Streetwise with road maintenance

Exploring various options to mitigate the effects of temporary closure of the Maastunnel in the city of Rotterdam

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Preface

In front of you is my thesis: Streetwise with road maintenance. This thesis is written to finalize my MSc in Business and Economics, specialization Urban, Port and Transport Economics at the Erasmus University Rotterdam. From September 2016 until May 2017 I have been working on this research and writing the thesis.

During this research my supervisor, Dr G. Mingardo, was flexible in making appointments, face-to-face as well as by phone, in order that I could combine my sports career with writing my thesis. He stood me by at any time to answer my questions and guide me through the research process. Therefore I could put all my energy in the quality of this process. Hereby I would like to thank my supervisor for the pleasant guidance and support during the process.

I would also like to thank the Verkeersonderneming for the supply of the research data. Without this data I would not be able to write my thesis.

My friends and family have been providing me advice and have been a moral support for me. At last I would like to thank my parents for all their wisdom and motivating words which enabled me to finish my thesis.

I hope that you enjoy reading this thesis!

Evelien Berndsen

Rotterdam, May 2017

Executive summary

The Maastunnel is an important connection between the north and the south of Rotterdam. From July 2017 onwards, the tunnel will be partially closed for motorized traffic for two years, due to renovation work. Severe traffic congestion is expected, especially during peak hours.

The aim of this thesis is to find out which routes are available for relevant alternative ways of travelling throughout the city other than using the car. The main research question is: *Which routes have the highest potential for modal split during the renovation of the Maastunnel?*

To answer the research question first a literature study is done. Also, an empirical research is done using an explorative research method. This research method is used to gain insight in and understanding of the current traffic situation in Rotterdam and more specifically the traffic situation around the Maastunnel.

The data concerns the locations of cameras that detect and register the licence plates of the cars driving through the city of Rotterdam and the registrations themselves. The data is organized in matrix tables where origins and destinations are combined. Three day parts have been distinguished: Throughout the whole day, morning peak and evening peak. For every day part the 25 routes with the highest number of cars have been examined for potential alternatives.

The research shows that only a few routes have potential to switch form modality, because the travel times deviate the least from the travel times by car. For all routes the travel times are higher using public transport than using the car, but the travelling costs are lower. For the water taxi it is the other way around. For the northern as well as the southern direction the most important period to develop policies for is the evening peak.

Suggestions are made to achieve a switch of mode of transportation. Further researchers could find out the impact of these suggestions and what is needed to make such a switch happen. The findings of this thesis could be used as basis for further research on reducing traffic congestion during the closure of the Maastunnel.

Content

1. Introduction

The city of Rotterdam is the industrial and logistic heart of The Netherlands. Mobility is a key enabler of economic growth. An effective mobility infrastructure is therefore key. Modifications or maintenance to this this infrastructure may have a big impact on the economic activities. This thesis assesses the impact of modifications and maintenance work on the Maastunnel, one of the main infrastructural facilities in the city centre of Rotterdam.

The city of Rotterdam is separated in two parts by the Maas river. The Maastunnel is one of the main connections between the northern and the southern part of Rotterdam. From July 2017 onwards, the Maastunnel will be partially closed for motorized traffic for two years, due to renovation work. One tunnel tube at a time will be dealt with, so the other tunnel tube will remain in operation for traffic. The open tunnel tube can only be used for traffic travelling from south to north. Reason for this is that it is of great importance that the Erasmus MC Hospital can always be reached in case of an emergency.

The municipality of Rotterdam is expecting severe congestion problems. The most serious problems are expected during peak hours. A lot of traffic wants to enter or leave the city simultaneously. Traffic that initially uses the Maastunnel to leave or enter the city will be diverted via other routes. These routes are not used to the extra traffic demand. The closure of the Maastunnel will affect the mobility in the city of Rotterdam and therefore might have an impact on the economic activities. The expected congestion could be a temporary barrier for economic growth. The city of Rotterdam has many other modes of transportation available for travelling throughout the city. The aim of this thesis is to find out for which routes there are relevant alternative ways of travelling throughout the city other than using the car. Travelling with other modes of transportation relieves the pressure on the road infrastructure and prevents severe congestion, in order to minimize the negative effects on economic growth.

The main research question is: *Which routes have the highest potential for modal split during the renovation of the Maastunnel?*

To be able to answer this research question, first a literature study will be executed to understand the use of an efficient transportation network and what factors affect its efficiency. Hereby traffic management in general and during maintenance are treated. Next an explorative research is done to discover which routes cause traffic congestion in Rotterdam and which routes are relevant for the use of alternative modes of transportation. A dataset with information about car flows in the city [detected by cameras] is used for the analysis. The relevance is determined by differences in travel times and travelling costs.

In the next chapter the theoretical framework will be presented, in which existing literature will be discussed concerning the use of a transportation network and explaining the concept of an O-D matrix. Subsequently the collected data and methodology for this research will be made clear. Then the results of this research are put together. First the results of the northern direction will be presented and after that the results of the southern direction. In the conclusion the research question will be answered and policy recommendations will done. Finally in the discussion limitations are discussed and recommendations will be done for further research.

2. Theoretical Framework

Horse-drawn vehicles were already used for centuries, but in the second half of the 19th century the first concepts of a motorized car were developed (SAHO, 2017). In the next 45 years these cars were further developed so that they could be considered as reasonable reliable means of transport. Cars became more and more part of the normal street scene (Buchanan, 2015)

Before World War II motorized vehicles were heavy, inefficient and cumbersome to use, but after World War II knowledge and technologies drove innovations that made cars more convenient and reliable (Eckermann, 2001). Cars became faster and more practical to use and gradually became a fierce competitor for the more inflexible railway transport. Until that period, transport by rail was the popular mode of transportation (Buchanan, 2015).

