safety	0	
Noise	+	
	€ 9,100,000	€ 126,600,000
Total	€ -	€ 117,500,000

Actual situation & Unbundled 2-2

	Costs	Benefits
Reconstruction	€ 6,750,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 84,340,000
Freight	€ -	€ 51,770,000
Emissions	€ -	€ -
PM	€ -	€ 470,000
Nox	€ -	€ 4,100,000
CO2	€ -	€ 1,340,000
Safety	-	
Noise	0	
	€ 6,750,000	€ 142,030,000
Total	€ -	€ 135,280,000

Actual situation & Unbundled 3-1 & shortcut

	Costs	Benefits
Reconstruction	€ 6,350,000	€ -
Travel times	€ -	€ -
Car	€ -	€ 80,410,000
Freight	€ -	€ 49,590,000
Emissions	€ -	€ -
PM	€ -	€ 140,000
Nox	€ -	€ 3,270,000
CO2	€ -	€ 700,000
Safety	-	
Noise	0	
	€ 6,350,000	€ 134,110,000
Total	€ -	€ 127,760,000

6.5 Conclusion

This chapter has aimed to verify the found results from the archetype simulations, which are discussed in chapter 5. The results of these simulations are in this chapter verified by an actual case, the A4 near Leiden, in which unbundling is applied recently.

In order to do so, the alternatives of the archetype simulations are adjusted so they met the characteristics of the actual case. The actual case and the actual traffic demand, obtained from a license plate investigation, of the 1st of September 2015 are used to reconstruct the bottlenecks and the length of the congestion. Alternatives with initially three lanes and the alternatives with initially four lanes are compared, but all six alternatives are also compared to the actual case in order to say something about the best alternative for solving the bottlenecks in reality.

The unbundling measure is not societally beneficial for the actual case. This means that these results are in line with the archetype results. For each case with initially three lanes, it is the best option to extend the motorway with one lane. Both the results of the performance as well as the results of CBAs show this. Therefore it can be stated that it was not a good idea to unbundle the infrastructure at the A4 near Leiden.

Moreover, it turned out that in order to solve the bottlenecks in the actual case, at least three lanes must be available over the full length of the main carriageway, instead of partly two, or the parallel road should be provided with two lanes over the full length of the parallel road (and two lanes on the main carriageway as it is in the current situation) in case of an unbundled situation. It can be questioned if this situation at the A4 near Leiden should have been unbundled, because the not-unbundled main carriageway with four lanes lead to a great performance and societal benefits as well.

7 Conclusion & Recommendations

This chapter provides the conclusions to the main research question through its sub-questions and those are presented in Section 7.1. Additionally, Section 7.2 provides recommendations for further research.

7.1 Conclusions

Two main goals were appointed for this study. On the one hand, the situations in which unbundling can be considered an option and, on the other hand, circumstances under which unbundling can be deemed beneficial. Consequently, the following research question was specified:

'To what extend can unbundling of traffic flows be considered as a potential solution in solving bottlenecks on motorways and are there (any) circumstances in which unbundling can be deemed societally beneficial?'

7.1.1 Finding viable solution

Unbundling of traffic flows can be considered a potential solution in solving bottlenecks on motorways, but to a limited extend. A base case (road design/infrastructure) and five alternatives were tested under two circumstances. The circumstances under which these alternatives were tested are the distribution of through and local traffic, and the (total) traffic demand. There are six distributions of through traffic determined which start at 50% through traffic till 100% through traffic, with steps of 10%. Besides, the determined traffic demand was raised by 10% and 20% in order to test the robustness of the alternatives. There were six alternatives, six distributions of through and local traffic and three amounts of traffic demand. Therefore, 108 simulations were executed. The simulations were evaluated based on road performance indicators and cost-benefit analysis.

The unbundling measure can only be deemed societally beneficial for one alternative. The unbundled alternative is societally beneficial under the circumstances of 50% through traffic and 50% local traffic and the initial traffic demand. This alternative consists of a main carriageway with two lanes and the parallel road exits of two lanes as well (the unbundled 2-2 alternative). However, there are three main limitations on how the simulations are executed which will be explained later on.

Moreover, when only evaluating based on the performance indicators, there is one more situation in which an unbundled alternative performed the best. This is again the unbundled 2-2 alternative, but now under the circumstances of 60% through traffic and 40% local traffic and the initial traffic demand. In none of the other simulations, an unbundled alternative performed better than a not-unbundled situation (extended alternative) or was societally beneficial. This can partly be explained by the high investment & maintenance costs for unbundled alternatives in comparison to building an extra lane.

Besides, in order to say something about the robustness of the unbundling measure, the traffic demand was increased with 10% and 20%. From this it can be concluded that the performances of the alternatives come closer together when the traffic demand increases. Moreover, it can be concluded that the extended and the unbundled 2-2 alternatives perform the best under increased traffic demand circumstances and therefore are the most robust alternatives.

7.1.2 Main limitations

The three main limitations are discussed hereafter, but the conclusions will probably not be influenced by them.

First of all, besides the two circumstances, all data was static. The circumstances under which the alternatives have been tested are the distribution of through and local traffic, and the (total) traffic demand. The distribution of local traffic that took the first exit was 20% and local traffic that left the motorway at the second off-ramp was 80% in all simulations. A different distribution of this local traffic can have a huge impact on the performance of some alternatives. Besides, MARPLE does not take into account the effect of shorter travel times (road design change) attracting more traffic. Therefore, the traffic for each OD-pair was static as well.

Secondly, the simulations are strongly simplified. Only two types of vehicles are taken into account, no road design parameters are considered, no weather conditions and no accidents (unusual situations) are taken into account. However, the simulations of the actual case, in which actual data was used, verified the results of the archetype simulation.

Lastly, two reasons for applying unbundling include freeing a part of the traffic from turbulence because of weaving areas and because unbundled situations are assumed to be safer. Due to turbulence weaving areas have less capacity than the standard capacity known for the amount of available lanes, which is not taken into account in the simulations. Therefore, it could be the case that some alternatives performed better in the simulations than that they would do in reality. Besides, the effects of safety could not be monetarized and are therefore roughly qualitatively estimated. This can mean that CBAs for some alternatives are more negative than that they would be with the safety effects taken into account. Nevertheless, these effects are not taken into account but can have a significant influence on the simulations and CBA outcomes.

7.1.3 Answers to sub-questions

The rest of this section will provide the answers to the sub-questions presented in Section 1.5.

1. *What is meant by unbundling?*

Unbundling is generally in defined as follows: separation of disparate traffic (flows) which all ask for different handling qualities (speed, travel time, etc.) (i.e. Level of Service). However, unbundling is in this study defined as the separation of through and local traffic. Local traffic is defined as traffic that enters or leaves the motorway (or both) in the considered network.

Besides that this type is the most common type, the documents of The Ministry of Infrastructure and the Environment refer explicitly to the separation of through and local traffic. Moreover, they also state that unbundling should be considered during the exploration phases of infrastructural projects on solving bottlenecks on motorways. Besides, unbundling is described as the separation of through and local traffic within Rijkswaterstaat as well and this type of unbundling is also of most interest for Rijkswaterstaat.

Unbundling in practice is in this study understood as static separation by the presence of a parallel road which has to be a continuous road. Therefore, it must be possible to drive with a constant speed on this parallel road, without any disruptions (e.g. roundabouts or intersections). The parallel carriageway should begin and end at the same motorway.

2. In which situations can unbundling be applied?

There are three situations in which unbundling can be applied: policy-, safety- or capacity reasons. First, unbundling can be applied due to policy reasons. In these situations, unbundling is considered as the main instrument in order to reach the goal. The main decision is which traffic flows to separate. Secondly, applying unbundling because of safety reason is to prevent any accidents or deaths. Thirdly, problems with a capacity nature, can be described as; traffic flows are not getting the LoS they ask for or they should get. In order to provide (one or more) traffic flows with the LoS asked for, redistribution can be the solution to do this. Therefore, capacity problems refer to the redistribution of capacity, not necessarily to solving the capacity problem itself. A decision tree was built of these situations in which unbundling can be applied.

3. How can costs and benefits of an unbundling project be determined?

In this kind of infrastructural road design projects, the most significant factor are the investment costs (including maintenance) and the travel time gains. This is because the main effect of a road extension project, is usually to shorter travel times. Furthermore, the externalities taken into account include safety, emissions and noise pollution.

The investment and maintenance costs are determined with the SSK[9] method and are higher for unbundling than for building an extra lane. Therefore, more travel time gains and less congestion was needed in unbundled alternatives in order to be societal beneficial. Travel time effects are calculated based on the total spent time difference divided over car and freight traffic. Since the maximum speed on the parallel road (in unbundled situations) was lower than on the main carriageway, the route via the parallel road took longer. However, when congestion decreased in an unbundled alternative there were still travel time gains which lead to benefits. Local air quality is mainly determined by the amount of nitrogen oxides and particulate matter, because the concentrations of these components are often the closest to the health damage limits. The emission is higher in case of congestion due to constant accelerating and braking. Besides, higher speeds lead to more emission. Therefore, in case of no congestion the unbundled alternatives lead to societal benefits because of less emissions. The safety and noise pollution effects could not be monetarised and are qualitatively analysed. It is assumed that the bigger the difference in speeds of weaving traffic, the less safe the situation is. In unbundled situations the weaving movements take place at the parallel road, which means that not all traffic suffers from turbulence. Therefore,

[9] This method is used by Rijkswaterstaat to make cost estimation of infrastructural road design changes.

unbundled situations are assumed to be more safe than not-unbundled situations. Besides, the maximum speed at the parallel road is lower than on the main carriageway. Therefore, the weaving movements take place at lower speeds (more homogeneity in terms of speed), which is assumed to be safer. The effects of noise pollution are expressed in the size of the traffic flow, the speeds and the acceleration. When more lanes are available (comparing alternatives at the same location in each network), more vehicles can drive over the same length of the road. This results in more noise production. Therefore alternatives with more lanes have a negative influence on noise pollution. Secondly, higher speed causes higher noise levels. Since only alternatives will be compared with initially the same amount of lanes and the maximum speed on the parallel road is lower than on the main carriageway, it is assumed that all unbundled alternatives have a positive effect on noise pollution. Lastly, the noise level increases during acceleration. Therefore, congestion leads to more noise pollution than in situations without congestion.

4. What performance indicators are needed in order to analyse a road network?

With the indicators can be perceived what effects the alternatives, changes in the infrastructure, have on the network performance. Performance of a network indicates how 'good' or 'bad' the network is exploited and is a multi-faceted indicator. Based on the performance indicators stated in the *'Capaciteitswaarden Infrastructuur Autosnelwegen'*, the performance indicators considered in this study include amount of vehicles loss hours (total delay), total distance travelled, congestion, average speed and the total time spent in the network (total travel time).

5. Which standard road designs (archetypes) can be defined?

This research question has been answered through defining different areas in the Netherlands for which all possible motorway road designs have been determined. The areas include a rural area, a radial area and an urban area. In order to determine all the possible road designs in each area in which unbundling could be applied, is looked to all already unbundled situation in the Netherlands. There are five standard road designs (archetypes) defined for the urban area, which are shown in Figure 7-1. The first archetype, straight through, is the only archetype that is tested under certain circumstances.

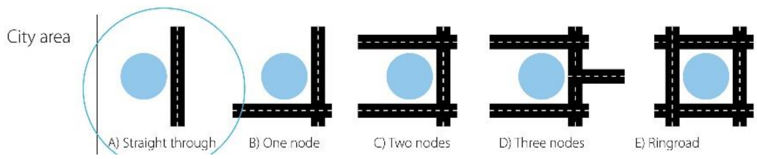


Figure 7-1. Archetypes for urban area

6. Which model can be used for simulating both the archetypes and a real-life case?

A list of criteria was determined and all simulations models that are currently used in the Netherlands and internationally were listed in order to choose a simulation model. The criteria that are determined include that the model should simulate macroscopic, it must be possible to insert the capacity of the links and the OD matrix as input, the simulation must be dynamic (en-trip route choice), simulation of different user classes must be possible (car and freight) and the model should be able to simulate motorway. Besides, access to the simulation models must be obtained without paying for it or without using the trial version. Moreover, the model had to be able to provide the defined performance indicators as output. The model that met all criteria was chosen and is named MARPLE, which is an abbreviation of ”Model for Assignment and Regional Policy Evaluation”. MARPLE is fast and simple model that can simulate route choice. The model does, however, not take into account the effect that when shorter travel times are provided, more traffic is attracted. Therefore, the amount of traffic demand stayed the same for all simulations.

7. Which circumstances that may influence the performance of unbundled networks can be defined?

Since unbundling of through and local traffic is mainly done in order to improve the traffic handling and free through traffic of turbulence. It is assumed that the distribution of through and local traffic has the highest impact on the performance of an unbundled network. Therefore, six different distributions of through and local traffic are determined:

- 50% through traffic - 50% local traffic
- 60% through traffic - 40% local traffic
- 70% through traffic - 30% local traffic
- 80% through traffic - 20% local traffic
- 90% through traffic - 10% local traffic
- 100% through traffic - 0% local traffic

Through traffic is in this case considered the traffic that does not leaves or enters the network and local traffic is considered the traffic that enters the network at node 1 and takes either the first or the second off-ramp.

Besides, the other circumstance concerns the amount of traffic demand. Therefore, an initial demand was determined and increased with 10 and 20 percent.

8. Is there a relation between the circumstances and the performance of the unbundling measure?

All the simulations are evaluated based on the network performances, the location (and length) of the congestion and the cost-benefit results.

For the alternatives with initially three lanes, for all of the distributions for through and local traffic the extended alternative performed the best. Besides, the extended alternative also leads in all distributions, except for the distribution of 60% through traffic, to the (highest) societal benefits. With a distribution of 60% through traffic, the travel time gains did not outweigh the costs. However, based on these results only, it can be said that unbundling alternative cannot be considered an option in situations with initially three lanes.

Unbundled is only societal beneficial for one of the alternatives with initially four lanes, namely the unbundled 2-2 alternative. For all other alternatives the with initially four lanes none of the unbundled alternatives lead to societal benefits. Although, the unbundled 2-2 alternative performed better than the extended alternative in for both distributions of through traffic of 50% and 60%. Only for a distribution of 50% through traffic, the unbundled 2-2 performed better and lead to societal benefits. In all other considered distributions for through traffic the extended alternative is turned out to be the best option. Since the extended alternative is the base case for alternatives with initially four lanes, this means that 'do nothing' is the best option.

9. Can the found results be verified by an actual study case?

The results from these archetype alternatives were compared to the unbundled situation at the A4 near Leiden. This is done in order to verify the found results of the simulations of the archetype alternatives. All the simulations are evaluated by the performance indicators and by cost-benefits analysis as well. In order to do so, the alternatives of the archetypes simulations are adjusted so they met the characteristics of the actual case. The actual case and the actual traffic demand, obtained from a license plate investigation, of the 1st of September 2015 are used to reconstruct the bottlenecks and the length of the congestion. The distribution of through and local traffic in the Leiden case is equal to 87% through traffic and 13% local traffic, which corresponds the best to the distribution of 90% through traffic and 10% local traffic as defined as a circumstance for the archetype simulations.

It turned out that the results of both the performance and the costs-benefit analysis are in line with the results of the archetype simulations for a distribution of 90% through traffic. Therefore, unbundling cannot be deemed beneficial for a distribution of 90% through traffic.

7.2 Recommendations

Since there are just a few studies on unbundling, the recommendations are split in practical and scientifically recommendations.

7.2.1 Practical recommendations

There are four main practical recommendations determined.

First, mainly static data is used in this study. For instance, the distribution of local traffic leaving the motorway at the first or the second exits was fixed during this study. However, this can have a major impact on the performance of the networks. It is assumed that when the local traffic is more equally distributed over the two exits, the networks perform better. Therefore it is important to also take this distribution into account. Besides, in order to improve the applicability and the reliability of the results, it is essential to define more circumstances and simulate more different road designs to get a better overview. Another static aspect were that during the simulations the exit turned out to be the bottleneck because the off-ramps exist of one lane. Therefore, the whole network was blocked and nothing could be said about unbundling being a good option to implement. It is recommended to adapt the number of lanes on the on- and off-ramps to the traffic demand in order to provide enough capacity and to not create the bottleneck there.

Secondly, the only variation taken into account in this study is the distribution between through and local traffic. More circumstances should be taken into account than only this one. For instance, what happens when accidents, other time of day, detours or bad weather occurs. Besides, in order to create a manual on under which circumstances unbundling can be deemed an option, it is important that all possible road designs on motorways in the Netherlands are included. Therefore, all archetypes (i.e. road designs) should be included to create a complete overview.

Additionally, decreased capacity in weaving areas is not taken into account during the simulations. Due to the turbulence that usually occurs at weaving areas the capacity is lower than for the standard capacity for the amount of lanes available. Therefore, the performances of the alternatives (networks) are probably overestimated.

Lastly, in order to say something about robustness, alternatives with shortcuts should be simulated better. Besides, more and other circumstances will also have impact on the robustness. Therefore, it should also be taken into account that the distribution of through local traffic should not be varying too much during the day. Otherwise, it is possible that the unbundled measure works fine between 07:00AM and 10:00AM (peak hours) and because the distribution of through and local traffic differs during the day or during the weekend, this leads to new problems/ bottlenecks.

7.2.2 Scientifically recommendations

The one main scientifically recommendations is to conduct research on the monetarisation of safety and noise effect in unbundled situations in order to execute more reliable cost-benefit analysis. It should be investigated what the effect of unbundling is on those effects and maybe even more important, how big the effect is and how this can be captured in values or risks. This is important because safety can have a much bigger influence (positive or negative) on the outcome of the cost-benefit analysis than travel time effects.

The other recommendation is to conduct more research on unbundling itself. Currently, there are only studies which address only one specific way of unbundling and some specific reasons for applying it. However, it not really known what the effects are of the unbundling measure. This can be illustrated by the fact that the results of the already unbundled situations in the Netherlands are varying.

Bibliography

Calvert, S. et al., 2016. *Traffic assignment and simulation models - State-of-the-Art Background Document,* Delft: TrafficQuest - Centre for Expertise on Traffic Management.

Cassidy, M. J., Jang, K. & Daganzo, C. F., 2010. The smooting effect of carpool lanes on freeway bottlenecks. *Elsevier,* Februari, 44(2), pp. 65-75.

CROW, 2013. *Handleiding SSK-rekenmodel,* s.l.: CROW.

Davis, M., 2011. *Current Industry Trends for Separating Express Lanes from General Purpose Lanes,* Orlando: Atkins.

de Dios Ortúzar, J. & Willumsen, L. G., 2011. *Modelling transport.* 4th ed. s.l.: John Wiley & Sons, Ltd.

DECISIO, 2014a. *MKBA Ring Utrecht,* s.l.: Ministerie van Infrastructuur en Milieu.

DECISIO, 2014b. *MKBA Ruit Eindhoven,* Amsterdam: DECISIO.

Eichler, M. & Daganzo, C. F., 2006. Bus lanes with intermittent priority: Strategy formulae and an evaluation. *Elsevier,* 40(9), pp. 731-744.

Eijgenraam, C. J., Koopmans, C. C., Tang, P. J. & Verster, A., 2000. *Evaluatie van infrastructuurprojecten; Leidraad voor kosten-batenanalyse,* Den Haag: Sdu.

Gelder, E., 2016. *Ontvlechten - Randweg Eindhoven,* Delft: ITS Edulab.

Google Maps, 2017. *Typical traffic on tuesday morning at A4 near Leiden.* [Online] Available at: https://www.google.nl/maps/@52.1339944,4.5125487,13z/data=!5m1!1e1 [Accessed 18 February 2017].

Grontmij, 2015. *Capaciteitswaarden Infrastructuur Autosnelwegen (CIA),* s.l.: Dienst Water, Verkeer en Leefomgeving.

Haak, A., 2010. *Verkeerskundige effecten- en financiële haalbaarheidstudie voor vrachtbanen,* Zoetermeer: Technische Universiteit Delft.

Hoogendoorn, S., Bliemer, M. & van Nes, R., 2007. Modellen voor netwerkmanagement. *NM; Het vakblad voor netwerkmanagement in verkeer en vervoer,* Oktober, 2(3), pp. 22-26.

IBM Cognos PowerPlay Studyio, 2016. *Ongevallen.* [Online] Available at: https://cognos.swov.nl/ibmcognos/cgi-bin/cognos.cgi?b_action=xts.run&m=portal/cc.xts&m_folder=i27247CABFD124B1FB4185E788CAD8098 [Accessed 30 January 2017].

Iliadi, A., Farah, H., Schepers, P. & Hoogendoorn, S., 2015. *A CRASH PREDICTION MODEL FOR WEAVING SECTIONS IN THE NETHERLANDS,* Delft: Delft University of Technology.

Kijk in de Vegte, N., van Toorenburg, J. & Nijenhuis, T., 2012. *Ontvlechting - Analyse en advies m.b.t. ontvlechting op het hoofdwegennet,* Amersfoort: Transpute.

Klunder, G. & Stelwagen, U., 2013. *Manual EM4MARPLE - Emission Module for RBV - Version 1.0,* Delft: TNO.

Kwakernaak, C., 2002. *Dubbeldeks ontvlechten op het hoofdwegennet; Een verkeerskundige studie naar het ontwerp en de haalbaarheid van dubbeldeksautosnelwegen,* Delft: Technische Universiteit Delft.

Ligterink, N. & van Zyl, S., 2015. *CO2-emissiefactoren voor de snelweg,* s.l.: TNO.

Litman, T., 2013. *Measuring Transport System Efficiency.* [Online] Available at: http://www.planetizen.com/node/59995 [Accessed 1 December 2016].

Marathe, P., 2012. Traffic noise pollution. *IJED,* 9(1), pp. 63-68.

Methorst, R. et al., 2014. Ontvlechten van fiets en snelverkeer. *Verkeerskunde: vaktijdschrift over verkeer en vervoer,* Issue 4, pp. 1-8.

Ministerie van Infrastructuur en Milieu, 2012. *Structuurvisie Infrastructuur en Ruimte,* Den Haag: Ministerie van Infrastructuur en Milieu.

Ministerie van Infrastructuur en Milieu, 2016a. *Steunpunt Economische Expertise - Bereikbaarheid.* [Online] Available at: ttps://www.rwseconomie.nl/kengetallen/documenten/publicaties/2016/2016/bereikbaarheid/kengetallen-bereikbaarheid [Accessed 1 December 2016].

Ministerie van Infrastructuur en Milieu, 2016b. *Steunpunt Economische Expertise - Leefomgeving.* [Online] Available at: https://www.rwseconomie.nl/kengetallen/documenten/publicaties/2016/2016/leefomgeving/leefomgeving [Accessed 1 February 2017].

Ministerie van Verkeer en Waterstaat, 2008. *Mobiliteitsaanpak.* [Online] Available at: https://www.rijksoverheid.nl/documenten/brochures/2010/08/27/mobiliteitsaanpak [Accessed 1 December 2016].

Newmark, G. L., 2014. HOT for Transit? Transit's Experience of Hihg-Occupancy Toll Lanes. *Journal of Public Transportation,* 17(3), pp. 97-114.

Rijksinstituut voor Volkgezondheid en Milieu, 2016. *emissiefactoren-voor-snelwegen GCN2016.* [Online] Available at: http://www.rivm.nl/Documenten_en_publicaties/Wetenschappelijk/Tabellen_grafieken/Milieu_Leefomgeving/Emissiefactoren/Download/emissiefactoren_voor_snelwegen_GCN2016 [Accessed 1 February 2017].

Rijksoverheid, 2004. *Nota Mobiliteit - Naar een betrouwbare en voorspelbare bereikbaarheid.* [Online] Available at: https://www.rijksoverheid.nl/documenten/beleidsnota-s/2004/09/30/nota-mobiliteit [Accessed 26 October 2016].

Rijkswaterstaat, 2012. *KBA bij MIRT-verkenningen,* s.l.: Ministerie van Infrastructuur en Milieu, DG Ruimte en Water.

Rijkswaterstaat, 2014. *ViVA Viewer (v4.0.0).* s.l.:[computer program].

Rijkswaterstaat, 2015. *Richtlijn Ontwerp Autosnelwegen 2014,* s.l.: Ministerie infrastructuur en milieu.

Rijkswaterstaat, 2016. *Evaluatietools verkeersmanagement.* [Online] Available at: https://www.rijkswaterstaat.nl/zakelijk/verkeersmanagement/wegverkeer/evaluatietools-verkeersmanagement/index.aspx#vraag4 [Accessed 22 February 2017].

Rijkswaterstaat & Goudappel Coffeng, 2015. *Beter Rijden op de A4 Burgerveen - Leiden.* [Online] Available at: https://gemeente.leiden.nl/fileadmin/files/Projecten/Ruimtelijke_Ordening/00WABO/Doorstroming_A4/O/b_NL.IMRO.0546.OV00094-0201_bd6.pdf [Accessed 18 januari 2017].

Rijkswaterstaat & Ministerie van Verkeer en Waterstaat, 2007. *Nieuwe Ontwerprichtlijn Autosnelwegen,* Rotterdam: Rijkswaterstaat [Adviesdienst Verkeer en Vervoer].

Romijn, G. & Renes, G., 2013. *General guidance for Cost-Benefit Analysis,* The Hague: CPB/PBL.

Schnabel, C., 2015. *We need to 'idiot proof' our roads.* [Online] Available at: http://www.rappler.com/business/industries/208-infrastructure/103867-map-traffic-solutions-manila-roads [Accessed 30 September 2016].

Snelder, M., 2010. *Designing Robust Road Networks - A general design method applied to the Netherlands,* Delft: TRAIL Research School.

Snelder, M., Wesseling, B., Hertogh, M. & van Arem, B., 2014. *Robuustheid en verkeersveiligheid project Ring Utrecht,* s.l.: Rijkswaterstaat Midden-Nederland.

Snelder, M., Wesseling, B., van Arem, B. & Hertogh, M., 2016. *Evaluating the robustness effects of infrastructure projects based on their thopological and geometrical roadway designs,* Submitted for publication, s.l.: s.n..

Soekroella, A., 2011. *Separation of Freeway Traffic Flows by Dynamic Lane Assignment,* Delft: ITS Edulab.

SWARCO, 2015. *Official launch of the dynamic routing system bavaria.* [Online] Available at: https://www.swarco.com/en/News-Events/News/Archive/Official-Launch-of-the-Dynamic-Routing-System-Bavaria-dNet-Bayern [Accessed 30 September 2016].

Taale, H., 2008. *Integrated Anticipatory Control of Road Networks - A game-theoretical approach,* Rijswijk: Rijkswaterstaat.

Taale, H., 2016. *MARPLE - Beschrijving en handleiding,* s.l.: Rijkswaterstaat.

The free dictionary, 2016. *The free dictionary - separation.* [Online] Available at: http://www.thefreedictionary.com/separation [Accessed 1 December 2016].

Transportation Research Board, 2000. *Highway capacity manual,* Washington: Transportation Research Board.

Utgoff, P. E., 1989. Incremental Induction of Decision Trees. *Machine Learning ,* 4(2), pp. 161 - 186.

Van der Velden, B., 2015. *Verkeerskundige afwegingen bij ontvlechten op autosnelwegen - en weggebruikers wegwijs maken,* Breda: NHTV Internationaal Hoger Onderwijs Breda.

van Loon, A., 2016. *Data on unbundled situation in the Netherlands* [Interview] (12 October 2016).

Van Nes, R., 2002. *Design of multimodal transport networks - a hierarchical approach.* Delft: DUP Science.

van Reeken, H., 2010. *Verkeersdrukte op de snelweg viaduct ID379944.* [Online]
Available at: https://beeldbank.rws.nl/(S(0qvexxqh31nhc4jbgbabob3e))/MediaObject/Details/Verkeersdrukte_op_de_snelweg__viaduct_379944 [Accessed 30 September 2016].

Walhout, R., 2016. *Unbundled situation in the Netherlands* [Interview] (11 November 2016).

Walhout, R., 2016. *Unbundling in the Netherlands* [Interview] (16 november 2016).

Watts, K., 2013. *Travel time charts.* [Online] Available at: http://crossroadsnews.com/news/2013/oct/11/traffic-improvement-cd-lanes-charts/ [Accessed 30 September 2016].

Wever, E. & Rosenberg, F., 2012. *Omgevingskwaliteiten bij MIRT-projecten - Overzicht van methoden voor het meten en waarderen van welvaartseffecten in een MKBA,* Amsterdam: RIGO Research en Advies BV.

Zeitler, U., 1996. Traffic Separation, Safety and Ethics. *Proceedings of the Conference road safety in europe - Part 1,* Issue 7A, pp. 37-50.

8 Appendices

A. Unbundled situations in the Netherlands

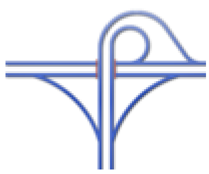
A1. List of unbundled situations

The list of unbundled situation in the Netherlands, composed by Van der Velden (2015), is used as starting point for the this current list of unbundled situation. This list is adapted to the definition of unbundling used during this study (Section 2.1.3) and, the recent applied unbundling situations are added (Walhout, 2016; van Loon, 2016). The situations that are not considered as unbundling in in this study, but are considered as unbundling by Van der Velden, are shown in Table 8-1(p.114).

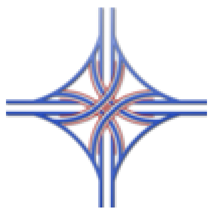
The list with all the unbundled situation in the Netherlands can be found Table 8-2 (p.114). Following is some explanation about the information that can be found in each column:

- **Location**: where in the Netherlands the unbundled situation is located.
- **Nodes**: the amount of connected motorways. 0.5 means that the connected motorway is not crossing the other motorway, but is only connected. 1 means in almost every situation that the node is designed as a cloverleaf interchange. This column also shows which motorway is connected.
- **Connections**: the amount of roads (excluding motorways) connected to the motorway. One connections is defined as one on-ramp and one off-ramp.
- **Unbundled flows:** which traffic flows are separated. As mentioned in Section there are only three types that occur in the Netherlands: separation of through and local traffic, Public and/or freight traffic. There is one special type, which is not mentioned in the report: reversible lane. In this situation an extra lane is located in the middle of two carriageways, which can be used as an rush-hour lane. Only one of the carriageways (one of the directions) at the time can use the lane. This can also be seen as a form of separation of local and through traffic, because traffic that makes use of the reversible lane cannot exit the motorway.
  In this column is also mention what kind of node there is when two motorways are intersecting. There are three options:

Cloverleaf intersection



Trumpet intersection



4-level stack

https://www.wegenwiki.nl/Knooppunt

- **Type**: how the traffic flows are separated, physical or non-physical.

Table 8-1. All unbundled situation in the Netherlands

Functional

Nr	Road	Location	Nodes	Connections	Unbundled flows	Type
1	A1	Amsterdam <>Muiden *Node Muiderberg - Diemen*	0.5 (x2, A6&A9)	1	Reversible lane	Physical separation
2	A1	Diemen *West of node Diemen*	0.5 (A9)	1	Through and local traffic	Non-physical separation, flexible poles
3	A1	Eemnes *Node Eemnes*	1 (A27)	2 East&west	Through and local traffic Cloverleaf interchange	Physical separation
4	A1	Hoevelaken *Node Hoevelaken*	1 (A28)	1 East	Through and local traffic Cloverleaf interchange	Physical separation
5	A2	Holendrecht *Node Holendrecht*	0.5 (x2, A9&A9)	1 Middle	Through and local traffic Separation over two nodes	Physical separation
6	A2	Utrecht *West of Utrecht - Node Oudenrijn*	1 (A12)	3 North	Through and local traffic End in cloverleaf interchange	Physical separation
7	A2	Den Bosch *Node Empel - St. Michielsgestel*	0.5 (x2, A59&A59)	3	Through and local traffic Separation over two nodes	Physical separation
8	A2	Eindhoven *Node Ekkersweijer - Leenderheide*	0.5(x3, A50&A58&A67)	6	Through and local traffic Trumpet interchanges	Physical separation
9	A79	Maastricht *¬ Under construction¬*	?	?	Through and local traffic	Physical separation, vertical
10	A4	Hoofddorp *South of Node De hoek*	0.5 (A5)	2	Through and local traffic	Physical separation
11	A4	Den Haag westvliet *Node Prins Clausplein*	1 (A12)	1 North	Through and local traffic 4-level stack	Physical separation
12	A4	Ypenburg *Plaspoelpolder*	0.5 (A13)	1 South	Through and local traffic Trumpet interchange	Physical separation
13	A10	Amsterdam *Coentunnel*	0.5 (x2, A8&A5)	1	Reversible lane	Physical separation
14	A12	Ringroad Utrecht-Zuid *Node Lunetten - Oudenrijn*	2 (A2) (A27)	3 Middle	Through and local traffic Cloverleaf interchanges	Physical separation
15	A15	Brielle *Oostvoorne*	0	1	Through and local traffic	Physical separation
16	A15	Ridderkerk *Node Ridderkerk*	1.5 (A16, 0.5 A38)	1	Through and local traffic *Cloverleaf interchange*	Physical separation
17	A15	Gorinchem *Node Gorinchem*	1 (A27)	1	Through and local traffic Cloverleaf interchange	Physical separation
18	A16	Brienenoordbrug <> kralingen	0	4	Through and local traffic/ Public transport & freight traffic	Physical separation/ Non-physical separation, line on pavement
19	A20	Terbregseplein *Node Terbregseplein*	0.5 (A16)	0	Public transport & freight traffic Trumpet interchange	Both physical and non-physical separation
20	A28	Utrecht <> Zeist *Node Rijnsweerd*	1 (A27)	1	Through and local traffic Cloverleaf interchange	Physical separation
21	A50	Beekbergen *Node Beekbergen*	1 (A1)	0	Through and local traffic Cloverleaf interchange	Physical separation
22	A4	Leiden *Zoeterwoude-Rijndijk - Zoeterwoude-Dorp*	0	2	Through and local traffic	Physical separation

Table 8-2. Situations which are not considered unbundling

No Unbundling = sluipwegen

Nr	Road	Location	Reason
1	A4	Amsterdam (Zuidas)	This is not unbundling because the parallel road is interrupted by a crossing.
2	A4	Leiderdorp Connection to N446	This is not unbundling because the parallel road is interrupted by a roundabout.
3	A7	Groningen Hoogkerk	This is not unbundling because the parallel road is interrupted by a roundabout.
4	A9	Diemen <> Holendrecht	This is not unbundling because the parallel road is interrupted by a crossing.
5	A16	Drechttunnel	Fysical limits of the construction, because it is build in the '70s.
6	A37	Hoogeveen Node Hoogeveen	There are no parallelroads in the cloverleaf interchange.

At the A6, near Almere, is planned to apply unbundling and at the A35, near Borne, an unbundled situation is removed.

A2. Unbundled situations linked to the archetypes

City Area	Straight through	22
	One node	3 4 11 21
	Two nodes	6 7 14
	Three nodes	5 8 12 20
	Ringroad	13 16 18 19
Radial area	Node before city	1 2 9 10
	Node after city	
Rural area	Straight through	15
	Node	17

B. Characteristics base case and alternatives (infrastructure)

B1. Base case values

Length network - The length of the network is based on some roads located next to a city, measure with the measure tool in Google Earth.

City	Length of network
Amsterdam	10,1 km (length) / 9,0 km (width)
Utrecht	7,8 km (length) / 5,9 km (width)
Rotterdam	8,5 km (length) / 10,6 km (width)
Eindhoven	9,7 km (length) / 6,3 km (width)
Den Haag	8,7 km (length) / 6,7 km (width)
Average	*8,96 km (length) / 7,7 km (width)*

Number of ramps - In order create a bottleneck, two connections are considered. Another reasons for considering two connections, is that one of them can serve as the connection to another motorway.

Number of lanes main carriageway – The amount of lanes on the main carriageway is set to 3. In this way unbundled, 2 lanes on the main carriageway and 1 on the parallel road, and not unbundled situations can be compared. The amount of lanes stays the same.