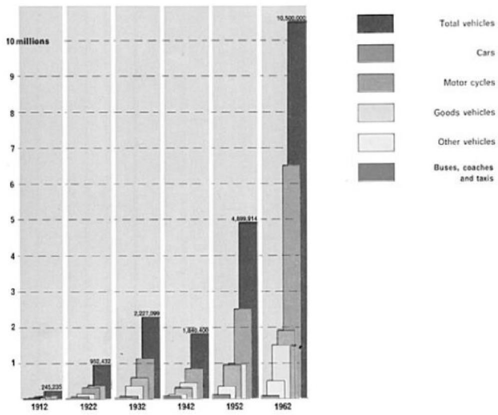

Figure 1: Growth number and type of motor vehicles in Great Britain between 1912 and 1962 (Buchanan, 2015)

During World War II a large number of men gained experience with car maintenance and management of motor transport fleets. After the war these men established garages and petrol stations or set up their own transport companies aimed at transporting goods and people. This caused a significant increase in the number of cars (see figure 1)(Buchanan, 2015). The growing number of cars increased the density on the roads, which were not laid out for such a volume of traffic, and the first congestion problems and traffic jams became a fact (Whitlock, 2017).

The strongest growth of motorized vehicles was caused by the transportation of goods (Hellinger & Mnich, 2009). Motor vehicles on the road had the flexibility to deliver goods from door-to-door where railway transportation does not have that capability. The construction of motorized vehicles became more and more purpose built for the function it had to fulfil. For example trucks for large loads that could not be transported by trains, refrigerated vans for fast transportation of refrigerated and/or perishable goods and busses for transportation of large groups of people (Buchanan, 2015).

Nowadays almost every person with a drivers licence has the availability of a car. Business and private life without a car is hardly imaginable. The ever increasing number of cars on the roads makes an efficient use of the road infrastructure and transportation network increasingly important.

2.1 Transportation network use

2.1.1 The realization of efficient transportation network use

Ortuzar & Willumsen (2001) present a model with the various steps that drives the capacity demand for the transportation network and road infrastructure. A travelling individual needs to make choices in four steps that will influence the traffic-flow load level of the transportation network. 'Traffic-flow load level' is determined by:

- who is travelling on the road,
- by when, and
- on which road.

The four steps an individual needs to make choices on according to Ortuzar and Willumsen are the following(see figure 2):

1. The first step is *trip generation*. An individual must decide to make a trip or not. He or she can determine whether or not it is necessary to make a trip. In some cases he/she can choose to cancel the trip or postpone it. For example, people decide to work from home for some time and commute later in the morning or afternoon.

2. The second step is *trip distribution*. The factor concerns the destination of the trip. For example when an individual needs to go to the grocery store, it can choose between several grocery stores or supermarkets. It then depends on the choice of the individual to which store it will go.

3. The third step is *modal split*. After an individual has chosen to make a trip and what its destination will be, the next step is to choose which mode of transportation will be used. Travelling by car means more traffic on the roads than when traveling by public transport as busses, trains and metros will ride anyway.

4. The last step is r*oute choice*. After the first three steps, only the route has to be chosen in order to know the traffic-flow load level, as there are several routes that could lead to the same destination.

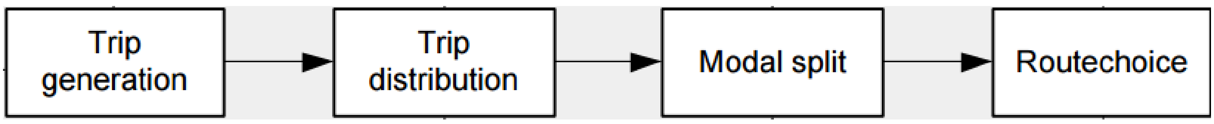

Figure 2: 4-step model to determine demand for transportation network (Ortuzar & Willumsen, 2001)

Patriksson (2015) supports the steps in this model, as he states that the trip generation, trip distribution and modal split are input factors how many traffic is on the roads. The route choice then completes the determination of the traffic load level as then is known how many traffic is on the road at the same time.

An application of the model of Ortuzar and Willumsen been executed by McNally (2007). He states that, given institutional requirements and financial limitations, this approach is effective to use in order to forecast traffic demand. A criticism on this model is that the approach is not activity-based, which would better represent underlying travel behaviour. Huerne et al. (2012) discussed the model and although the traditional model is used as framework for several systems, a criticism is that the model lacks realism in case of road works where also traffic management measures are implemented.

By knowing de traffic-flow load level, the routes that will be travelled are known, including the origins and destinations of the travellers. Also the number of travellers on the same road in the transportation network is known, so it is possible to assess the flow and intensity on the road.

The decisions that individuals make are affected by the capacity of a certain route (Hymel, Small & Van Dender, 2010). If the capacity of a specific part of the transportation network is low relative to the number of cars on that part, the average speed on that road will decrease. No doubt this phenomenon drives individuals to different decision making on one or more the four steps. A shortage of road capacity will lead to road congestion. Eventually an equilibrium will be reached when changing choices on these four steps would not lead to a time advantage.

The traditional model presented by Ortuzar and Willumsen (2001) is valid for normal and regular circumstances under the assumption that people make rational decisions. However, the situation may not be valid during abnormal circumstances and specific occasions such as road constructions. The reduction of the transportation network capacity during road construction but also mitigating actions to keep the traffic flowing smoothly could also influence the decisions of the travellers.

2.1.2 Causes of inefficient transportation network use

Although the model of Ortuzer & Willumsen gives us a clear insight/understanding on how a traveller plans his trip most time- efficiently, it does not give us insight or an explanation on how efficient the network itself is being used.

In his research, Tanis (2016) distinguished three main causes of inefficient use of transportation network supported by the following theories:

Firstly, he states that there is no specific owner for the problem of an inefficient transportation network. In other words, the damage that inefficient transport networks are inflicting on the society cannot be attributed to any single individual. Therefore there are no direct incentives for an individual to change it behaviour for the good of society. An individual would not make a small extra effort to his/her expense, e.g. travelling during off-peak hours if it only benefits the society and not themselves (Helbing et al., 2005). This problem is known as the 'Prisoner's dilemma'.

To drive people to change their behaviour it is necessary to make the problem theirs by re-distributing the cost incurred by the society directly to the individual. An incentive will then be created as everyone will bear the burden of the costs to society and it becomes more attractive to change behaviour as costs will decrease, not only for the society but also for the individual.