Number of lanes on off-and on ramps – The number of lanes on the entry and exit ramp is 1, because this is the most common in the Netherlands.

Distance between on-off ramps – In the 'Guideline Design Motorways' (Rijkswaterstaat, 2015) all numbers and values are given, which are needed for designing motorways. The table below shows the minimal distances. In case of two consecutive convergence points (entering, merging), just sum up the values in the table. In all other cases, take half of the sum of the values. This comes down to:

- Distance between exit and on-ramp: ½ * [Downstream of exit]+ ½ * [Upstream of entrance] = ½ * 150m + ½ * 150m = 150m.
- Distance between on-ramp and exit: ½ * [Downstream of entrance]+ ½ * [Upstream of exit] = ½ * 750m + ½ * 750m = 750m.

Table 8-3. Road design values (Rijkswaterstaat, 2015)

Location road section	***Design speed***		
	120 km/h	***90 km/h***	***70 km/h***
Upstream of entrance	150 m	110 m	90 m
Downstream of entrance	750 m	550 m	450 m
Upstream of merging	150 m	110 m	90 m
Downstream of merging	375 m	275 m	225 m
Upstream of exit	750 m	550 m	450 m
Downstream of exit	150 m	110 m	90 m
Upstream of junction	150 m	110 m	90 m
Downstream of junction	150 m	110 m	90 m

Length of ramps (connection lanes) – The length of connection lanes at several nodes are measures with the measure tool in Google Earth.

Node	**Length of ramp**
Holendrecht	570m
Hoevelaken	450m
Eemnes	480m
Ridderkerk	510m
Rijnsweerd	460m
Average	*494m → 500m*

B2. Additional network characteristics for alternatives

The distance between the junction (towards the parallel road) and the first exit, is represented by link 10 in the unbundled alternatives. Since the speed is 100 km/h on the parallel road, the length of the link is based on a design speed of 120 km/h (Rijkswaterstaat, 2015). Therefore, the length of link 10 is:

½ * [Downstream of junction] + ½ * [Upstream of exit] = ½ * 150m + ½ * 750m = 450m.

Then, the distance between the second on-ramp (entrance) and the merging of the parallel road and the main carriageway (also based on a design speed of 120 km/h):

[Downstream of entrance] + [Upstream of merging] = 750m + 150m = 900m.

This distance is represented by the length of link 15 in the unbundled alternatives. Since, these are two converging points, the values must be summed up (ibid.).

C. Example of input file simulations

This example concerns the base case, with at distribution of 60% through traffic at the initial demand amount (0).

Network input file

//Title

Base case, 60-40, 0

//Parameters

;nrTimePeriods LengthTim LTimeStep ScaleFlow ScaleCap ScaleSpeed DemandPar

10 900 5 1.00 1.00 1.00 0

;nettype : number of subnetwork ;linktype: 0 = normal, 1 = controlled intersection, 2 = controlled ramp meter, 3 = roundabout ;link, 4 = give way link ;nrSG can be more than one, due to shared movements ;CTR is controller number, nrSG is the number of traffic signals which control the link and ;Signal(s) are the signal numbers. These should correspond with //TrafSignals. ;nrCL is number of conflicting links and ConfLinks are the numbers of the conflicting links ;(only for roundabouts and priority junctions).

//Links

;linknr nettype length nrlanes satflow speed type CTR nrSG Signal(s) nrCL ConfLinks

; (m) (veh/hr) (km/hr)

1	1	1000	3	6200	120	0
2	1	1000	3	6200	120	0
3	1	1400	3	6200	120	0
4	1	350	3	6200	120	0
5	1	750	3	6200	120	0
6	1	750	3	6200	120	0
7	1	350	3	6200	120	0
8	1	1400	3	6200	120	0
9	1	1000	3	6200	120	0
10	1	1000	3	6200	120	0
11	2	500	1	2100	80	0
12	2	500	1	2100	80	0
13	2	500	1	2100	80	0
14	2	500	1	2100	80	0

;nodetype: 0 = normal, 1 = input node, 2 = output node, 3 = controlled node, 4 = node with ramp ;metering, 5 = controlled node (FT), 6 = roundabout 1 lane, 7 = roundabout 2 lanes, 8 = give way node ;In this network link 13 is for through traffic and link 14 is a left turn. That means that some combinations for node 8 are not possible, e.g. also taking the off-ramp and then the on-ramp. These combinations are given a 1 and allowed combinations a 0. Route choice (if no routes are specified) will take this into account. For metered nodes an up and downstream link is specified. The algorithm checks the flow upstream and the capacity downstream and will not all more vehicles to enter the on-ramp (RWS algorithm). AllowedTurns can be used to block specific movements on a node. For every incoming link – outgoing link combination a 0 (movement is allowed) or 1 (movement is blocked) should be given.

//Nodes

;nodenr type nIn links nOut links AllowedTurns

```
1    1   0        1   1
2    0   1   1    1   2
3    0   1   2    1   3
4    0   1   3    2   4  11
5    0   2   4  12   1   5
6    0   1   5    1   6
7    0   1   6    2   7  13
8    0   2   7  14   1   8
9    0   1   8    1   9
10   0   1   9    1   10
11   2   1   10   0
12   2   1   11   0
13   1   0        1   12
14   2   1   13   0
15   1   0        1   14
//Origins
;nrOrigins nodenrs
 3      1 13 15
//Destinations
;nrDestinations nodenrs
 3       11 12 14
//OD table
;origin destination nRoutes Routenrs.   timeperiod 1 - timeperiod n
1  11   1   1   3660  4026  3660  3477  2928  2379  1464  732   732   366
1  12   1   2   488   537   488   464   390   317   195   98    98    49
1  14   1   3   1952  2147  1952  1854  1562  1269  781   390   390   195
13  11  1   4   400   440   400   380   320   260   160   80    80    40
13  14  1   5   100   110   100   95    80    65    40    20    20    10
15  11  1   6   1000  1100  1000  950   800   650   400   200   200   100
;If distribution is specified MARPLE will use this to redistribute flows for the 4 LMS types: type 1: commuters, type 2: business, type 3: other travel purposes, type 4: trucks. For every OD pair and type a line must be specified with a distribution in percentage per time period.
//Distribution
;origin destination type   timeperiod 1 - timeperiod n
1   11    1   85  90  90  85  85  85  85  85  85  85
1   11    2    0   0   0   0   0   0   0   0   0   0
1   11    3    0   0   0   0   0   0   0   0   0   0
1   11    4   15  10  10  15  15  15  15  15  15  15
1   12    1   95  95  95  95  95  95  95  95  95  95
1   12    2    0   0   0   0   0   0   0   0   0   0
1   12    3    0   0   0   0   0   0   0   0   0   0
```

1	12	4	5	5	5	5	5	5	5	5	5	5
1	14	1	95	95	95	95	95	95	95	95	95	95
1	14	2	0	0	0	0	0	0	0	0	0	0
1	14	3	0	0	0	0	0	0	0	0	0	0
1	14	4	5	5	5	5	5	5	5	5	5	5
13	11	1	95	95	95	95	95	95	95	95	95	95
13	11	2	0	0	0	0	0	0	0	0	0	0
13	11	3	0	0	0	0	0	0	0	0	0	0
13	11	4	5	5	5	5	5	5	5	5	5	5
13	14	1	100	100	100	100	100	100	100	100	100	100
13	14	2	0	0	0	0	0	0	0	0	0	0
13	14	3	0	0	0	0	0	0	0	0	0	0
13	14	4	0	0	0	0	0	0	0	0	0	0
15	11	1	95	95	95	95	95	95	95	95	95	95
15	11	2	0	0	0	0	0	0	0	0	0	0
15	11	3	0	0	0	0	0	0	0	0	0	0
15	11	4	5	5	5	5	5	5	5	5	5	5

;If routes specified model will use these routes, otherwise it will generate it's own routes by Dijkstra algorithm. These routes are saved in 'routes.txt' and can be used later on. See also 'Routes' parameters in 'MARPLEparm.txt'.

//Routes

;Routenr nrLinksRoute Links

```
  1     10      1  2  3  4  5  6  7  8  9  10
  2      4      1  2  3  11
  3      7      1  2  3  4  5  6  13
  4      7      12  5  6  7  8  9  10
  5      4      12  5  6  13
  6      4      14  8  9  10
```

//RouteParts

;RoutePnr nrLinksRouteP Links

```
  1     10      1  2  3  4  5  6  7  8  9  10
```

;//TrafSignals

;controller signal green cycle mingr maxgr

; (sec) (sec) (sec) (sec)

;//RampMeters

;controller signal green cycle mingr maxgr uplink downlink percInc algCap

; (sec) (sec) (sec) (sec)

;//VMSinfo

;linknr routeinfo incident deltaTeta

```
   11      1      0      1.0
```

;userclass: 1=habitual, 2=unguided, 3=guided

;For the habitual travellers only the percentage has to be specified. The users are equally distributed on the available routes. For the other users the percentage and a teta is specified: level of information (the higher the more information travellers have).

//UserClasses

;userclass percentage teta

```
   1        10        0.0
   2        70        1.0
   3        20        3.0
```

;user can specify initial flow distribution, if not present model calculates flow distribution based on distance or free flow (paramater initialAssign)

;//InitialFlows

;Route timeperiod1 - timeperiodn

;User can specify events, which can be used to change link attributes during the simulation. This change is relative to old attribute.

;//Events

;begintime endtime linknr nrlanes satflow vfree   type

```
;                              (%)      (%)
    900      2700      3      -1    50       70      1
```

;User can specify links for a selected link analysis, but also to change the OD flows which these links. A positive 'perc change' means extra traffic on that link. If this number is zero, only a selected link analysis is performed. This change is relative to old attribute.

;//SelectedLinks

;selected links perc change

```
                        3         5.0
          11          0
```

;//NetTolls (euro/km)

;nettype timeperiod1 - timeperiodn

```
   2      0.10  0.10  0.10  0.10  0.10  0.10  0.10
   1      0.10  0.10  0.10  0.10  0.10  0.10  0.10
```

;//LinkTolls

;linknr toll (euro's)

```
   1      1.00  1.00  1.00  1.00  1.00  1.00  1.00
   6      2.00  2.00  2.00  2.00  2.00  2.00  2.00
```

;For visualisation purposes

;//NodeCoordinates

;nodenr   x-coord   y-coord

Parameters input file

//Title
Simulation Parameters

//General
;Assign Optimization Metering SmoothG SmoothFlow DelayType InitialFlow ThresFlow ConvError minCounter maxCounter
2 0 0 0 1 0 1 0 1.0 1 30

Assign parameter for assignment
0 = no assignment
1 = DDUO (deterministic dynamic user equilibrium)
2 = SDUO (stochastic dynamic user equilibrium with C-logit model using overlap in routes)

Optimization parameter to determine optimisation of green times
0 = no optimization
1 = local optimization with Webster

Metering parameter to determine type of ramp metering
0 = no ramp metering
1 = local ramp metering using capacity algorithm

SmoothG parameter to smooth the optimised green times or not
0 = no smoothing
1 = smoothing with g=gold+alpha*(gnew-gold)

SmoothFlow parameter to smooth the new route flows or not
0 = no smoothing
1 = smoothing with u=uold+delta*(unew-uold)

DelayType parameter for calculation of delay
DelayType = 0: basis for the calcultion of delay is the maximum speed specified by the user
DelayType > 0: basis for the delay is the maximum speed specified by the user and possibly adjusted with events

InitialFlow parameter to determine initial flows in the network at the start of the simulation
0 = initial flows are zero
1 = initial flows are the same as for the first time period

ThresFlow threshold for the minimum flow for a route

ConvErr maximum allowed difference in flows between two iterations for convergence (percentage of demand)

minCounter minimum number of iterations
maxCounter maximum number of iterations

//Assignment
; rho beta gamma Kirchhoff initialAssign
10 1 2 0 0

rho parameter projection method
beta, gamma parameters C-logit model
Kirchhoff parameter to determine if Kirchhoff assignment is used
0 = stochastic assignment with overlap in routes
1 = assignment according to Kirchhoff's law
2 = stochastic assignment without overlap in routes

initialAssign parameter for initial assignment
0 = initial assignment is based on distance
1 = initial assignment is based on free flow travel time, including junction delay
2 = initial assignment is based on free flow travel time, without junction delay

```
//LocalControl
;LContrMethod LOptPeriod
        1         60
```

```
//AntControl
;nrAssign nRTperiods optCriterium LTimeStepOpt
      2         1            2          150
```

nrAssign number of assignment iterations to predict route choice

```
//Routes
;nrRoutes nrRand scaleFac linkCost linkEqual junctionDelay ODdist
    1      60    0.66      1      1.00       0         1
```

nrRoutes maximum number of routes for each OD pair (route generation)
nrRand number of random generations to determine routes
scaleFac scale factor for scaling the random component
linkCost parameter for shortest path calculations:
0 = calculation is based on distance
1 = calculation is based on free flow travel time
linkEqual percentage of links that is allowed to be equal in routes
if higher percentage is found, routes are considered to be equal
JunctionDelay 0 = calculation of routes does not take into account delay at junctions
1 = calculation of routes does take junction delay into account
ODdist 0 = OD relations with flow smaller than ThresFlow are uniformly distributed among other OD relations with same origin or destination
1 = OD relations with flow smaller than ThresFlow are distributed amont other OD relations with same origin or destination, taking into account the flows.

```
//VehPar
;VehLen  TruckV  minV1  minV2  Ja1  Ja2  Ja3  Ja4  Ja5  Ja6  Ja7  Ja8  Ja9
  7.5      90     10     10    85   75   60   50   40   20   15   10   10
```

VehLen average vehicle length
TruckV free speed for trucks (used for travel time calcualations for trucks)
minV1 minimum speed for links with free speed > 90
minV2 minimum speed for links with free speed <= 90
Ja1 speed at congestion for links with free speed > 110
Ja2 speed at congestion for links with 90 < free speed <= 110
Ja3 speed at congestion for links with 70 < free speed <= 90
Ja4 speed at congestion for links with 60 < free speed <= 70
Ja5 speed at congestion for links with 50 < free speed <= 60
Ja6 speed at congestion for links with 40 < free speed <= 50
Ja7 speed at congestion for links with 30 < free speed <= 40
Ja8 speed at congestion for links with 20 < free speed <= 30
Ja9 speed at congestion for links with 0 < free speed <= 20

```
//TollPar
;TollType  ValTime1  ValTime2  ValTime3  ValTime4
    0        10.0      15.0       8.5      24.6
```

TollType type of toll: 0 = no tolling
1 = tolling on every link (price (euro) per km)
2 = tolling on specified links (//TollLinks)

ValTime1 Value of Time (euro/hr) for travel motive 1 (commuting)
ValTime2 Value of Time (euro/hr) for travel motive 2 (business)
ValTime3 Value of Time (euro/hr) for travel motive 3 (other purposes)
ValTime4 Value of Time (euro/hr) for travel motive 4 (freight)

```
//EventSimPar
;EventSimType  EventSimAssign  EventSimNrIter
          0             2            3
```

EventSimType Type of event simulation: 0 = no extra simulation of events
1 = extra simulation of events
2 = extra simulation of events + VMS info
3 = extra simulation with only VMS info
EventSimAssign Value for Assignment type for extra simulation of events
EventSimNrIter Number of iterations for extra simulation of events

```
//PlotPar
;MFDplot  MFDperiod  ContourPlot  StartTime  FlowPlot  SpeedPlot  ControlPlot  TravelTimePlot
      0         5          1          7         0        0           0            1
```

MFDplot flag to determine if MFD plots will be generated
MFDperiode aggregation period for the MFD plots in minutes
ContourPlot flag to determine if speed contour plots for the route parts will be generated
StartTime start time of the contour plot in hours on a 24 hour scale (so 6 = 06:00 and 15.5 is 15:30).
FlowPlot flag to generate plots for link flows for the links specified in the file 'MARPLE-Graphs.txt'
SpeedPlot flag to generate plots for link speeds for the links specified in the file 'MARPLE-Graphs.txt'
ControlPlot flag to generate plots for timings for the signals specified in the file 'MARPLE-Graphs.txt'

```
//EmissionPar
;truckperc excelout binout
   15        0      0
```

```
//Output
;outputflag  binary  emissions
        1       0         1
```

outputflag flag for output: 0 = minimal, 1 = normal, 2 = selected link, 3 = LMS, 4 = selected link + LMS
binary flag for writing output directly into the OmniTRANS database
emissions flag for calculating emissions from MARPLE output

D. Index numbers used in CBA

Safety

Table 8-4. Social costs of safety (eurocent per vehkm)

	Bibeko	Bubeko
Auto	6,3	2,5
Bus	15	8,7
Motorfiets	6,3	10,7
Trein	8,5	

	Bibeko	Bubeko
Bestelauto	2,4	3,5
Vracht solo	14,6	6,2
Vracht Combi	13,2	4,9
Trein	85,2	
Binnenvaartschip	5,4	

(Wever & Rosenberg, 2012)

Bibeko = inside the residential area

Bubeko = outside the residential area

Noise

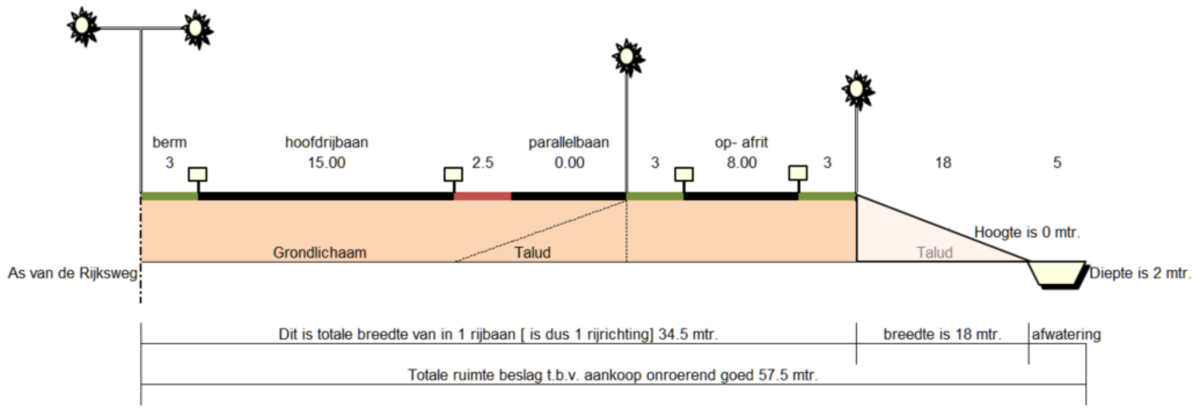
Table 8-5. Index numbers on noise effects (eurocents per vehkm)

Voertuigcategorie	Subcategorie	Bibeko	Bubeko
Personenauto	Benzine	0,2	0,1
	Diesel	1,3	0,1
	LPG	1,0	0,1
	Gemiddeld	1,1	0,1
Bus		9,7	0,4
Motorfiets		13,0	1,9
Bestelauto		1,5	0,2
Voertuigcategorie	< 12 t	9,7	0,4
	> 12 t	13,0	0,6
	Combi	16,2	0,8
Binnenvaart		0,0	0,0
Trein	Passagier	180,1	14,1
	Goederen	720,4	56,0

(Wever & Rosenberg, 2012)

E. Investment and maintenance costs base case

E1. Input SSK model base case



Aantal rijstroken hoofdrijbaan		3	stuks		
Aantal rijstroken parallelbaan en doorsteek		0	stuks	0	Doorsteek
Aantal rijstroken op- afrit		1	stuks		
Aanleg niveau rijbaan t.o.v. M.V. [6 of 0]		0	mtr.		
Talud breedte is18 mtr.	1 : 3	18	mtr.		
Diepte is 2 mtr.		2	mtr.		
KW over de Rijksweg hoogte t.o.v. M.V.		6	mtr.		

	Lijn hoofdrijbaan parallelbaan	Knoop	afstand hoofdrijbaan parallelbaan	afsand op- afrit	Lijn	Knnoop	Hoofdrijbaan aantal rijstroken	Parallelbaan aantal rijstroken	Op- Afrit aantal rijstroken
Eenheid	nr.	nr.	mtr.	mtr.	nr.	nr.	stuks	stuks	stuks
Zonder parallelbaan			9000	2000					
		11							
	10		1000				3		
		10							
	9		1000				3		
		9							
	8		1400				3		
		8							
				500	14	15			1
	7		350				3		
				500	13	14			1
		7							
	6		750				3		
		6							
	5		750				3		
		5							
				500	12	13			1
	4		350				3		
				500	11	12			1
		4							
	3		1400				3		
		3							
	2		1000				3		
		2							
	1		1000				3		

Aankoop onroerend goed	hect.	30.45
Aankoop Vastgoed	stuks	2
Aanbrengen Grondlichaam	m3	0
	m2	151,000
Aanbrengen 3-1 Markering lijnen	mtr.	18,000
Aanbrengen 20 Markering lijnen	mtr.	22,000
Aanbrengen Markering vlakken	m2	225
Aanbrengen Geleiderails	mtr.	20,000
Aanbrengen Openbare verlichting	mtr.	11,000
Aanbrengen DVM signaalgevers	stuks	51
Aanbrengen DVM portalen	stuks	17
Aanbrengen Kunstwerk	m2	630

E2. Summary SSK for base case

Samenvatting SSK						Versie 3.05 (17 maart 2013)
Kostengroepen / Kostencategorieën	Directe kosten Benoemd	Directe kosten Nader te detailleren	Indirecte kosten	Voorziene kosten	Risicoreservering	Totaal
Investeringskosten (indeling naar categorie):						
Bouwkosten Deelraming RWS_Dummy	€ 15,531,625	€ 465,949	€ 4,864,862	€ 20,862,436	€ 2,086,244	€ 22,948,680
Bouwkosten	€ 15,531,625	€ 465,949	€ 4,864,862	€ 20,862,436	€ 2,086,244	€ 22,948,680
Vastgoedkosten	€ 9,962,500	€ -	€ -	€ 9,962,500	€ -	€ 9,962,500
Engineeringskosten	€ 3,546,614	€ -	€ -	€ 3,546,614	€ -	€ 3,546,614
Overige bijkomende kosten	€ 584,148	€ -	€ -	€ 584,148	€ -	€ 584,148
Subtotaal investeringskosten	**€ 29,624,887**	**€ 465,949**	**€ 4,864,862**	**€ 34,955,698**	**€ 2,086,244**	**€ 37,041,942**
Objectoverstijgende risico's					€ -	€ -
Investeringskosten deterministisch	**€ 29,624,887**	**€ 465,949**	**€ 4,864,862**	**€ 34,955,698**	**€ 2,086,244**	**€ 37,041,942**
Scheefte					€ -	€ -
Investeringskosten exclusief BTW				**€ 34,955,698**	**€ 2,086,244**	**€ 37,041,942**
BTW				€ 5,248,572	€ 438,111	€ 5,686,683
Investeringskosten inclusief BTW				**€ 40,204,270**	**€ 2,524,355**	**€ 42,728,625**
#WAARDE!						#WAARDE!
Bandbreedte : met 70% zekerheid liggen de investeringskosten inclusief BTW tussen				€ -	en	€ -
Variatiecoëfficiënt					-	
			€ 3,546,614			
Levensduurkosten:						
Levensduurkosten Deelraming RWS_Dummy	€ 31,269,310	€ 1,563,466	€ 16,621,117	€ 49,453,892	€ 4,945,389	€ 54,399,281
Subtotaal levensduurkosten	**€ 31,269,310**	**€ 1,563,466**	**€ 16,621,117**	**€ 49,453,892**	**€ 4,945,389**	**€ 54,399,281**
Objectoverstijgende risico's					€ -	€ -
Levensduurkosten deterministisch	**€ 31,269,310**	**€ 1,563,466**	**€ 16,621,117**	**€ 49,453,892**	**€ 4,945,389**	**€ 54,399,281**
Scheefte					€ -	€ -
Levensduurkosten exclusief BTW				**€ 49,453,892**	**€ 4,945,389**	**€ 54,399,281**
BTW				€ 10,340,359	€ 1,034,036	€ 11,374,395
Levensduurkosten inclusief BTW				**€ 59,794,251**	**€ 5,979,425**	**€ 65,773,676**
#WAARDE!						#WAARDE!
Bandbreedte : met 70% zekerheid liggen de levensduurkosten inclusief BTW tussen				€ -	en	€ -
Variatiecoëfficiënt					-	
Projectkosten inclusief BTW				**€ 99,998,521**	**€ 8,503,780**	**€ 108,502,301**
#WAARDE!						#WAARDE!
Budgetvaststelling investeringskosten:						
Investeringskosten inclusief BTW				€ 40,204,270	€ 2,524,355	€ 42,728,625
Organisatiegebonden kosten		0%	€ 42,728,625	€ -		€ -
Onzekerheidsreserve (in te vullen door financier)					€ -	€ -
Reservering scope wijzigingen (in te vullen door financier)					€ -	€ -
Aan te houden risicoreservering en totaal budget investeringskosten				**€ 40,204,270**	**€ 2,524,355**	**€ 42,728,625**
Budgetvaststelling levensduurkosten:						
Levensduurkosten inclusief BTW				€ 59,794,251	€ 5,979,425	€ 65,773,676
Organisatiegebonden kosten		0%	€ 65,773,676	€ -		€ -
Onzekerheidsreserve (in te vullen door financier)					€ -	€ -
Reservering scope wijzigingen (in te vullen door financier)					€ -	€ -
Aan te houden risicoreservering en totaal budget levensduurkosten				**€ 59,794,251**	**€ 5,979,425**	**€ 65,773,676**

E3. All the costs taken into account

Deelraming RWS_Dummy — Versie 3.05 (17 maart 2013)

Deelraming aan

Code	Omschrijving post	Hoeveelheid	Eenheid	Prijs	Hoeveelheid per keer	Eenheid hoeveelheid	Prijs per hoeveelheid	aarlijkse onderhoudkosten	Totaal
	Investeringskosten:	Hoeveelheid	Eenheid	Prijs					
Code	AanbrengenGrondlichaam	-	m3	€ 12.00					€ -
Code	AanbrengenVerhardings- constructie	151,000.00	m2	€ 68.70					€ 10,373,700
Code	Aanbrengen 3-1Markering lijnen	18,000.00	mtr.	€ 1.60					€ 28,800
Code	Aanbrengen 20Markering lijnen	22,000.00	mtr.	€ 4.50					€ 99,000
Code	AanbrengenMarkering vlakken	225.00	m2	€ 45.00					€ 10,125
Code	AanbrengenGeleiderails	20,000.00	mtr.	€ 60.00					€ 1,200,000
Code	AanbrengenOpenbare verlichting	11,000.00	mtr	€ 125.00					€ 1,375,000
Code	Aanbrengen WKS	17.00	stuks	€ 25,000.00					€ 425,000
Code	AanbrengenDVM portalen	17.00	stuks	€ 50,000.00					€ 850,000
Code	AanbrengenDVM signaalgevers	51.00	stuks	€ 7,500.00					€ 382,500
Code	AanbrengenKunstwerk	630.00	m2	€ 1,250.00					€ 787,500
Code	Post benoemde directe bouwkosten	-	ehd	€ -					€ -
00-BDBK	**Benoemde directe bouwkosten**								**€ 15,531,625**
Code	Nader te detailleren directe bouwkosten	-	ehd	€ -					€ -
Code	Nader te detailleren directe bouwkosten	-	ehd	€ -					€ -
Code	Nader te detailleren directe bouwkosten	-	ehd	€ -					€ -
00-NTDBK	Nader te detailleren bouwkosten (%)	3.00%	%	€ 15,531,625					€ 465,949
00-DBK	**Directe bouwkosten**								**€ 15,997,574**
Code	Eenmalige kosten	-	euro	€ -					€ -
Code	Eenmalige kosten	-	euro	€ -					€ -
Code	Eenmalige kosten	-	euro	€ -					€ -
00-IBKEK99	Eenmalige kosten (%)	6.00%	%	€ 15,997,574					€ 959,854
00-IBKEK	**Totaal eenmalige kosten**			**€ 959,854**					
00-IBKABK	Algemene bouwplaatskosten (%)	3.00%	%	€ 15,997,574					€ 479,927
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
00-IBKUK	Uitvoeringskosten (%)	6.00%	%	€ 15,997,574					€ 959,854
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
00-IBKAK1	Algemene kosten (%)	8.00%	%	€ 18,397,210					€ 1,471,777
00-IBKAK2	Algemene kosten	-	ehd	€ -					€ -
00-IBKW1	Winst (%)	2.00%	%	€ 19,868,987					€ 397,380
00-IBKW2	Winst	-	ehd	€ -					€ -
00-IBKR1	Risico (%)	3.00%	%	€ 19,868,987					€ 596,070
00-IBKR2	Risico	-	ehd	€ -					€ -
00-IBKB1	Bijdrage RAW (%)	0.00%	%	€ 20,862,436					€ -
00-IBKB2	Bijdrage FCO (%)	0.00%	%	€ 20,862,436					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
Code	Post benoemde indirecte bouwkosten	-	ehd	€ -					€ -
00-IBKS1	Stelpost(en)	-	euro	€ -					€ -
00-IBKS2	Stelpost(en)	-	euro	€ -					€ -
00-IBK	**Indirecte bouwkosten**	30.41%	t.o.v. directe bouwkosten						**€ 4,864,862**
00-VBK	**Voorziene bouwkosten**								**€ 20,862,436**
Code	Benoemd objectrisico bouwkosten	0.00%	k*g	€ -					€ -
Code	Benoemd objectrisico bouwkosten	0.00%	k*g	€ -					€ -
Code	Benoemd objectrisico bouwkosten	0.00%	k*g	€ -					€ -
00-NBORBK	Niet benoemd objectrisico bouwkosten (%)	10.00%	%	€ 20,862,436					€ 2,086,244
00-RBK	**Risico's bouwkosten**	10.00%	t.o.v. voorziene bouwkosten						**€ 2,086,244**
00-BK	**Bouwkosten Deelraming RWS_Dummy**								**€ 22,948,680**

Code	Aankooponroerend goed	30.45	hect	€ 250,000.00	€ 7,612,500
Code	AankoopVastgoed	2.00	stuks	€ 1,000,000.00	€ 2,000,000
Code	Planschade	1.00	pst	€ 100,000.00	€ 100,000
Code	Nadeel compensatie	1.00	pst	€ 250,000.00	€ 250,000
Code	Post benoemde directe vastgoedkosten	-	ehd	€ -	€ -
Code	Post benoemde directe vastgoedkosten	-	ehd	€ -	€ -
Code	Post benoemde directe vastgoedkosten	-	ehd	€ -	€ -
Code	Post benoemde directe vastgoedkosten	-	ehd	€ -	€ -
00-BDVK	**Benoemde directe vastgoedkosten**				**€ 9,962,500**
00-NTDVK	Nader te detailleren vastgoedkosten (%)	0.00%	%	€ 9,962,500	€ -
00-DVK	**Directe vastgoedkosten**				**€ 9,962,500**
Code	Eenmalige vastgoedkosten	-	ehd	€ -	€ -
Code	Eenmalige vastgoedkosten	-	ehd	€ -	€ -
Code	Eenmalige vastgoedkosten	-	ehd	€ -	€ -
00-IVK010	Notaris- en kadasterkosten	-	dossier	€ -	€ -
00-IVK015	Taxatiekosten van taxateurs en/of adviseurs	-	dossier	€ -	€ -
00-IVK020	Kosten gerechtelijke onteigeningsprocedure (advocaat- en rechtbankkosten	-	zaak	€ -	€ -
00-IVK025	Bijdrage kosten deskundige bijstand rechthebbende (%)	0.00%	%	€ 9,962,500	€ -
00-IVK030	Kosten planschade en/of nadeelcompensatie (%)	0.00%	%	€ 9,962,500	€ -
00-IVK035	Overdrachtsbelasting bij verandering juridisch of economisch eigenaar (%)	0.00%	%	€ 9,962,500	€ -
00-IVKAK	Algemene kosten (%)	0.00%	%	€ 9,962,500	€ -
00-IVKW	Winst (%)	0.00%	%	€ 9,962,500	€ -
00-IVKR	Risico (%)	0.00%	%	€ 9,962,500	€ -
00-IVK	**Indirecte vastgoedkosten**	0.00%	t.o.v. directe vastgoedkosten		**€ -**
00-VVK	**Voorziene vastgoedkosten**				**€ 9,962,500**
Code	Benoemd objectrisico vastgoedkosten	0.00%	k*g	€ -	€ -
Code	Benoemd objectrisico vastgoedkosten	0.00%	k*g	€ -	€ -
Code	Benoemd objectrisico vastgoedkosten	0.00%	k*g	€ -	€ -
00-NBORVK	Niet benoemd objectrisico vastgoedkosten (%)	0.00%	%	€ 9,962,500	€ -
00-RVK	**Risico's vastgoedkosten**	0.00%	t.o.v. voorziene vastgoedkosten		**€ -**
00-VK	**Vastgoedkosten Deelraming RWS_Dummy**				**€ 9,962,500**
00-DEK010	Ontwerpkosten aannemer na gunning (%)	10.00%	%	€ 20,862,436	€ 2,086,244
00-DEK015	Managementkosten aannemer na gunning (%)	0.00%	%	€ 20,862,436	€ -
00-DEK020	Vergoeding tenderkosten 'verliezende' inschrijvers door opdrachtgever (%	0.00%	%	€ 20,862,436	€ -
00-DEK025	Engineeringskosten opdrachtgever na gunning (%)	0.00%	%	€ 20,862,436	€ -
00-DEK030	Onderzoek- & ontwerpkosten opdrachtgever voor gunning (%)	0.00%	%	€ 20,862,436	€ -
00-DEK035	Engineeringskosten opdrachtgever voor gunning (%)	7.00%	%	€ 20,862,436	€ 1,460,371
Code	Procentuele post benoemde directe engineeringskosten (%)	0.00%	%	€ 20,862,436	€ -
Code	Procentuele post benoemde directe engineeringskosten (%)	0.00%	%	€ 20,862,436	€ -
Code	Procentuele post benoemde directe engineeringskosten (%)	0.00%	%	€ 20,862,436	€ -
Code	Post benoemde directe engineeringskosten	-	ehd	€ -	€ -
Code	Post benoemde directe engineeringskosten	-	ehd	€ -	€ -
Code	Post benoemde directe engineeringskosten	-	ehd	€ -	€ -
00-BDEK	**Benoemde directe engineeringskosten**				**€ 3,546,614**
00-VEK	**Voorziene engineeringskosten**				**€ 3,546,614**
00-NBOREK	Niet benoemd objectrisico engineeringskosten (%)	0.00%	%	€ 3,546,614	€ -
00-REK	**Risico's engineeringskosten**	0.00%	t.o.v. voorz. engineeringskosten		**€ -**
00-EK	**Engineeringskosten Deelraming RWS_Dummy**				**€ 3,546,614**
00-DOBK010	Leges & heffingen voortvloeiend uit vergunningaanvragen opdrachtnemer	0.30%	%	€ 20,862,436	€ 62,587
00-DOBK015	Verzekeringspremies (CAR, ontwerp, aansprakelijkheid, e.d) opdrachtnem	0.50%	%	€ 20,862,436	€ 104,312
00-DOBK020	Kosten kabels & leidingen niet via contract (%)	0.00%	%	€ 20,862,436	€ -
00-DOBK025	Communicatiekosten niet via contract (%)	0.00%	%	€ 20,862,436	€ -
00-DOBK030	Compenserende maatregelen niet via contract (%)	0.50%	%	€ 20,862,436	€ 104,312
00-DOBK035	Mitigerende maatregelen niet via contract (%)	0.50%	%	€ 20,862,436	€ 104,312
00-DOBK040	Ruimen niet gesprongen explosieven niet via contract (%)	0.00%	%	€ 20,862,436	€ -
00-DOBK045	Archeologische opgravingen niet via contract (%)	1.00%	%	€ 20,862,436	€ 208,624
00-DOBK050	Planschade (%)	0.00%	%	€ 20,862,436	€ -
Code	Procentuele post benoemde directe overige bijkomende kosten (%)	0.00%	%	€ 20,862,436	€ -
Code	Procentuele post benoemde directe overige bijkomende kosten (%)	0.00%	%	€ 20,862,436	€ -
Code	Post benoemde directe overige bijkomende kosten	-	ehd	€ -	€ -
Code	Post benoemde directe overige bijkomende kosten	-	ehd	€ -	€ -
00-BDOBK	**Benoemde directe overige bijkomende kosten**				**€ 584,148**
00-VOBK	**Voorziene overige bijkomende kosten**				**€ 584,148**
00-NBOROBK	Niet benoemd objectrisico overige bijkomende kosten (%)	0.00%	%	€ 584,148	€ -
00-ROBK	**Risico's overige bijkomende kosten**	0.00%	t.o.v. voorz. overige bijk. kosten		**€ -**
00-OBK	**Overige bijkomende kosten Deelraming RWS_Dummy**				**€ 584,148**
00-INV	**Investeringskosten Deelraming RWS_Dummy**				**€ 37,041,942**
	Investeringskosten Deelraming RWS_Dummy (contante waarde)				#WAARDE!