Secondly Tanis (2016) mentions in his research that inefficient use of the transportation network can be caused by the fact that people are not willing to take the risk by choosing a different route when it creates uncertainty. For example, using the car is perceived as more certain than using public transport, the uncertainty of public transport arriving on time is perceived considerable. Also taking an alternative route trying to avoid congestion presents a certain uncertainty. This problem can be explained by the prospect theory. The prospect theory states that people become risk-averse when the consequence of a decision is uncertain (Avineri & Boyy, 2008). The most certain option is the one that will be chosen, which causes people to stick to their standard behaviour irrationally long before choosing another alternative.

Providing information will increase the likelihood that people will assess other travelling options. If they know that a certain route is not congested during peak hours, this route will be seriously considered as an alternative for the usual route. Better informed people tend to make more efficient decisions taking into account all alternatives.

At last people are not easily convinced to change their habits. When an individual is used to take a specific route he or she will stick to this route. People are creatures of habit, and as such resistant to change (Berveling, Schaap & Storm, 2014). If they feel comfortable with their fixed travelling pattern they will not easily change. Therefore it is important to inform people in the right way and the right time using the appropriate media. In that way people can absorb the information and make a better informed decision.

2.1.3 Forms of inefficient transportation network use

Taking into account the above-mentioned causes of an inefficient transportation network, the assumption by Ortuzar and Willumsen that people take rational decisions in their 4-step model cannot be upheld. The irrational decisions that people make have consequences for the outcome of the traffic-flow load level and therefore can cause unnecessary congestion on the roads of a transportation network. Referring to the 4-step model of Ortuzar and Willumsen (2001) and the causes of inefficiencies of Tanis (2016), three forms of inefficiencies of the transportation network use can be identified. These inefficiencies occurring due to the irrational decisions can be expressed as follows:

Inefficiency regarding the time of the trip

People often decide to travel to work during peak hours while during off-peak hours the traffic load is low. This will cause capacity problems. During peak hours there will be insufficient capacity and during off-peak hours there will be overcapacity. It would be more efficient when the timing that people travel would be more spread out over the day. While this might be inefficient from an economic point of view, travels might be subject to constraints. For example people need to be at work at 9:00 am.

Inefficiency regarding the modal split

Travelling by car is popular under commuting travellers. The surplus of cars on the road with people who have the same origin and destination can create a shortage of capacity. The shortage of capacity can be reduced by using public transport, which could well be underutilised. Car pulling, i.e. sharing one car with people having the same origin and destination is another alternative to reduce the traffic load on the road. Also if the destination is not too far away, using a bicycle instead of a car can solve part of the capacity problem. This could offer a solution especially in city centres, where many traffic lights and crossings slows down cars more than bicycles, often resulting in similar travelling times. Extra benefit is that bicycles do not need parking spaces.

Inefficiency regarding the route choice

Some routes are always congested and people keep lining up in the same traffic jams every day. It can therefore be more efficient to choose a slightly longer route with overcapacity that is less congested and where traffic flows rather than using a route where there is traffic stagnation due to capacity constraints. Although the distance is longer, it will lead to shorter travel time.

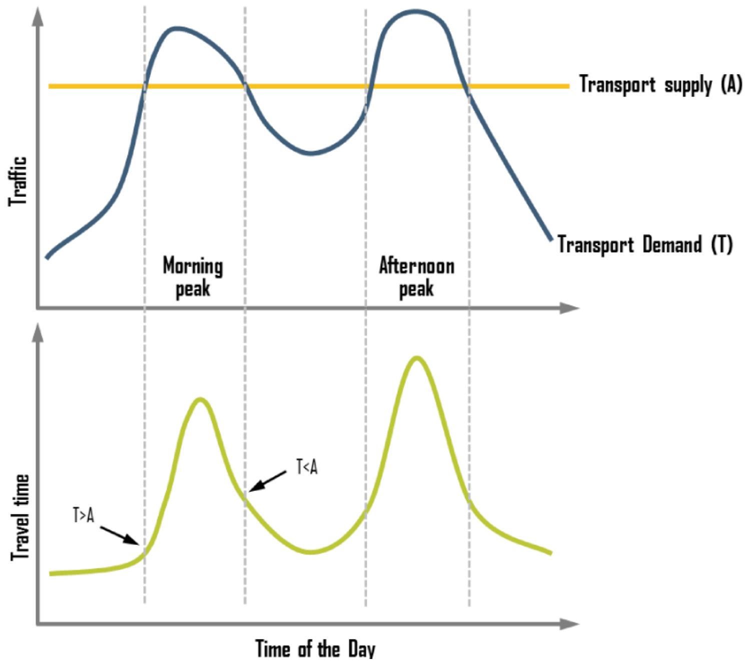

Figure 3: Daily transport supply and demand and related travel times (Rodrigue, 2013).

Figure 3 is an example of the previous mentioned inefficiencies. In this figure the demand and supply of transport is shown in relation to the timing of travel. On the one hand, transport supply or capacity is assumed to be stable throughout the day. However, the opening and closing of peak hour lanes throughout the day influence capacity on the short term. Also public transport might adjust its services/capacity during peak hours. It can add capacity by increasing the frequency of services in order to cope with peak hours. On the other hand, transport demand varies considerably, particularly in the morning and afternoon peak hours. These are commuting patterns that we see almost every week day. During these periods transport demand usually exceeds transport supply creating a situation of over under capacity. As a result congestion may occur, significantly increasing the travel time. Off-peak periods are characterized by overcapacity. The same trip can therefore take more time or less time depending on the timing in the day.

This inefficient use of the transportation network could therefore be caused by both the choice of an *inefficient timing* and the choice for an *inefficient mode of transportation*.

Inefficient timing because it can be expected that during off-peak hours there would be overcapacity on the road avoiding delays.

Inefficient mode of transportation because during peak hours alternative means of transport provide adequate capacity while the roads are more congested making travelling by car inefficient.