Code	Levensduurkosten:	Aantal keren	Eenheid	Kosten per keer	Hoeveelheid per keer	Eenheid hoeveelheid	Prijs per hoeveelheid	aarlijkse onderhoudkosten	Totaal levensduur
Code	Inspectiekosten:			€	-	ehd	€ -		
s-02.01.06	Rijbaan	96	keer	€ 2,500	1.00	keer	€ 2,500.00	ja	€ 240,000
s-02.01.06	Kunstwerk	96	keer	€ 2,500	1.00	keer	€ 2,500.00	ja	€ 240,000
s-02.01.06	DVM	96	keer	€ 2,500	1.00	keer	€ 2,500.00	ja	€ 240,000
Code	AanbrengenVerhardings- constructie	-	keer	€ -	-	ehd	€ -	ja	€ -
s-02.02.01	Vervangen Rijbaan breed	6	keer	€ 2,265,000	151,000.00	m2	€ 15.00	ja	€ 13,590,000
s-02.02.02	Vervangen Rechter rijstrook	7	keer	€ 302,000	50,333.33	m2	€ 6.00	ja	€ 2,114,000
Code	Aanbrengen 3-1Markering lijnen	-	keer	€ -	-	ehd	€ -	ja	€ -
s-02.04.01	Markering 3-1	7	keer	€ 28,800	18,000.00	mtr.	€ 1.60	ja	€ 201,600
s-02.04.02	Markering 20	7	keer	€ 99,000	22,000.00	mtr.	€ 4.50	ja	€ 693,000
s-02.04.03	Markering vlakken	7	keer	€ 10,125	225.00	m2	€ 45.00	ja	€ 70,875
Code	AanbrengenGeleiderails	-	keer	€ -	-	ehd	€ -	ja	€ -
r-02.03	Vervangen geleiderails	3	keer	€ 1,300,000	20,000.00	mtr.	€ 65.00	ja	€ 3,900,000
Code	AanbrengenOpenbare verlichting	-	keer	€ -	-	ehd	€ -	ja	€ -
s-02.05.02	Vervangen lampen	33	keer	€ 22,000	220.00	stuk	€ 100.00	ja	€ 726,000
s-02.05.08	Vervangen openbare verlichting	1	keer	€ 1,485,000	11,000.00	mtr.	€ 135.00	ja	€ 1,485,000
Code	AanbrengenDVM signaalgevers	-	keer	€ -	-	ehd	€ -	ja	€ -
s-02.06.03	Vervangen signaalgevers	6	keer	€ 408,000	51.00	stuks	€ 8,000.00	ja	€ 2,448,000
s-02.06.01	Vervangen WKS	6	keer	€ 425,000	17.00	stuk	€ 25,000.00	ja	€ 2,550,000
s-02.06.01	Vervangen portalen	1	keer	€ 1,105,000	17.00	stuk	€ 65,000.00	ja	€ 1,105,000
t-02.06.02.02	Conserveren portalen	2	keer	€ 340,000	17.00	stuk	€ 20,000.00	ja	€ 680,000
t-02.06.02.02	Conserveren portalen	2	keer	€ 340,000	17.00	stuk	€ 20,000.00	ja	€ 680,000
Code	AanbrengenKunstwerk	-	keer	€ -	-	ehd	€ -	ja	€ -
Normkosten	Leuning vervangen	3	keer	€ 36,300	121.00	mtr	€ 300.00	ja	€ 108,900
Normkosten	Leuning conserveren	4	keer	€ 10,890	121.00	mtr	€ 90.00	ja	€ 43,560
Normkosten	Asfalt vervangen + H.W.A. herstellen	4	keer	€ 31,500	630.00	m2	€ 50.00	ja	€ 126,000
Normkosten	Beton reparatie gehele kw + talud	1	keer	€ 9,450	630.00	m2	€ 15.00	ja	€ 9,450
Normkosten	Voegconstructie vervangen	2	keer	€ 28,800	12.00	mtr	€ 2,400.00	ja	€ 57,600
Normkosten	Voegprofiel vervangen	9	keer	€ 2,100	12.00	mtr	€ 175.00	ja	€ 18,900
Normkosten	Opleggingen vervangen	1	keer	€ 40,000	2.00	lokatie	€ 20,000.00	ja	€ 40,000
Code	Gladheidsbestrijding	100	keer	€ -	1.00	ehd	€ -	ja	€ -
Code	Zout strooien	100	keer	€ -	1,350.00	kr	€ -	ja	€ -
Code	Reinigen vluchtstroken	100	keer	€ -	1.00	st	€ -	ja	€ -
s04.05.01	Reinigen ZOAB vluchtstrook	100	keer	€ -	3,360.00	m2	€ -	ja	€ -
Code	Groenvoorziening	100	keer	€ -	1.00	ehd	€ -	ja	€ -
r-04.01	Bermen maaien	100	keer	€ -	1,350.00	hect	€ -	ja	€ -
Code	Energie verbruik	100	keer	€ -	1.00	ehd	€ -	ja	€ -
s-04.06.03	DVM	5	keer	€ 40,953	372,300.00	kilo Watt	€ 0.11	ja	€ 204,765
t-04.06.01.01	Openbare verlichting	5	keer	€ 35,332	321,200.00	kilo Watt	€ 0.11	ja	€ 176,660
Code	Calamiteiten dienst	100	keer	€ -	1.00	ehd	€ -	ja	€ -
aanname	Afvoeren motorvoertuigen	2	keer	€ -	100.00	keer	€ -	ja	€ -
Code	----	100	keer	€ -	1.00	m2	€ -	ja	€ -
aanname	----	2	keer	€ -	6,920.00	m2	€ -	ja	€ -
Code	----	100	keer	€ -	1.00	ehd	€ -	ja	€ -
Code	Post benoemde directe levensduurkosten	-	keer	€ -	-	ehd	€ -	ja	€ -
00-BDLEV	**Benoemde directe levensduurkosten**								**€ 31,269,310**
00-NTDLEV	Nader te detailleren levensduurkosten (%)	5.00%	%	€ 31,269,310					€ 1,563,466
00-DLEV	**Directe levensduurkosten**								**€ 32,832,776**
00-ILEVEK	Eenmalige kosten (%)	3.00%	%	€ 32,832,776					€ 984,983
00-ILEVABK	Algemene bouwplaatskosten (%)	3.00%	%	€ 32,832,776					€ 984,983
00-ILEVUK	Uitvoeringskosten (%)	9.00%	%	€ 32,832,776					€ 2,954,950
00-ILEVAK	Algemene kosten (%)	8.00%	%	€ 37,757,692					€ 3,020,615
00-ILEVW	Winst (%)	2.00%	%	€ 40,778,307					€ 815,566
00-ILEVR	Risico (%)	3.00%	%	€ 40,778,307					€ 1,223,349
00-ILEV001	Engineeringskosten binnen levensduurkosten (%)	15.00%	%	€ 42,817,223					€ 6,422,583
00-ILEV002	Leges & heffingen voortvloeiend uit vergunningaanvragen (%)	0.50%	%	€ 42,817,223					€ 214,086
00-ILEV005	Overige bijkomende levensduurkosten (%)	0.00%	%	€ 42,817,223					€ -
00-ILEV005	Overige bijkomende levensduurkosten (%)	0.00%	%	€ 42,817,223					€ -
00-ILEV005	Overige bijkomende levensduurkosten (%)	0.00%	%	€ 42,817,223					€ -
00-ILEV	**Indirecte levensduurkosten**	50.62%	t.o.v. directe levensduurkosten						**€ 16,621,117**
00-VLEV	**Voorziene levensduurkosten**								**€ 49,453,892**
Code	Benoemd objectrisico levensduurkosten	0.00%	k*g	€ -				ja	€ -
Code	Benoemd objectrisico levensduurkosten	0.00%	k*g	€ -				ja	€ -
Code	Benoemd objectrisico levensduurkosten	0.00%	k*g	€ -				ja	€ -
00-NBORLEV	Niet benoemd objectrisico levensduurkosten (%)	10.00%	%	€ 49,453,892					€ 4,945,389
00-RLEV	**Risico's levensduurkosten**	10.00%	t.o.v. voorziene levensduurkosten						**€ 4,945,389**
00-LEV	**Levensduurkosten Deelraming RWS_Dummy**								**€ 54,399,281**
	Levensduurkosten Deelraming RWS_Dummy (contante waarde)								#WAARDE!
00-LCC	**Investerings- & levensduurkosten Deelraming RWS_Dummy**								**€ 91,441,223**
	Investerings- & levensduurkosten Deelraming RWS_Dummy (contante waarde)								#WAARDE!

E4. Calculated investments costs for each alternative

Alternative	*Investment & maintenance costs*
Base case	€ 52,503,866.65
Extended	€ 59,494,275.94
Unbundled 2-1	€ 63,233,451.52
Unbundled 3-1	€ 70,683,136.30
Unbundled 2-2	€ 72,486,016.25
Unbundled 3-1 + shortcut	€ 70,841,991.27

F. Overview all simulation results

F1. Distribution of 50% through traffic

As already mention in the report (Section 5.2), the performances of the 10% and 20% increased traffic simulations are in line with the performances of the '0' traffic demand circumstance. Therefore, the main capacity problems for the unbundled 2-1, the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives occur on the parallel road at the first on-ramp. Since the parallel road consist of only one lane, not enough capacity is provided to handle the traffic that wants to leave the motorway at the second exit and the entering traffic at the first on-ramp together. This has to do with the amount of traffic that enters the motorway at the first on-ramp, by changing this amount, the results could be different. In the base case, the extended 2-2 and the extended alternatives, problems occurred because the second off-ramp exists of only one lane (bottleneck).

Based on the performances and the location of congestion the extended alternative performs best when having initially three lanes and the unbundled 2-2 alternative performs best with initially four lanes. This also holds for the +10% and +20% traffic demand.

Increased traffic demand

The first thing that stands out is that with the increase of 10% traffic demand, not all traffic departs and arrives in the unbundled 2-1, unbundled 3-1 and the unbundled 3-1 with shortcut alternatives. This also holds for the 20% increase of traffic demand. Therefore it can already be stated that the other three alternatives are more robust and are more resilient to an increase of traffic.

When comparing the base case to the extended alternative, it turns out that in both cases (+10% and +20% traffic demand increase) the extended alternative performs better that the base case. However, for the +20% traffic demand increase the difference is very small between the alternatives. In the extended alternative slightly more time is spent in the network but there is less delay. Since the difference is so small between the extended alternative and the base case for +20% traffic, it can be questioned if this would be an alternative.

The unbundled 2-2 alternative performs in both circumstances better than the extended alternative. In both cases the total time spent is lower, the total delay is lower and the average is higher. It can be stated that the unbundled 2-2 alternative can cope with increasing traffic the best.

50-50	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12160	12581	12161	Total	81808	1914	1274	43	1726	187	74006	7801
				1	78027	1848	1256	42				
				2	3781	65	18	58				
Extended	12160	12581	12161	Total	81808	1572	874	52	1412	160	74006	7801
				1	78027	1507	856	52				
				2	3781	65	18	58				
Unb. (2-1)	12161	12292	12161	Total	81071	2506	3350	32	2276	230	73350	7721
				1	63345	2070	3100	31				
				2	17726	436	250	41				
Unb. (3-1)	12161	12291	12161	Total	81074	2419	2627	34	2195	224	73353	7721
				1	63348	1982	2377	32				
				2	17726	437	250	41				
Unb. (2-2)	12160	12598	12161	Total	82190	1219	494	67	1108	111	74363	7828
				1	64022	590	56	109				
				2	18168	629	438	29				
Unb. (3-1) & shortcut	12161	11840	12161	Total	79135	2405	2961	33	2180	225	71600	7535
				1	62037	2012	2748	31				
				2	17098	393	213	43				
10%												
Base case	13376	13839	13376	Total	89987	2649	2394	34	2393	256	81405	8581
				1	85828	2566	2363	33				
				2	4159	83	31	50				
Extended	13376	13839	13376	Total	89987	2400	1633	38	2163	237	81405	8581
				1	85828	2317	1602	37				
				2	4159	83	31	50				
Unb. (2-1)	13265	12445	13376	Total	82903	2629	5134	32	2389	240	75008	7895
				1	64929	2180	4874	30				
				2	17974	449	260	40				
Unb. (3-1)	13376	12445	13376	Total	83421	2627	4257	32	2386	242	75476	7944
				1	65446	2178	3997	30				
				2	17974	449	260	40				
Unb. (2-2)	13376	13856	13376	Total	90405	1951	1155	46	1776	175	81796	8610
				1	70841	1162	571	61				
				2	19564	789	583	25				
Unb. (3-1) & shortcut	13225	12013	13376	Total	80661	2537	4647	32	2301	235	72981	7680
				1	63316	2136	4429	30				
				2	17345	401	218	43				
20%												
Base case	14592	15097	14592	Total	98166	3267	3805	30	2953	315	88804	9361
				1	93629	3163	3757	30				
				2	4537	104	48	44				
Extended	14592	15097	14592	Total	98165	3340	2605	29	3018	322	88804	9361
				1	93629	3236	2557	29				
				2	4537	104	48	44				
Unb. (2-1)	13364	12594	14592	Total	82889	2608	6979	32	2370	238	74996	7894
				1	64678	2145	6708	30				
				2	18211	463	271	39				
Unb. (3-1)	13765	12595	14592	Total	83702	2661	6084	31	2418	243	75731	7971
				1	65490	2199	5814	30				
				2	18212	463	271	39				
Unb. (2-2)	14592	15115	14592	Total	98625	2731	2118	36	2489	241	89233	9392
				1	77583	1806	1415	43				
				2	21042	925	703	23				
Unb. (3-1) & shortcut	13347	12184	14592	Total	80819	2539	6417	32	2304	234	73125	7694
				1	63232	2130	6193	30				
				2	17587	409	223	43				

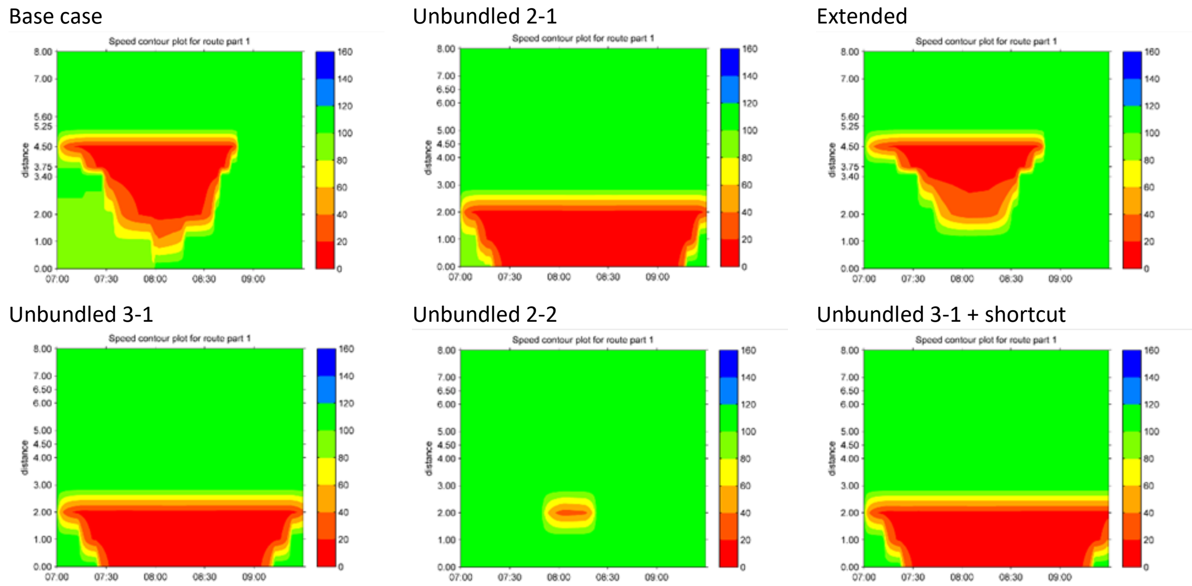


Figure 8-1. Contour plot for '0' traffic demand

Table 8-6. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	3050	3355	3050	2898	2440	1983	1220	610	610	305
2	610	671	610	580	488	397	244	122	122	61
3	2440	2684	2440	2318	1952	1586	976	488	488	244
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	3050	3355	3050	2898	2440	1983	1220	610	610	305
2	610	671	610	580	488	397	244	122	122	61
3	2440	2684	2440	2318	1952	1586	976	488	488	244
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	2871.646	3231.823	2943.19	2793.895	2347.262	1880.818	1091.056	535.728	535.28	267.624
2	178.354	123.177	106.81	104.105	92.738	102.182	128.944	74.272	74.72	37.376
3	610	671	610	580	488	397	244	122	122	61
4	2440	2684	2440	2318	1952	1586	976	488	488	244
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100

Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	2604.273	3227.192	2963.512	2817.195	2371.96	1927.628	1181.811	440.451	380.591	190.234
2	445.727	127.808	86.488	80.805	68.04	55.372	38.189	169.549	229.409	114.766
3	610	671	610	580	488	397	244	122	122	61
4	2440	2684	2440	2318	1952	1586	976	488	488	244
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	2866.774	3229.488	2943.367	2794.006	2347.267	1880.238	1090.761	535.872	535.465	267.717
2	183.226	125.512	106.633	103.994	92.733	102.762	129.239	74.128	74.535	37.283
3	610	671	610	580	488	397	244	122	122	61
4	2440	2684	2440	2318	1952	1586	976	488	488	244
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	2664.763	3151.081	2874.723	2723.126	2278.179	1782.612	995.451	492.377	492.004	245.984
2	238.382	144.547	126.018	124.615	112.884	129.243	134.936	70.478	70.721	35.371
3	146.855	59.372	49.259	50.259	48.937	71.145	89.613	47.145	47.275	23.645
4	610	671	610	580	488	397	244	122	122	61
5	2440	2684	2440	2318	1952	1586	976	488	488	244
6	202.609	234.769	214.214	203.665	171.778	139.97	86.547	43.671	43.809	21.932
7	197.391	205.231	185.786	176.335	148.222	120.03	73.453	36.329	36.191	18.068
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

F2. Distribution of 60% through traffic

As discussed in Section 5.3 no congestion occurred at the base case, unbundled 2-2 and the extended alternative for '0' traffic demand. Therefore, it can be concluded that with the decreased distribution of local traffic as opposed to 50% through traffic, the second off-ramp with lane does provide enough capacity now. The problems, location of congestion, for the other alternatives remained the same as for the distribution of 50% through traffic.