The higher the density of an urban region, the more congestion is expected (Cox & Consultancy, 2000). The use of other modes of transportation, such as public transport, are more recommended as this would lead to less cars and thus less congestion on the roads. An efficient distribution of the several available modes of transportation would lead to less congestion and smoother traffic flows.

It must mentioned that figure 3 is a simplified representation of reality as it is assumed that the transport supply remains stable across time although this is not always the case.

2.1.4 Effects of inefficient transportation network use

Inefficient use of the transportation network has consequences for the travelling people using this network. The degree of severe traffic congestion can have a huge impact on many aspects of people's lives such as career, personal life and even safety. The following four effects of congestion can be identified:

Delay

Congestions cause delays (Arnott, 2013). This is the effect that comes to mind first and that people experience most during congestion. When cars are stuck in traffic, it takes more time to reach the destination. Commuters arrive late at work in the morning or decide to go home early in the afternoon to de-stress from work.

People who are familiar with the route they have to travel and know the average travel time of the route at specific times of the day, often build in some extra travel time in order to arrive on time at their destination. This extra time is at the expense of leisure time or time for business. It also may result in a delay of goods delivery or loss of production. Also, when it appears that the roads are not congested for whatever reason people arrive at their destination earlier than planned. In these cases time is lost because the extra travel time was not needed.

Unnecessary fuel consumption and pollution

The congestion occurring due to inefficient use of the transportation network affects fuel consumption (De Vlieger, De Keukeleere & Kretzschmar, 2000). Starting and stopping in traffic jams demands extra consumption of fuel compared to driving the same route without congestion. The increase in fuel consumption is costing the driver extra money. Also, the increase in fuel consumption leads to higher emissions released by the vehicles that are stuck in the traffic jams. These emissions create air pollution that contributes to global warming.

Road rage

Congestion has an emotional impact on some drivers. Road rage is an undesired emotional frustration reaction to traffic jams caused by the perception that other drivers do not drive as fast as they should do. As a consequence tailgating, cutting in in front of someone, shouting, retaliatory traffic manoeuvres and not paying attention to traffic situations are often seen as acts of frustration (Hennessy & Wiesenthal, 1999). These acts are dangerous both for the offender and other road users. More accidents happen on congested roads, however the number of fatalities caused by these accidents are lower (Chang & Xiang, 2003). A reason for this may be the low speed that reduces the impact of an accident or car crash.

Emergency vehicles

An important mission for emergency vehicle drivers is to arrive safely and as quickly as possible at the location where help is needed. When minutes can make the difference between life and death, a quick response is vital. Congestion on the roads makes it more complicated for these people to reach the location quickly. The lack of space on congested roads and delays in travel time could be fatal for anybody that needs help urgently. To mitigate these risks sometimes emergency vehicles are equipped with devices allowing their drivers to influence traffic by changing traffic lights or other traffic management systems (Qin & Khan, 2012).

2.1.5 Measures to reduce traffic congestion

As mentioned before, one of the effects of congestion is delay. All economists know that time is money, so delays cause a loss of productivity and is costly. To reduce the loss of productivity and the associated cost, congestion must be tackled. Mostly the government is in a position to minimise or resolve congestion. The measures that a government can take can be identified in two types: hard measures and soft measures.

Hard measures that are taken to resolve mobility issues are investments in the capacity of a transportation network (Biggiero, 2014). With these measures the transportation network will be expanded allowing more vehicles to use the transportation network so that more people can travel through the transportation network simultaneously. In general, the required investments are relatively high. Examples of these measures are:

Additional road construction

Adding an extra lane on the highway or on roads in urban areas allows more vehicles to use these roads simultaneously. On the highway it is even possible to close off this lane during peak hours to avoid unnecessary wear and tear of the road surface. These lanes are so-called ‘peak hour lanes’.

Additional infrastructure public transport

Additional infrastructure capacity for public transport can be facilitated by building additional subway lines, buses or tram lines. It will increase both the capacity to transport more people but also increase the number of pick-up points and destination points.

Additional parking spaces

Increasing the number of available parking spaces in the city centre will allow more people to park their vehicles at their destination.

However, as the hard measures are relatively expensive, governments prefer to use soft measures first to increase the efficiency of the transportation network (Cairns et al., 2008).

Soft measures for resolving mobility issues are investments in the efficiency of a transportation network rather than expanding its capacity (Cairns et al., 2008). Soft measures will make the transportation network more efficient when applied in an effective way. The advantage of soft measures compared to hard measures is that the investments of soft measures are relatively low. Examples of soft measures are:

Providing information

Providing information is an important measure as it makes people aware of the various options available to make a trip. This could be information about congestion during peak hours, alternative non-congested routes, information on alternative modes of transport, such as public transport, etc. Information sharing can be a useful tool to trigger the thinking about many other alternatives.

Communication

It is not only the information itself that is important to make the transportation network more efficient, but how also this information is being communicated. People need to have easy access to the information. Not many people will actively acquire the information themselves, however, when presented to them they will make use of it. In other words, people are more likely to absorb information when it is communicated/presented to them directly.

Organization of (public) services

To create more efficiency in the transportation network, it is important to organize services more efficiently. Regarding public transport, people are more likely to make use of it when the connections from one mode to the other run smoothly. Also facilitating efficient change overs from car to public transport will boost the use of public transport. Park & Ride parking lots close to the mode of public transport are good examples that will improve the efficiency of the transportation network as a whole (Ferguson, 1990).

Tradeable network permits

To improve the efficiency of a transportation network, a system of tradeable network permits can be implemented for travelling busy routes during peak hours. Such a system implies that people have to pay to use a specific part of the transportation network. The maximum number of permits sets boundaries to the amount of traffic travelling at the same time. Tradeable network permits force people to change the travel period. People who need to travel specifically during peak hours can buy a permit (Akamatsu & Wada, 2017).

Congestion pricing

To reduce the amount of traffic during the peaks and therefore reduce traffic congestion, implementing congestion pricing can be a useful strategy. People travelling during the peaks have to pay a toll. The difference of this strategy compared to a tradeable network permit is that no maximum amount of traffic is permitted. Implementing congestion pricing can be an incentive for people to change mode of transportation and take the bus or bicycle to travel a specific route (Meyer, 1999).

Fuel tax

Implementing taxes on fuel will reduce the demand for fuel and therefore reduce the total traffic demand. Less traffic on the roads will create less congestion, especially during peak hours, and therefore a more efficient transportation network. This mechanism creates less demand throughout the whole day and does not deal with traffic congestion during peak in particular (Meyer, 1999).

Subsidizing

The government could consider to subsidize users of a transportation network when travelling during off-peak hours, when changing mode of transportation or when carpooling. Where congestion pricing and tradeable network permits are punishments to the users of a transportation network during peak hours, subsidizing users travelling during off-peak hours can be seen as a reward. People can actually earn money when switching travel period and therefore contribute to congestion reduction.

2.2 Temporary traffic arrangements during maintenance work on the transportation network

During maintenance work on the transportation network so called 'work zones' are created. A work zone is 'a spatial and temporal restriction on a roadway that negatively impacts the normal flow of traffic' (Karim & Adeli, 2003). During the maintenance work in work zones, mitigating actions can be taken in order to improve mobility and thus avoid severe traffic congestion. There are various options to mitigate congestion during maintenance work in work zones:

Providing signed alternative routes

Research on the effect of providing alternative routes by Chien and Zhao (2016) shows a decrease in traffic volume during peak hours when signed alternative routes are provided (see figure 4). A remarkable reduction can be seen in the number of cars flowing through a specific route under the normal condition compared to the same route under the work zone condition when signed alternative routes are provided. It must be taken into account that there is a risk that alternative routes might become congested as well due to the extra traffic that takes the alternative route responding to the signs provided.

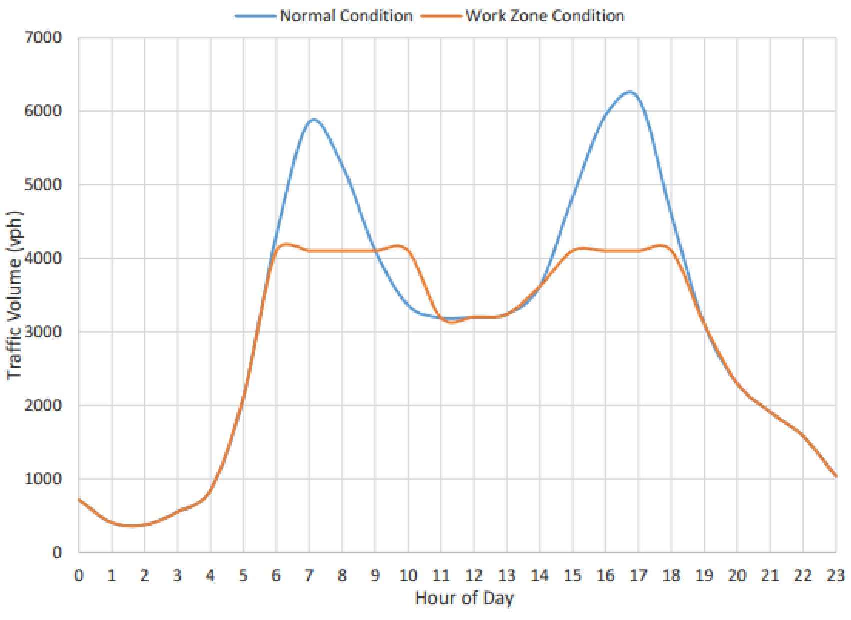

Figure 4: Traffic volume under normal and work conditions (Chien and Zhao, 2016)

Advanced roadside warnings

The smoothly running of the traffic during maintenance work can be boosted by placing warning signs with announcements of upcoming maintenance work (Karim & Adeli, 2003). People can anticipate on these warnings by planning their trip at a different time, either by bringing it forward or postponing it, or by changing the mode of transportation of the trip. By announcing in advance people have time to come up with a well-considered solution. Without announcing in advance people will be confronted with the maintenance work when it is too late to come up with a decent alternative solution.

Informative messages and updates on traffic conditions through the mass media

Mass media are very effective means to reach large groups of people. Through these mass media informative messages and updates on traffic conditions can be spread quickly. People can be kept up-to-date easily about delays or other changes in intended schedules. The quick spread of information allows people to anticipate quicker to the changed situation, which is beneficial to tackle congestion (Karim & Adeli, 2003).

Reducing speed limits in the work zone

A lower speed limit in work zones facilitates the insertion of traffic from one lane to another and therefore results in less braking and accelerating when reaching a work zone. This stimulates the flow of traffic and less congestion will occur (Li, 2002)(Atkins, 2009). The fact that reduced speeds limits stimulates the flow of traffic is shown in the following figure 5.

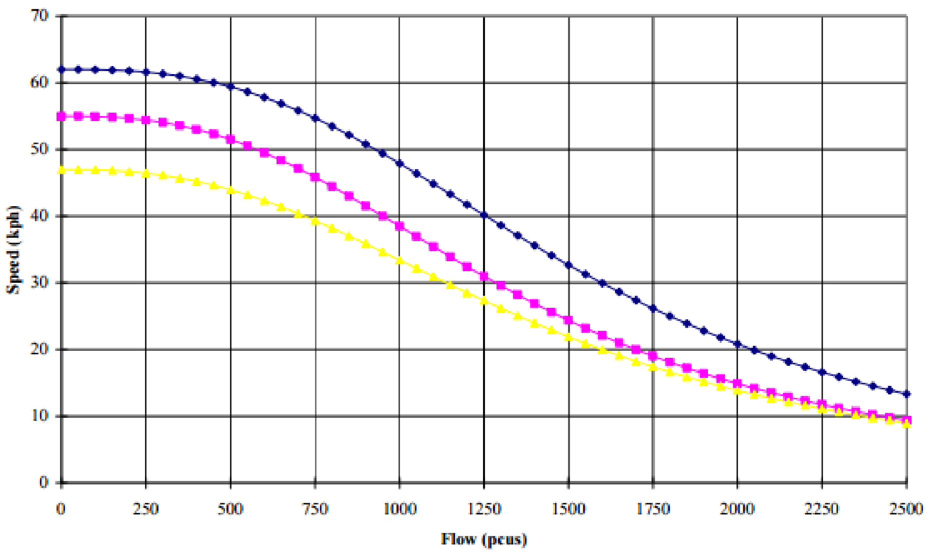

Figure 5: Relationship between speed and traffic flow in urban areas (Atkins, 2009)

This figure illustrates the relationship between speed and traffic flow in urban areas. Traffic flow is defined as the number of passenger cars passing on the road per hour. The relationship is negative, which means the lower the speed the more flow of traffic. The greatest effect is reducing medium speed. When the speed is high the increase in traffic flow is relatively low compared to a medium speed. Also the effect of low speed is also lower compared to medium speed. However, the relationship remains negative.