This results in, for a distribution of 60% through traffic and 40% local traffic, the extended alternative performing best when having initially three lanes and the unbundled 2-2 alternative performing best in cases with initially four lanes. The same results are obtained with a distribution of 50% through traffic and 50% local traffic.

Increased traffic demand

All traffic was able to depart and arrive for 10% of traffic demand increase. Besides, only for the unbundled 2-1, unbundled 3-1 and the unbundled 3-1 with shortcut not all traffic was able to arrive for 20% traffic demand increase.

It is remarkable that for both increased traffic demand circumstances the average speed for the extended alternatives is lower than for the base cases, while the total delay is lower and the total time spent in the network is higher. Therefore, it can be said that neither of them performs better.

The same can be said for the unbundled 2-1 and unbundled 3-1 alternatives. They perform equal for an increase of 10% and 20% traffic demand. However, they both perform worse than the base case and the extended alternative. This is in line with the result of the '0' circumstance of 60% through traffic. The unbundled 2-2 alternative performs again the best for both traffic demand increase circumstances.

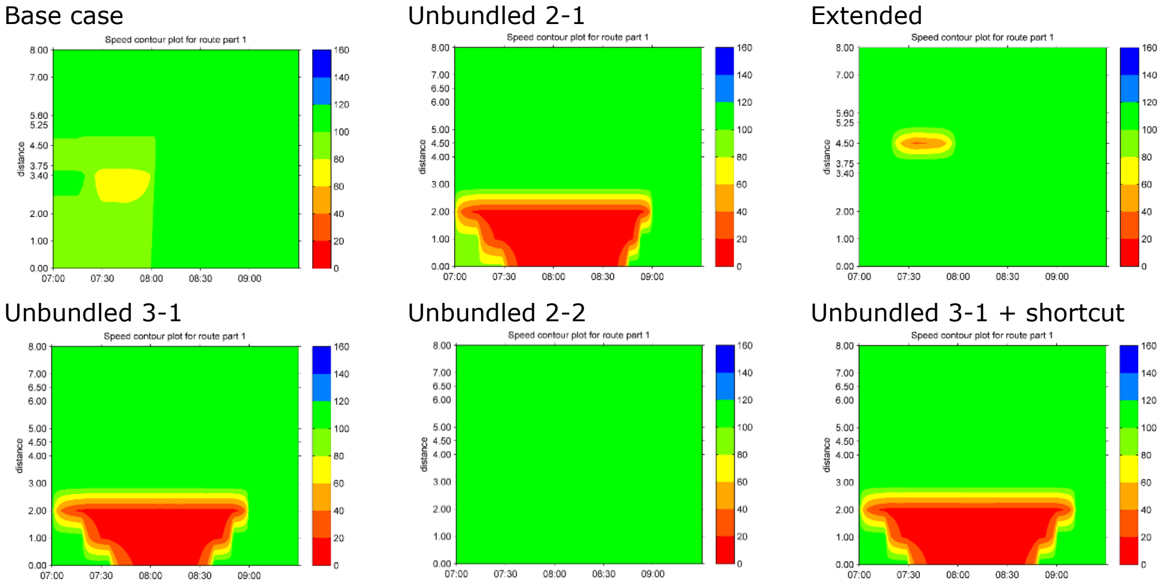


Figure 8-2. Contour plot '0' traffic demand

60-40	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12160	12598	12161	Total	85452	849	181	101	752	97	76719	8733
				1	82171	804	177	102				
				2	3281	45	4	73				
Extended	12160	12598	12160	Total	85452	781	56	109	684	97	76719	8733
				1	82171	736	51	112				
				2	3281	45	4	72				
Unb. (2-1)	12160	12611	12160	Total	85795	2221	1784	39	1995	226	77037	8758
				1	69630	1856	1588	38				
				2	16166	366	196	44				
Unb. (3-1)	12160	12611	12160	Total	85799	2064	1320	42	1851	213	77040	8759
				1	69648	1698	1124	41				
				2	16151	366	196	44				
Unb. (2-2)	12160	12617	12160	Total	85829	808	49	106	711	97	77065	8764
				1	64930	552	11	118				
				2	20899	256	38	82				
Unb. (3-1)	12160	12612	12160	Total	85989	2207	1621	39	1979	228	77213	8776
& shortcut				1	69875	1847	1429	38				
				2	16113	361	191	45				
10%												
Base case	13376	13858	13376	Total	93998	1090	804	86	971	120	84392	9606
				1	90389	1039	798	87				
				2	3609	51	6	71				
Extended	13376	13858	13376	Total	93999	1237	438	76	1095	142	84392	9606
				1	90389	1182	429	76				
				2	3609	55	9	66				
Unb. (2-1)	13376	13872	13376	Total	94369	2585	3082	37	2323	261	84736	9633
				1	76764	2172	2854	35				
				2	17605	413	228	43				
Unb. (3-1)	13376	13872	13376	Total	94366	2548	2394	37	2289	259	84733	9633
				1	76757	2134	2166	36				
				2	17609	414	228	43				
Unb. (2-2)	13376	13876	13376	Total	94346	1039	212	91	925	115	84714	9632
				1	75218	652	26	115				
				2	19127	387	186	49				
Unb. (3-1)	13376	13667	13376	Total	93890	2631	2874	36	2363	269	84308	9581
& shortcut				1	76479	2236	2662	34				
				2	17410	396	213	44				
20%												
Base case	14592	15117	14592	Total	102539	1367	1776	75	1219	147	92060	10479
				1	98602	1310	1769	75				
				2	3937	57	8	69				
Extended	14592	15117	14592	Total	102539	1997	1126	51	1780	216	92060	10479
				1	98602	1931	1110	51				
				2	3937	65	16	60				
Unb. (2-1)	14592	14557	14592	Total	100470	2891	4738	35	2600	291	90214	10256
				1	82052	2441	4482	34				
				2	18417	450	256	41				
Unb. (3-1)	14592	14561	14592	Total	100532	2914	3885	35	2621	293	90270	10262
				1	82114	2464	3629	33				
				2	18417	450	256	41				
Unb. (2-2)	14592	15135	14592	Total	102905	1421	521	72	1360	61	92400	10505
				1	83445	824	129	101				
				2	19460	597	392	33				
Unb. (3-1)	14592	13833	14592	Total	96514	2869	4506	34	2578	291	86665	9849
& shortcut				1	78872	2468	4291	32				
				2	17642	401	215	44				

Table 8-7. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	3660	4026	3660	3477	2928	2379	1464	732	732	366
2	488	537	488	464	390	317	195	98	98	49
3	1952	2147	1952	1854	1562	1269	781	390	390	195
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	3660	4026	3660	3477	2928	2379	1464	732	732	366
2	488	537	488	464	390	317	195	98	98	49
3	1952	2147	1952	1854	1562	1269	781	390	390	195
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	3341.16	3848.424	3513.978	3333.132	2798.675	2233.76	1299.561	638.885	500.707	235.205
2	318.84	177.576	146.022	143.868	129.325	145.24	164.439	93.115	231.293	130.795
3	488	537	488	464	390	317	195	98	98	49
4	1952	2147	1952	1854	1562	1269	781	390	390	195
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	2335.275	2974.836	3045.582	2606.382	1838.824	1488.504	913.955	456.613	456.599	228.258
2	1324.725	1051.164	614.418	870.618	1089.176	890.496	550.045	275.387	275.401	137.742
3	488	537	488	464	390	317	195	98	98	49
4	1952	2147	1952	1854	1562	1269	781	390	390	195
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	3335.139	3845.382	3514.925	3334.328	2799.313	2237.112	1307.098	639.376	496.405	235.247
2	324.861	180.618	145.075	142.672	128.687	141.888	156.902	92.624	235.595	130.753
3	488	537	488	464	390	317	195	98	98	49
4	1952	2147	1952	1854	1562	1269	781	390	390	195
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	3140.995	3766.198	3432.907	3249.138	2719.154	2140.462	1196.908	588.345	564.875	183.376
2	318.95	181.911	160.528	159.607	143.712	154.403	160.845	86.042	98.966	104.444
3	200.056	77.892	66.566	68.255	65.134	84.135	106.247	57.613	68.159	78.18
4	488	537	488	464	390	317	195	98	98	49
5	1952	2147	1952	1854	1562	1269	781	390	390	195
6	213.244	237.249	215.887	205.278	173.189	141.084	87.162	43.804	43.896	22.039
7	186.756	202.751	184.113	174.722	146.811	118.916	72.838	36.196	36.104	17.961
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

F3. Distribution of 70% through traffic

As mentioned in Section 5.4, for a distribution of 70% through traffic and 30% local traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

For the alternatives with initially three lanes, the extended alternative performed better than the base case and the unbundled 2-1 alternative performed worse than the base case. For the alternatives with initially four lanes, the unbundled 3-1 and the unbundled 3-1 with shortcut alternatives performed worse than the extended alternative and the unbundled 2-2 alternative performed quite equal. The same holds for the circumstances of increased traffic demand.

Increased traffic demand

Unlike the distribution of 50% and 60% through traffic all traffic can depart and arrive for increased traffic demand.

The differences between performance of 10% and 20% increased traffic demand do not differ very much for the extended and unbundled 2-2 alternatives. This means that, for example, the average speed of the extended alternative for the '0' traffic demand alternative is 115 km/h, for the 10% increased traffic demand is 114 km/h and for the 20% increased traffic demand is 110 km/h. Therefore, those two alternatives are the most robust.

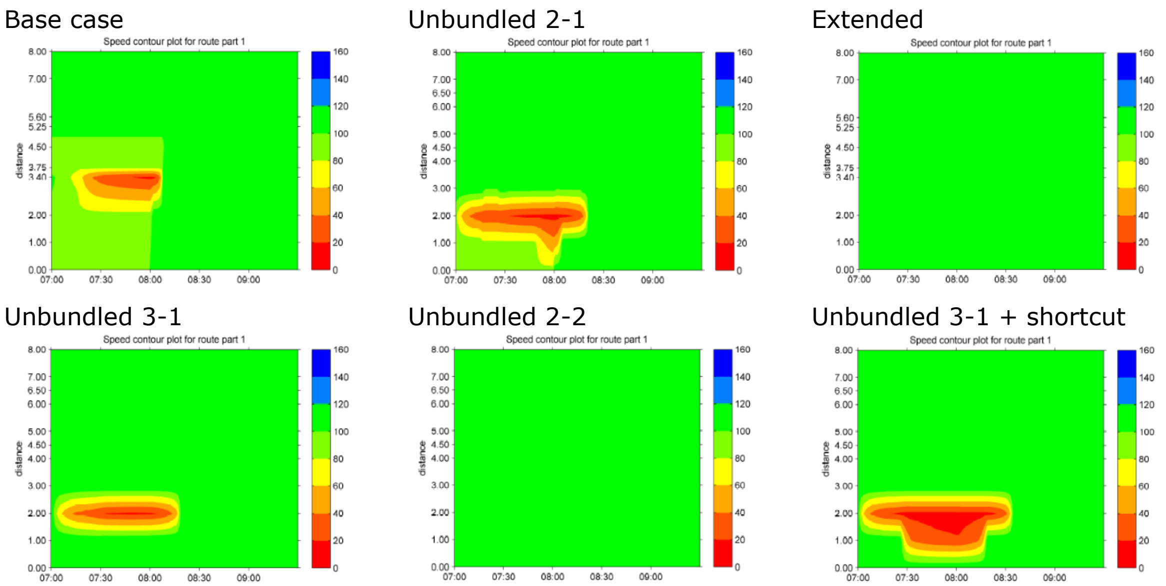


Figure 8-3. Contour plot for '0' traffic demand

70-30	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12160	12615	12161	Total	89103	938	242	95	825	113	79438	9665
				1	86322	903	241	96				
				2	2781	35	0	79				
Extended	12160	12615	12161	Total	89103	772	18	115	668	104	79438	9665
				1	86322	737	17	117				
				2	2781	35	1	79				
Unb. (2-1)	12160	12627	12161	Total	89371	1291	572	69	1146	145	79684	9687
				1	74646	1007	443	74				
				2	14726	284	130	52				
Unb. (3-1)	12160	12627	12161	Total	89375	1158	382	77	1023	135	79687	9687
				1	74665	877	254	85				
				2	14709	281	127	52				
Unb. (2-2)	12160	12634	12161	Total	89483	806	18	111	701	105	79781	9701
				1	68273	581	13	117				
				2	21210	224	5	95				
Unb. (3-1)	12160	12629	12161	Total	89635	1463	685	61	1295	167	79921	9714
& shortcut				1	75368	1171	543	64				
				2	14267	291	142	49				
10%												
Base case	13376	13876	13376	Total	98010	1287	970	76	1139	149	87378	10631
				1	94950	1249	970	76				
				2	3059	39	1	79				
Extended	13376	13876	13376	Total	98010	860	30	114	745	115	87379	10632
				1	94951	821	30	116				
				2	3059	39	1	78				
Unb. (2-1)	13376	13889	13376	Total	98325	1686	1346	58	1499	187	87668	10657
				1	82788	1359	1181	61				
				2	15537	327	164	47				
Unb. (3-1)	13376	13889	13376	Total	98317	1795	942	55	1592	203	87660	10656
				1	82835	1469	779	56				
				2	15482	326	163	48				
Unb. (2-2)	13376	13897	13376	Total	98425	897	30	110	781	116	87754	10670
				1	75288	648	21	116				
				2	23137	249	10	93				
Unb. (3-1)	13376	13890	13376	Total	98603	2189	1335	45	1943	246	87919	10685
& shortcut				1	83207	1861	1168	45				
				2	15396	328	166	47				
20%												
Base case	14592	15137	14592	Total	106919	1639	2014	65	1452	186	95321	11598
				1	103582	1596	2013	65				
				2	3337	42	1	79				
Extended	14592	15137	14592	Total	106919	973	68	110	847	126	95321	11598
				1	103582	930	67	111				
				2	3337	43	2	77				
Unb. (2-1)	14592	15151	14592	Total	107287	2082	2432	52	1852	230	95659	11629
				1	90571	1714	2239	53				
				2	16716	367.8	192	45				
Unb. (3-1)	14592	15150	14592	Total	107278	2518	1742	43	2238	280	95650	11627
				1	90590	2152	1552	42				
				2	16688	365	190	46				
Unb. (2-2)	14592	15159	14592	Total	107365	1008	63	107	881	127	95725	11640
				1	82624	733	44	113				
				2	24741	275	19	90				
Unb. (3-1)	14592	15151	14592	Total	107539	2711	2333	40	2410	301	95887	11652
& shortcut				1	90837	2346	2144	39				
				2	16702	365	189	46				

Table 8-8. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	4270	4697	4270	4057	3416	2776	1708	854	854	427
2	366	403	366	348	293	238	146	73	73	37
3	1464	1610	1464	1391	1171	952	586	293	293	146
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	4270	4697	4270	4057	3416	2776	1708	854	854	427
2	366	403	366	348	293	238	146	73	73	37
3	1464	1610	1464	1391	1171	952	586	293	293	146
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	3758.306	4432.354	4055.365	3846.28	3223.613	2553.575	1147.279	542.8	538.292	267.505
2	511.694	264.646	214.635	210.72	192.387	222.425	560.721	311.2	315.708	159.495
3	366	403	366	348	293	238	146	73	73	37
4	1464	1610	1464	1391	1171	952	586	293	293	146
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	2686.864	3007.472	2710.531	2546.451	2136.078	1733.188	1065.472	532.591	532.577	266.275
2	1583.136	1689.528	1559.469	1510.549	1279.922	1042.812	642.528	321.409	321.423	160.725
3	366	403	366	348	293	238	146	73	73	37
4	1464	1610	1464	1391	1171	952	586	293	293	146
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	3757.062	4447.732	4072.091	3862.773	3232.67	2524.944	1140.043	545.195	537.316	268.124
2	512.938	249.268	197.909	194.227	183.33	251.056	567.957	308.805	316.684	158.876
3	366	403	366	348	293	238	146	73	73	37
4	1464	1610	1464	1391	1171	952	586	293	293	146
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	3537.011	4362.002	3973.186	3761.017	3152.432	2527.487	1325.744	433.662	422.051	210.681
2	442.83	230.017	205.03	203.142	179.002	164.243	226.729	240.401	246.86	123.666
3	290.159	104.981	91.784	92.841	84.566	84.271	155.527	179.937	185.089	92.653
4	366	403	366	348	293	238	146	73	73	37
5	1464	1610	1464	1391	1171	952	586	293	293	146
6	217.05	239.138	217.926	207.304	175.032	142.461	87.704	44.034	44.058	22.048
7	182.95	200.862	182.074	172.696	144.968	117.539	72.296	35.966	35.942	17.952
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

F4. Distribution of 80% through traffic

As discussed in Section 5.5 for the '0' traffic demand circumstance, the unbundled 2-1 alternative performed better/equal to the base case and the extended alternative performs much better than the base case, and the unbundled 2-1 alternative.