Note that the impact of these measures will depend on existing traffic flow characteristics in the transportation network, such as flow rate and driver behaviour. The provision of information and using the appropriate method of communication towards the users of the transportation network remains of paramount importance.

2.3 Origin-Destination matrix

In several sciences matrices are widespread tools to manipulate and use data. Matrices are tools used for several purposes. In linear algebra matrices can be used to describe linear transformations and in mechanical engineering matrices are used to describe mechanical stress and tensions. Another purpose of matrices is organizing data. This is the purpose used in this research and where will be elaborated on, specifically an origin-destination matrix.

2.3.1. Structure of an Origin-Destination matrix

An origin-destination matrix (O-D matrix) consists of a table with rows and columns. Matrix rows present input nodes and matrix columns present exit nodes of the monitored transportation network. Each cell in the O-D matrix represents a link between two nodes, where the corresponding cell value is the number of vehicles travelled over this link. Nodes are specified by rows and columns (Ramirez & Kovacic, 2013).

Below is an example of how an O-D matrix is structured. In figure 6, a transportation network is displayed. This network has four nodes. The matrix in figure 7 corresponds to this transportation network. In this case, every node is both an input node and exit node, where $m_{i,j}$ stands the number of vehicles travelling from input node *i* to exit node *j*. As every node is an input node as well as an exit node, the O-D matrix in figure 7 is not symmetrical. This means that the number in the cell from input node 3 to exit node 4 ($m_{3,4}$) differs from the number in the cell from input node 4 to exit node 3($m_{4,3}$). To calculate the total number of vehicles to or from a specific node, the values of all cells in the row or column that node represents should be added up.

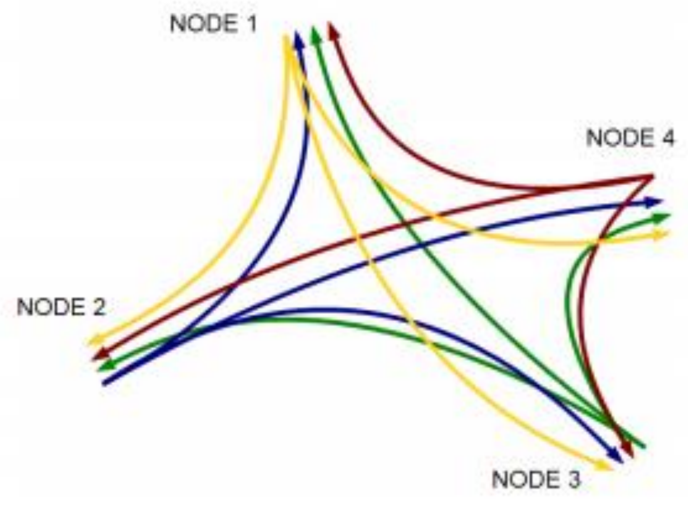

Figure 6: A transportation network with nodes and connections between nodes (Ramirez & Kovacic, 2013)

	$Node_1$	$Node_2$	$Node_3$	$Node_4$	
$Node_1$	m_{11}	m_{12}	m_{13}	m_{14}	$\sum_{j=0}^{4} m_{1,j}$
$Node_2$	m_{21}	m_{22}	m_{23}	m_{24}	$\sum_{j=0}^{4} m_{2,j}$
$Node_3$	m_{31}	m_{32}	m_{33}	m_{34}	$\sum_{j=0}^{4} m_{3,j}$
$Node_4$	m_{41}	m_{42}	m_{43}	m_{44}	$\sum_{j=0}^{4} m_{4j}$
	$\sum_{i=0}^{4} m_{i,1}$	$\sum_{i=0}^{4} m_{i,2}$	$\sum_{i=0}^{4} m_{i,3}$	$\sum_{i=0}^{4} m_{i,4}$	

Figure 7: O-D matrix of a four-node transportation network (Ramirez & Kovacic, 2013)

In this research regarding traffic flows from an origin to a destination, a node denotes the point where cameras are located in the transportation network that register license plates of passing vehicles. The registrations are logged. Every camera registers the obtained information in its own (local) database (see figure 8). The information in these local databases are aggregated in a large central database. With the collected information, the origins and destinations can be computed in this central database (Ramirez & Kovacic, 2013). More information about how this is done in this research will be provided in chapter 3.

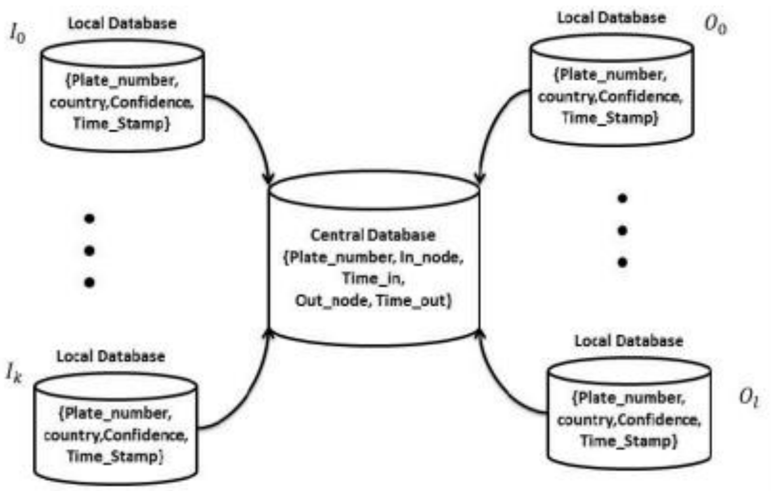

Figure 8: Logging of information acquired by license plate registering (Ramirez & Kovacic, 2013)

2.3.2 Obtainable information from license plate registration and O-D matrix

In section 2.3.1 is mentioned that it is necessary to obtain data in order to construct an O-D matrix and that this data can be obtained by registering license plates of vehicles. Various information elements are obtained by registering vehicle license plates:

Time of a vehicle passing a point where a camera is located

Direction in which the vehicle drives

Number of vehicles passing the registering camera

Type of vehicle

It could be the case that not all information is available for research due to privacy reasons. However, when license plates are encrypted it is still possible to determine the time of a vehicle passing a point where a camera is located. Also information concerning the direction in which the vehicle drives and the number of vehicles passing the registering camera can be obtained. Information concerning the type of vehicle is not possible to receive with encrypted licence plates.

With the information elements mentioned above, it is possible to compute the determine origins and destinations for the registered vehicles in the central database. These origins and destinations can be entered in the cells of the corresponding route in the O-D matrix. From an O-D matrix several information elements can be withdrawn:

Location a vehicle was registered for the first time

Location a vehicle was registered for the last time

Number of vehicles that was registered for the first time at a certain location

Number of vehicles that was registered for the last time at a certain location

With this information traffic flows can be determined from one place to another and so the density of traffic can be measured. Also it is possible to discover on which routes of the transportation network the quantity of vehicles is the greatest and where a change in mode of transportation could have a relatively high impact.

2.3.3 Unobtainable information from license plate registration and O-D matrix

We have seen which information is obtainable using license plate registration and O-D matrices. However, there is also a lot of information that cannot be obtained by these methods. Nevertheless the factors concerning the unobtainable information could be of influence on the amount of congestion that occurs in the transportation network. Therefore it is relevant to understand what these factors are. Some of the relevant factors are listed below:

The exact route that a vehicle took

What is certain is that a vehicle is first registered at the origin and is last registered at the destination. The exact starting point of the trip is unknown as well as its exact destination. We only know where the vehicle is registered for the first time and the last time. What occurred between the origin and destination is also unknown. When a vehicle does not take the shortest route possible but takes a detour, it could lead to unnecessary use of the available road capacity.

The purpose of the trip

Determining the purpose is of the trip is impossible using these methods as these methods are not able to distinguish commuting traffic from other traffic. It could be valuable to know the purpose of the trip. Commuting traffic usually will be driving the same route every work day. Other traffic could be driving at a specific route occasionally.

The continuality of the trip

Whether the vehicle is driving continuously or not could be of interest when making an attempt to search for the root cause of congestion. The time when a driver leaves its origin and arrives at its destination is the actual travel time when a driver travels from origin to destination continuously. This is not case when the driver stopped for other occasions, such as making a phone call, fuelling his petrol tank, posting a letter or delivering goods. The driver could have had a shorter travel time from the origin to the destination than the time that is registered. This could affect expected travel times.

The amount of people transported

With the used methods obtaining information it is not possible to determine the number of people transported within a vehicle. A vehicle can be transporting only the driver, which means only one person is transported. It could also be the case that a vehicle is full of people being transported from one location to another. Knowing the amount of people in a vehicle could be beneficial when suggesting alternatives.

The driver's driving style

Differences in driving style appeals for adaptability of drivers. A person with an aggressive driving style could easily get frustrated by drivers with a cautious style of driving. An aggressive driving style causes a higher risk of creating accidents. Accidents will affect the severity of congestion.

Driving speed of the vehicle

Driving speed of a vehicle determines the travel time a trip takes. The higher the speed the less time it takes to make a trip. However, the flow of traffic will be smoother when the speed is lower. In peak periods it would be more rational to drive at lower speed in order to stimulate the traffic flow.

3. Data & Methodology

For this research an explorative research method is used. An explorative research intends to explore a situation and the problems that it entails (Research Methodology, 2017). This research method helps to have a better understanding of the situation, not to offer final and conclusive solutions. It is the initial research that forms the basis of more conclusive research. This method is appropriate to gain insight in and understanding of new situations on which no or very little previous research has been done. This research is done to gain insight in and understanding of the current traffic situation in Rotterdam and more specifically the traffic situation around the Maastunnel. Having a clear understanding of the current situation is necessary to be able to understand what will happen when the Maastunnel closes and whether other modes of transportation can be seen as an realistic alternative for using the car to travel through the Maastunnel.

The city of Rotterdam is separated in two parts by the Maas river. The Maastunnel is one of the main connections between the northern and the southern part of Rotterdam. Nowadays more than 60.000 cars drivers, 7000 cyclists and hundreds of pedestrians use the tunnel. It has a length of 1710 metres, of which 584 metres really cross the river. In 2012 the Maastunnel even became a national monument. The tunnel is located in the centre of the city and connects the northern part of the city with the southern part (see figure 9).

Figure 9: Location of the Maastunnel in the city of Rotterdam (Google Maps)

3.1 Data

3.1.1 Collection of data

The data for the empirical part of this research has been obtained from the 'Verkeersonderneming'. The 'Verkeersonderneming' is a public-private partnership consisting of the municipality of Rotterdam, Metropole region Rotterdam/The Hague, the ministry of Infrastructure, Rijkswaterstaat and Havenbedrijf Rotterdam. The aim of the partnership is to jointly develop policies to improve and optimize the infrastructure for the Rotterdam region and reduce congestion (Verkeersonderneming, 2017).

The data concerns the locations of cameras that detect and register the licence plates of the cars driving through the city of Rotterdam and the registrations themselves. In figure 10 the locations of the cameras registering licence plates of passing vehicles are located.