For the alternatives with initially four lanes, the extended alternative performed better than the unbundled 3-1 alternative. Since no congestion occurred in the extended alternative and the unbundled 3-1 alternative already performed worse than the extended alternative, the unbundled 3-1 with shortcut alternative performs worse than the extended alternative. However, the unbundled 2-2 alternative performed quite equal to the extended alternative. The maximum speed on the parallel road is lower than on the main carriageway, which explains the lower average speed for the unbundled 2-2 alternative. Overall, it can be stated that the extended alternative performs slightly better. It could be concluded that for a distribution of 80% through traffic and 20% local traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, as with a distribution of 70% through traffic, no congestion occurred in the unbundled 2-2 alternative either.

Increased traffic demand

For the increased traffic demand circumstances all vehicles were able to depart and arrive. When looking at the base case and the unbundled 2-1 alternative, the unbundled 2-1 alternative starts to perform slightly better the more the traffic demand increases. However, the extended alternative performs better than both the base case and the unbundled 2-1 alternative for both increased traffic demands. Of the alternatives with initially three lanes, the performances of the extended alternative changes the least in case of increased traffic demand. The same holds for the unbundled 2-2 alternative and the alternatives with initially four lanes. Therefore, it can be stated that the extended and the unbundled 2-2 alternatives are the most robust in case of traffic demand increase.

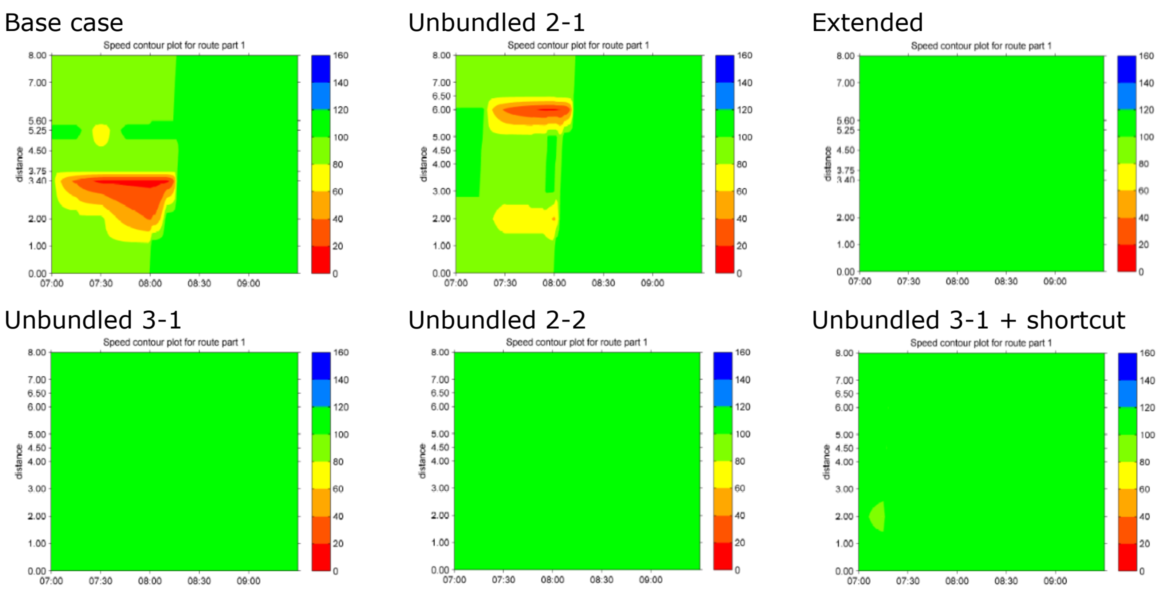


Figure 8-4. Contour plot for '0' traffic demand

80-20	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance traveled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12161	12631	12161	Total	92748	1124	399	83	988	135	82150	10598
				1	90466	1095	399	83				
				2	2281	29	0	79				
Extended	12160	12631	12160	Total	92748	804	22	115	690	114	82150	10598
				1	90466	775	21	117				
				2	2281	29	0	79				
Unb. (2-1)	12160	12643	12160	Total	93016	1126	378	83	993	133	82392	10624
				1	78211	879	285	89				
				2	14805	247	93	60				
Unb. (3-1)	12160	12643	12160	Total	93018	879	74	106	761	118	82394	10624
				1	78154	668	17	117				
				2	14864	211	57	70				
Unb. (2-2)	12160	12650	12160	Total	93101	835	20	111	720	115	82466	10635
				1	72843	623	16	117				
				2	20257	212	4	95				
Unb. (3-1) & shortcut	12160	12644	12160	Total	93364	912	105	102	791	121	82700	10664
				1	79460	684	22	116				
				2	13904	228	83	61				
10%												
Base case	13376	13895	13376	Total	102026	1662	1314	61	1467	195	90368	11658
				1	99516	1630	1314	61				
				2	2510	32	0	79				
Extended	13377	13895	13377	Total	102026	900	40	113	775	126	90368	11658
				1	99516	869	39	115				
				2	2510	32	0	79				
Unb. (2-1)	13377	13908	13377	Total	102316	1648	1276	62	1460	188	90630	11686
				1	86759	1290	1079	67				
				2	15557	358	197	43				
Unb. (3-1)	13377	13907	13377	Total	102309	997	113	103	865	132	90624	11685
				1	87032	757	32	115				
				2	15277	240	81	64				
Unb. (2-2)	13377	13915	13377	Total	102412	932	36	110	806	127	90714	11698
				1	80236	698	29	115				
				2	22176	235	7	95				
Unb. (3-1) & shortcut	13377	13908	13377	Total	102640	1142	256	90	997	145	90918	11722
				1	88209	886	150	100				
				2	14432	257	106	56				
20%												
Base case	14592	15157	14592	Total	111295	2279	2621	49	2012	267	98577	12717
				1	108557	2245	2621	48				
				2	2737	35	0	79				
Extended	14592	15157	14592	Total	111294	1044	105	107	906	139	98577	12717
				1	108557	1010	105	108				
				2	2738	35	0	79				
Unb. (2-1)	14592	15171	14592	Total	111606	2174	2538	51	1927	246	98859	12747
				1	94835	1716	2206	55				
				2	16771	458	332	37				
Unb. (3-1)	14592	15169	14592	Total	111586	1209	246	92	1058	151	98841	12745
				1	95911	930	131	103				
				2	15675	279	115	56				
Unb. (2-2)	14592	15179	14592	Total	111715	1066	88	105	927	139	98953	12761
				1	87631	805	75	109				
				2	24084	261	14	92				
Unb. (3-1) & shortcut	14592	15170	14592	Total	111919	1726	762	65	1516	210	99139	12780
				1	97134	1442	633	67				
				2	14785	284	129	52				

Table 8-9. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	4880	5368	4880	4636	3904	3172	1952	976	976	488
2	244	268	244	232	195	159	98	49	49	24
3	976	1074	976	927	781	634	390	195	195	98
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	4880	5368	4880	4636	3904	3172	1952	976	976	488
2	244	268	244	232	195	159	98	49	49	24
3	976	1074	976	927	781	634	390	195	195	98
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	4088.476	4692.302	4222.734	3979.815	3369.526	2340.902	1289.186	626.799	618.388	307.841
2	791.524	675.698	657.266	656.185	534.474	831.098	662.814	349.201	357.612	180.159
3	244	268	244	232	195	159	98	49	49	24
4	976	1074	976	927	781	634	390	195	195	98
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	3038.831	3369.953	3059.816	2886.032	2430.693	1976.049	1216.671	608.53	608.516	304.283
2	1841.169	1998.047	1820.184	1749.968	1473.307	1195.951	735.329	367.47	367.484	183.717
3	244	268	244	232	195	159	98	49	49	24
4	976	1074	976	927	781	634	390	195	195	98
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	4107.126	4820.034	4366.224	3971.169	3145.743	2221.682	1288.434	626.136	622.309	304.957
2	772.874	547.966	513.776	664.831	758.257	950.318	663.566	349.864	353.691	183.043
3	244	268	244	232	195	159	98	49	49	24
4	976	1074	976	927	781	634	390	195	195	98
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	3944.359	4901.697	4370.994	3942.754	3140.264	2228.895	1053.977	488.589	485.599	239.741
2	562.505	310.955	328.477	427.73	458.386	549.817	514.299	278.737	280.389	141.92
3	373.136	155.348	180.53	265.517	305.349	393.288	383.724	208.675	210.013	106.339
4	244	268	244	232	195	159	98	49	49	24
5	976	1074	976	927	781	634	390	195	195	98
6	218.814	244.996	220.002	208.004	174.685	141.946	87.938	44.074	44.08	22.055
7	181.186	195.004	179.998	171.996	145.315	118.054	72.062	35.926	35.92	17.945
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

F5. Distribution of 90% through traffic

As discussed in Section 5.6, of the alternatives with initially three lanes, the base case and the unbundled 2-1 alternative perform equal and the extended alternative performs way better than the base case. Besides, for the alternatives with initially four lanes, the extended alternative performs better than the unbundled 3-1 alternative and the unbundled 3-1 with shortcut alternative. When only looking at the numbers, the extended alternative performs better than the unbundled 2-2 alternative. In all alternatives congestion occurred, except in the extended and the unbundled 2-2 alternative. Since only 10% of the traffic that entered the network in node 1 leaves the motorway, congestion occurred at the on-ramps in the base case. The main carriageway cannot handle this amount of traffic. The problems that occurred due to congestion for the distribution of 90% through traffic are expected to be higher for the distribution of 100% through traffic.

As the distributions of 70% and 80% through traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

Increased traffic demand

In comparison the ‘0’ and the +10% traffic demand, the alternatives perform way worse for the increase of 20% traffic demand. For instance, the total delay for the extended alternative is in the ‘0’ circumstance 30 veh*hrs, for 10% of traffic demand increase 77 veh*hrs and for an increase of 20% traffic demand the delay is 336 veh*hrs.

Overall, the extended and the unbundled 2-2 alternatives performs the best for all traffic demands. However, the difference in performance between these two and the unbundled 3-1 alternative become smaller the more the traffic demand increases. This makes sense because when you keep increasing the demand, all networks will at some point suffer from congestion and the performances will be closer together and at one point maybe be the same.

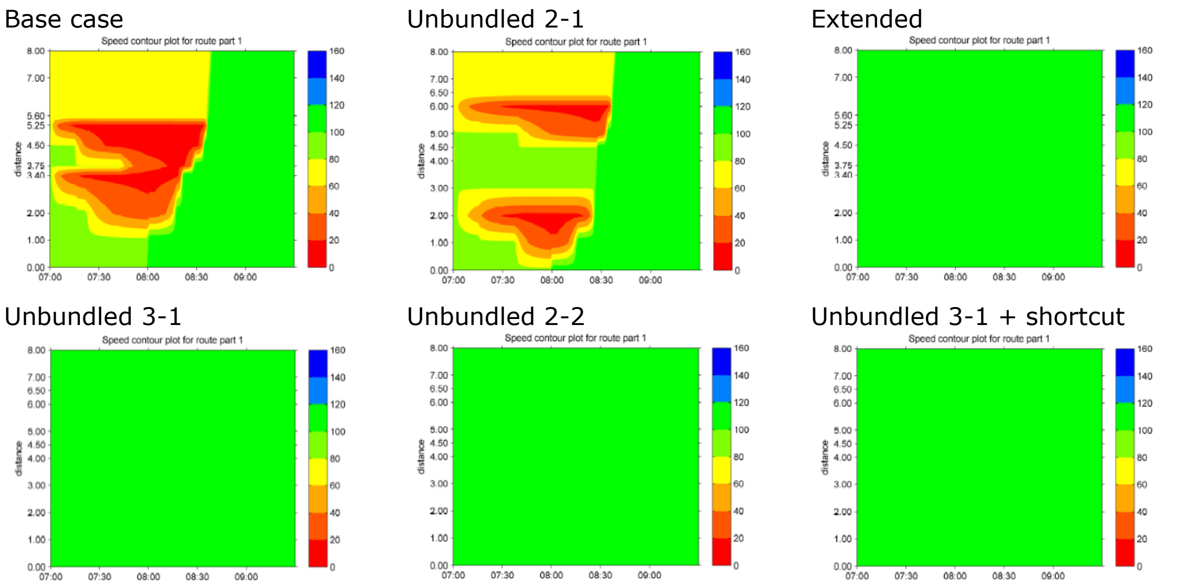


Figure 8-5. Contour plot for '0' traffic demand

90-10	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12161	12649	12161	Total	96399	1847	1093	52	1619	227	84867	11532
				1	94617	1824	1093	52				
				2	1782	22	0	80				
Extended	12160	12649	12160	Total	96399	841	30	115	717	124	84867	11532
				1	94617	818	30	116				
				2	1782	22	0	80				
Unb. (2-1)	12160	12659	12160	Total	96640	1853	1079	52	1627	226	85081	11559
				1	83487	1553	915	54				
				2	13154	300	164	44				
Unb. (3-1)	12160	12659	12160	Total	96618	903	71	107	774	128	85061	11556
				1	83514	721	25	116				
				2	13104	181	46	72				
Unb. (2-2)	12160	12666	12160	Total	96725	871	28	111	746	125	85155	11570
				1	77402	669	24	116				
				2	19323	201	4	96				
Unb. (3-1)	12160	12661	12160	Total	97119	918	82	106	788	130	85502	11617
& shortcut				1	83507	722	26	116				
				2	13612	196	55	69				
10%												
Base case	13376	13913	13376	Total	106036	2727	2347	39	2392	335	93351	12685
				1	104076	2702	2347	39				
				2	1960	25	0	80				
Extended	13376	13913	13376	Total	106036	968	77	109	831	138	93351	12685
				1	104076	944	76	110				
				2	1960	25	0	80				
Unb. (2-1)	13376	13925	13376	Total	106294	2694	2294	39	2366	328	93580	12713
				1	92079	2285	2030	40				
				2	14215	409	264	35				
Unb. (3-1)	13376	13923	13376	Total	106255	1062	151	100	918	144	93546	12709
				1	92987	838	63	111				
				2	13269	224	89	59				
Unb. (2-2)	13376	13933	13376	Total	106395	997	70	107	859	139	93669	12727
				1	85114	768	59	111				
				2	21282	229	12	93				
Unb. (3-1)	13376	13926	13376	Total	106756	1061	143	101	916	145	93988	12769
& shortcut				1	92623	844	72	110				
				2	14134	218	71	65				
20%												
Base case	14592	15178	14592	Total	115677	3590	3898	32	3149	441	101839	13838
				1	113539	3564	3898	32				
				2	2138	27	0	79				
Extended	14592	15178	14592	Total	115677	1309	336	88	1139	170	101838	13838
				1	113539	1282	336	89				
				2	2138	27	0	79				
Unb. (2-1)	14592	15191	14592	Total	115937	3484	3857	33	3060	424	102071	13867
				1	100675	2973	3423	34				
				2	15262	511	434	30				
Unb. (3-1)	14592	15188	14592	Total	115895	1367	451	85	1197	170	102033	13861
				1	102554	1087	233	94				
				2	13341	280	219	48				
Unb. (2-2)	14592	15199	14592	Total	116064	1348	337	86	1176	172	102181	13883
				1	93135	1019	243	91				
				2	22929	329	94	70				
Unb. (3-1)	14592	15191	14592	Total	116400	1405	406	83	1227	178	102480	13920
& shortcut				1	101815	1139	291	89				
				2	14585	266	115	55				

Table 8-10. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	5490	6039	5490	5216	4392	3569	2196	1098	1098	549
2	122	134	122	116	98	79	49	24	24	12
3	488	537	488	464	390	317	195	98	98	49
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	5490	6039	5490	5216	4392	3569	2196	1098	1098	549
2	122	134	122	116	98	79	49	24	24	12
3	488	537	488	464	390	317	195	98	98	49
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	4477.123	5352.617	4673.472	4379.114	3541.737	2766.688	1659.583	731.355	708.237	345.141
2	1012.877	686.383	816.528	836.886	850.263	802.312	536.417	366.645	389.763	203.859
3	122	134	122	116	98	79	49	24	24	12
4	488	537	488	464	390	317	195	98	98	49
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	3387.236	3696.791	3405.669	3251.257	2724.092	2219.23	1367.827	684.472	684.458	342.292
2	2102.764	2342.209	2084.331	1964.743	1667.908	1349.77	828.173	413.528	413.542	206.708
3	122	134	122	116	98	79	49	24	24	12
4	488	537	488	464	390	317	195	98	98	49
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	4604.721	5429.638	4889.232	4476.088	3527.258	2524.136	1457.807	700.632	698.712	342.833
2	885.279	609.362	600.768	739.912	864.742	1044.864	738.193	397.368	399.288	206.167
3	122	134	122	116	98	79	49	24	24	12
4	488	537	488	464	390	317	195	98	98	49
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	4160.531	5062.422	4438.979	4067.524	3231.692	2229.179	1188.303	562.341	544.629	265.973
2	782.226	605.27	633.034	683.621	681.518	772.759	577.479	306.594	316.394	161.735
3	547.243	371.308	417.987	464.855	478.79	567.062	430.218	229.064	236.977	121.291
4	122	134	122	116	98	79	49	24	24	12
5	488	537	488	464	390	317	195	98	98	49
6	217.752	242.774	219.8	207.647	174.751	141.852	87.592	44.03	44.091	22.057
7	182.248	197.226	180.2	172.353	145.249	118.148	72.408	35.97	35.909	17.943
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

F6. Distribution of 100% through traffic

As discussed in Section 5.7, it can be stated that the base case and the unbundled 2-1 alternative perform equal for the ‘0’ traffic demand circumstance. Besides, the extended alternative performs much better than the base case.

For the alternatives with initially four lanes, the extended alternative performs a little better than the unbundled 3-1 alternative. Besides, when looking solely to the amounts, the extended alternative performs better than the unbundled 2-2 alternative. Moreover, the unbundled 3-1 alternative performs worse than the extended alternative.

As expected the problems that occurred with a distribution of 90% through traffic, became worse. However, still no congestion occurred in the extended and unbundled 2-2 alternatives. Like the distributions of 70%, 80% and 90% through traffic, the extended alternative performs best for both situations of initially three lanes and initially four lanes. However, no congestion occurred in the unbundled 2-2 alternative either.

Increased traffic demand

The results for the alternatives with initially three lanes are the same for the increased traffic circumstances of 10% and 20% as for the ‘0’ traffic demand.

For the alternatives with initially four lanes, but same holds for the increase of 10%, but the unbundled 3-1 alternative performs better than the extended and unbundled 2-2 alternatives when traffic demand increases with 20%.

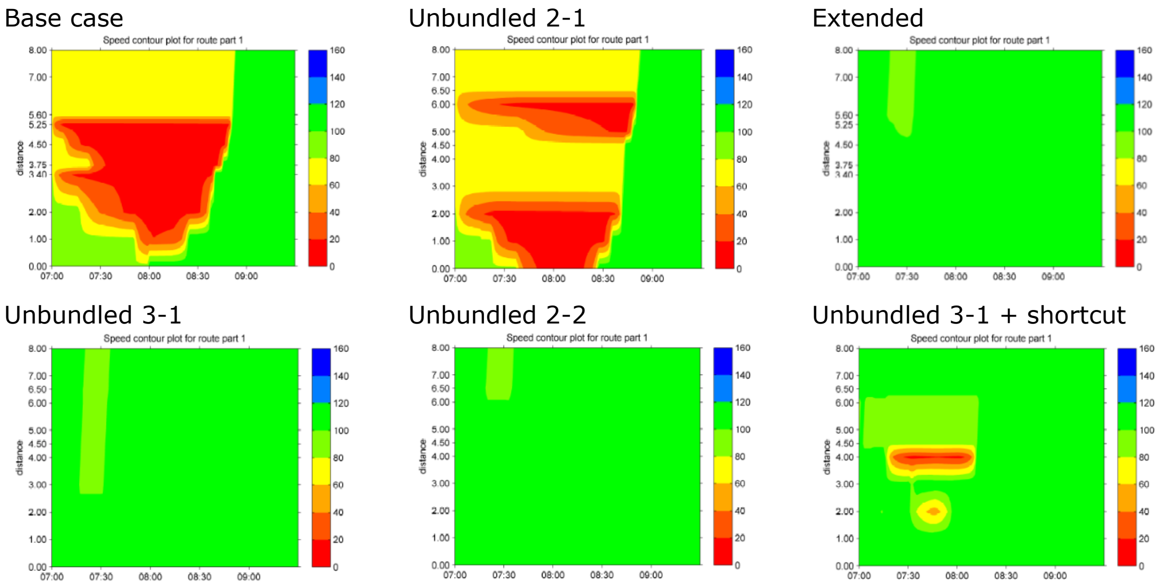


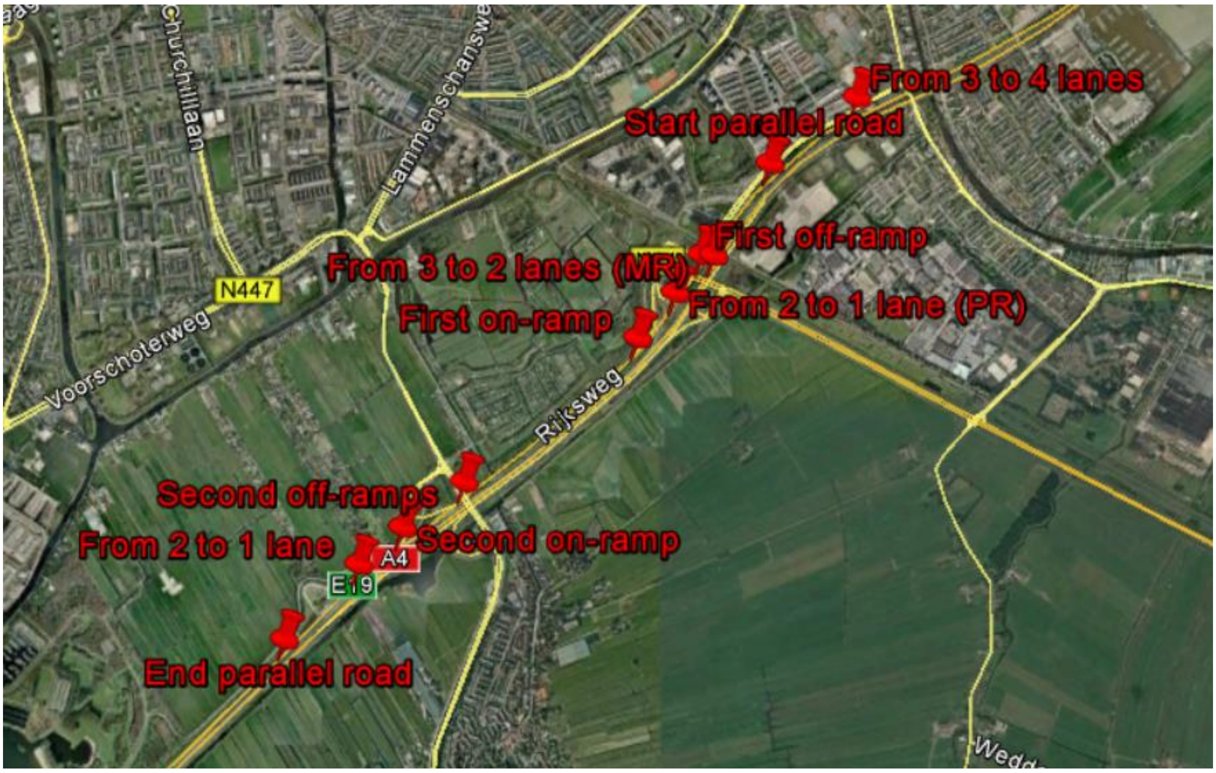
Figure 8-6. Contour plot for '0' traffic demand

100-0	# departed vehicles	# arrived vehicles	Total number of vehicles (demand)	Network part	Total distance travelled (veh*km)	Total time spent (veh*hrs)	Total delay (veh*hrs)	Average speed (km/hr)	Travel time (hour)		Distance travelled (km)	
									Car	Freight	Car	Freight
Base case	12161	12665	12161	Total	100045	2649	1867	38	2308	340	87579	12466
				1	98762	2632	1867	38				
				2	1282	16	0	80				
Extended	12160	12665	12160	Total	100045	898	59	111	763	135	87579	12466
				1	98762	882	59	112				
				2	1282	16	0	80				
Unb. (2-1)	12160	12675	12160	Total	100220	2651	1859	38	2311	340	87731	12489
				1	88412	2320	1650	38				
				2	11808	330	209	36				
Unb. (3-1)	12160	12673	12160	Total	100202	966	110	104	827	139	87715	12487
				1	89303	803	59	111				
				2	10899	164	51	67				
Unb. (2-2)	12160	12683	12160	Total	100346	926	56	108	791	136	87841	12505
				1	81854	732	50	112				
				2	18493	195	6	95				
Unb. (3-1) & shortcut	12160	12691	12160	Total	106098	1196	292	89	1032	164	93130	12967
				1	95233	992	198	96				
				2	10865	204	94	53				
10%												
Base case	13376	13932	13376	Total	110052	3652	3289	30	3181	471	96339	13713
				1	108641	3634	3289	30				
				2	1411	18	0	79				
Extended	13376	13932	13377	Total	110052	1207	284	91	1041	167	96339	13713
				1	108641	1190	284	91				
				2	1411	18	0	79				
Unb. (2-1)	13376	13942	13377	Total	110233	3485	3356	32	3040	445	96497	13737
				1	97463	3039	3039	32				
				2	12770	446	317	29				
Unb. (3-1)	13376	13940	13377	Total	110201	1299	362	85	1129	170	96469	13732
				1	99609	1077	247	92				
				2	10592	222	114	48				
Unb. (2-2)	13376	13951	13377	Total	110381	1257	300	88	1089	169	96625	13755
				1	90178	966	214	93				
				2	20203	292	86	69				
Unb. (3-1) & shortcut	13376	13960	13377	Total	116590	1961	984	59	1704	257	102341	14249
				1	105448	1710	846	62				
				2	11143	252	138	44				
20%												
Base case	14592	15198	14592	Total	120053	4502	5093	27	3923	579	105095	14959
				1	118515	4483	5093	26				
				2	1538	19	0	79				
Extended	14592	15198	14592	Total	120053	2104	1097	57	1831	273	105095	14959
				1	118515	2084	1097	57				
				2	1538	19	0	79				
Unb. (2-1)	14592	15209	14592	Total	120240	4303	5253	28	3756	547	105256	14983
				1	106391	3731	4742	29				
				2	13849	571	511	24				
Unb. (3-1)	14592	15207	14592	Total	120201	2036	1094	59	1780	255	105222	14978
				1	109674	1748	834	63				
				2	10526	288	260	37				
Unb. (2-2)	14592	15219	14592	Total	120415	2170	1126	55	2047	123	105409	15006
				1	98344	1673	853	59				
				2	22071	497	273	44				
Unb. (3-1) & shortcut	14592	15228	14592	Total	127139	2828	2019	45	2459	369	111601	15538
				1	115195	2539	1852	45				
				2	11945	289	167	41				

Table 8-11. Traffic flows for '0' traffic demand

RouteFlows (in veh/hr)										
Base case										
Route	1	2	3	4	5	6	7	8	9	10
1	6100	6710	6100	5795	4880	3965	2440	1220	1220	610
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Extended										
Route	1	2	3	4	5	6	7	8	9	10
1	6100	6710	6100	5795	4880	3965	2440	1220	1220	610
4	400	440	400	380	320	260	160	80	80	40
5	100	110	100	95	80	65	40	20	20	10
6	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-1										
Route	1	2	3	4	5	6	7	8	9	10
1	4936.069	6005.092	5187.936	4833.933	3896.302	3004.847	1743.083	921.064	778.076	384.487
2	1163.931	704.908	912.064	961.067	983.698	960.153	696.917	298.936	441.924	225.513
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 2-2										
Route	1	2	3	4	5	6	7	8	9	10
1	3687.365	4079.904	3718.8	3522.276	2980.553	2464.137	1555.77	760.348	760.34	380.289
2	2412.635	2630.096	2381.2	2272.724	1899.447	1500.863	884.23	459.652	459.66	229.711
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1										
Route	1	2	3	4	5	6	7	8	9	10
1	5179.703	6088.484	5533.086	5055.865	4024.541	2870.63	1622.319	778.389	778.303	384.642
2	920.297	621.516	566.914	739.135	855.459	1094.37	817.681	441.611	441.697	225.358
5	400	440	400	380	320	260	160	80	80	40
6	100	110	100	95	80	65	40	20	20	10
7	1000	1100	1000	950	800	650	400	200	200	100
Unbundled 3-1 + shortcut										
Route	1	2	3	4	5	6	7	8	9	10
1	4537.796	5266.426	4638.03	4475.091	3640.016	2578.347	1328.591	615.792	604.716	297.203
2	1010.224	971.149	982.346	887.144	811.052	814.253	639.83	345.998	352.059	178.846
3	551.98	472.425	479.623	432.765	428.932	572.4	471.579	258.21	263.225	133.951
6	371.135	419.108	380.231	359.787	300.03	228.308	133.206	65.454	65.338	32.631
7	28.865	20.892	19.769	20.213	19.97	31.692	26.794	14.546	14.662	7.369
8	100	110	100	95	80	65	40	20	20	10
9	1000	1100	1000	950	800	650	400	200	200	100

G. Actual network Leiden



H. Traffic flows A4

01-Sep	1	2	3	4	5	6	7	8
tijd	Totaal	A'dam-DH via HRB	A'dam-DH via PRB	A'dam-Rijndijk	A'dam-Dorp	Rijndijk-DH	Rijndijk-Dorp	Dorp-DH
0:00	660	473	22	0	58	28	32	47
0:15	643	487	12	0	53	8	40	43
0:30	639	490	15	19	57	12	20	27
0:45	560	460	9	23	11	4	16	37
1:00	443	337	12	13	25	8	12	37
1:15	388	293	13	8	25	20	8	20
1:30	323	250	11	0	26	12	4	20
1:45	363	283	12	0	27	8	16	17
2:00	410	373	2	0	17	8	0	10
2:15	359	293	0	15	9	4	8	30
2:30	260	200	8	7	19	12	8	7
2:45	367	300	9	0	12	28	8	10
3:00	350	267	7	0	45	0	8	23
3:15	437	367	0	4	26	20	4	17
3:30	360	297	9	0	21	8	12	13
3:45	306	250	1	3	9	12	4	27
4:00	390	303	17	0	6	16	4	43
4:15	428	330	0	15	32	20	8	23
4:30	526	367	0	25	25	44	12	53
4:45	650	480	19	0	37	28	20	67
5:00	778	523	14	51	11	56	32	90
5:15	872	590	24	32	21	76	36	93
5:30	1339	913	36	3	45	124	72	147
5:45	1582	1090	32	25	53	148	84	150
6:00	2644	1563	40	24	209	320	124	363
6:15	4305	2393	137	115	254	576	296	533
6:30	5599	3170	167	75	474	636	456	620
6:45	5888	3443	142	1	503	768	360	670
7:00	6802	4007	233	59	385	920	432	767
7:15	7619	4440	273	149	515	984	508	750
7:30	8294	4510	504	217	635	1076	568	783
7:45	7393	3697	382	273	575	1008	588	870
8:00	7662	4347	315	285	493	972	480	770
8:15	7151	3843	359	357	423	884	580	703
8:30	7172	3867	308	409	353	852	520	863
8:45	7419	3993	385	313	489	972	604	663
9:00	7308	4143	400	161	539	860	528	677
9:15	4674	2263	228	221	395	512	512	543
9:30	6293	3713	527	17	429	556	424	627
9:45	5817	3723	353	133	321	384	436	467
10:00	4958	3083	23	228	285	400	488	450
10:15	4721	2833	41	257	205	432	492	460
10:30	4805	2910	30	232	158	480	492	503
10:45	4180	2440	17	280	179	396	424	443
11:00	4214	2680	15	264	205	372	352	327
11:15	4402	2653	46	232	132	384	468	487
11:30	4641	2580	11	321	298	412	512	507
11:45	4680	2997	30	203	223	400	420	407
12:00	4941	2890	24	407	82	376	528	633
12:15	5345	3263	11	362	224	476	476	533
12:30	5248	3333	30	321	199	440	548	377

12:45	5183	3293	69	240	284	304	436	557
13:00	4935	2997	0	317	176	384	504	557
13:15	4850	3053	11	333	265	392	428	367
13:30	5265	3107	40	342	288	420	552	517
13:45	4756	2913	22	269	239	408	448	457
14:00	5265	3203	39	311	216	384	504	607
14:15	4996	2993	48	366	279	452	464	393
14:30	5566	3410	25	386	292	468	548	437
14:45	5729	3307	58	382	317	512	620	533
15:00	5825	3263	47	409	345	500	552	710
15:15	6281	3710	45	498	353	508	520	647
15:30	6887	4147	131	547	362	452	628	620
15:45	7534	4297	105	737	407	588	636	763
16:00	8032	4427	386	709	595	624	688	603
16:15	7835	4097	525	715	554	612	716	617
16:30	7949	4170	392	753	659	588	708	680
16:45	7850	4053	348	863	679	652	708	547
17:00	7934	3723	464	774	645	756	888	683
17:15	8328	3813	329	921	817	848	920	680
17:30	8071	3753	219	911	851	868	896	573
17:45	6529	2457	387	956	767	636	760	567
18:00	7759	3823	671	639	643	652	724	607
18:15	7208	3517	472	581	733	708	640	557
18:30	7157	3723	893	360	467	604	536	573
18:45	7427	4160	681	377	551	632	532	493
19:00	5404	3213	81	187	429	456	568	470
19:15	4411	2697	39	244	213	324	460	433
19:30	3641	2290	63	117	249	220	364	337
19:45	3539	2213	13	235	228	200	332	317
20:00	2913	1797	25	143	153	232	344	220
20:15	3053	1913	3	203	197	180	300	257
20:30	2729	1617	7	196	163	176	240	330
20:45	2635	1643	23	179	128	160	232	270
21:00	2372	1340	19	129	129	164	228	363
21:15	2305	1273	9	95	149	224	244	310
21:30	2635	1567	10	189	148	180	252	290
21:45	2315	1427	0	107	113	168	244	257
22:00	2146	1060	0	148	149	188	248	353
22:15	2213	1183	0	134	139	192	264	300
22:30	2067	1127	0	115	161	148	192	323
22:45	1925	1177	6	135	79	144	224	160
23:00	2012	1273	0	112	108	160	192	167
23:15	1827	1227	0	94	76	156	84	190
23:30	1164	753	15	37	58	72	112	117
23:45	1063	643	0	61	96	52	64	147

I. Investment costs A4 Leiden

	Actual length		Difference with actual case	
	Main carriageway	Parallel road	Main carriageway	Parallel road
Actual case	25 km	6.1 km	-	-
Base case	28 km	-	3 km	- 6.1 km
Extended	37 km	-	12 km	- 6.1 km
Unbundled 2-1	24 km	5.6 km	- 1 km	- 0.5 km
Unbundled 3-1	33 km	5.6 km	8 km	- 0.5 km
Unbundled 2-2	30 km	7.2 km	5 km	1.1 km
Unbundled 3-1 + shortcut	33 km	5.95 km	8 km	- 0.15 km

When there is a minus in front of the difference value, this means that the total length of the lanes is less than in the actual case.

An example, for the base case:

3 km * €777,000 + 6.1 km * €868,667 = €7,729,867.

Costs for adjustment to the actual case:

	Main carriageway	Parallel road	Total
Base case	€ 2,331,000	€ 5,298,867	€ 7,629,867
Extended	€ 9,324,000	€ 5,298,867	€ 14,622,867
Unb 2-1	€ -259,000	€ 434,333	€ 175,333
Unb 3-1	€ 6,216,000	€ 434,333	€ 6,650,333
Unb 2-2	€ 3,885,000	€ 2,866,600	€ 6,751,600
Unb 3-1 +	€ 6,216,000	€ 130,300	€ 6,346,300