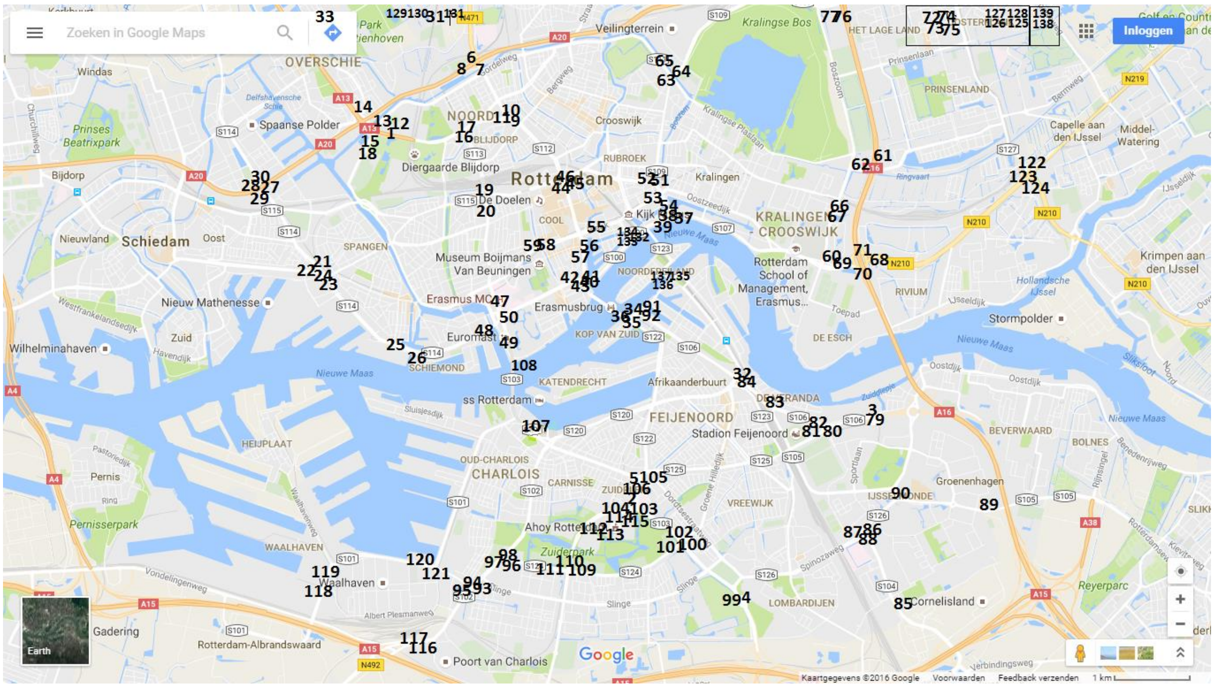

Figure 10: The locations of the cameras registering licence plates of passing vehicles (Google Maps)

Detection is done by registering licence plates of cars by cameras located throughout the whole city for the period from the 1st of January 2015 to the 29th of January 2015. A car is detected when it drives past a location where a camera is located. For privacy reasons, the licence plates are encrypted and cannot be identified. The locations of the cameras are given by GPS-coordinates, the name of the crossing and the street where a camera is located and the direction the camera points to.

For this research it is necessary to discover the routes cars have travelled. The origin is where a route started and the destination is the end of a route. The routes travelled can be determined by knowing its origin and destination. Since it is not known where the exact location is that a car has its origin, the first time a car is registered by a camera can be seen as the origin. Likewise, the last time a car is registered by a camera can be seen as its destination. Connecting these two locations will result in a route. Assuming a driver takes the shortest route, we now know the routes travelled and it is possible to use these for the research. So in the data the route is noted by a origin location and an destination location.

This research focuses only on the citizens of the city of Rotterdam. The registrations by cameras at the edge of the city have therefore not been taken into account. If these would be taken into account it is unsure that the real origins and destinations is in the city of Rotterdam. A car that is registered by a camera at the edge of the city, either for the first or the last time, could indeed have its origin or destination near the specific camera location. However, theoretically it could have its origin or destination anywhere outside the city, whether it is a nearby village or some place at the other side of the country. The only information you can extract from the registrations by the cameras located at the edge of the city is that it is the first or last time the car is detected by a camera in the city. It is unknown where the trip really started.

3.1.2 Storage of data

The registrations are collected and stored in Excel files containing the origin and destination of a car. Also the date, day and time period a car is detected by a camera is registered. Finally the number of cars that have matching origin and destination and are detected in the same time period are summed up.

> In the data, ‘Origin’ is recorded as a camera number. The number that will be recorded is the number of the camera that detects a specific car for the first time in a specific time period. With this information, we can observe where a car entered the city and we can see the location of this camera as the location where the trip through the city of Rotterdam started.
> ‘Destination’ is also recorded as a camera number. The number that is recorded belongs to the camera that detects a specific car for the last time in a specific time period. We can see the location of the camera that detects this car for the last time as the location where the specific car leaves the city of Rotterdam and thus as the location where the trip has ended.

‘Date’ indicates the date the registration of a specific car has taken place. The registration of the date a car is detected is done as follows: First the day is noted, next the month and finally the year. For example the 12th of January 2015 is noted as 12-1-2015.

With ‘Day’ is meant which day of the week a route has been travelled. The day is recorded as a number from 1 to 7 and this represents the days Monday to Sunday. For example, 2 represents the second day of the week, which is Tuesday.

‘Time period’ indicates in which time period the route has been travelled. A day is divided in five time periods: Morning rush hour, Off peak hours, Evening rush hour, Daytime and the rest of the day. Rest of the day only applies to weekend days. In table 1 the abbreviations used in the data and the time definitions of the various day parts are displayed.

Time Period	Abbreviation	Time of the day
Morning rush hour	OS	6:00-10:00
Off peak hours	Dal	10:00-15:00
Evening rush hour	AS	15:00-19:00
Daytime (weekends only)	Dag	6:00-19:00
Rest of the day	Rest	0:00-6:00 and 19:00-24:00

Table 1: Abbreviations and time definitions of various day parts

‘Number’ indicates the number of cars with similarity of the above mentioned variables. So they have the same origin and destination and travelled on the same date and day during the same time period.

3.1.3 Organizing data in matrix tables

To clarify the data all registrations are organized in matrix tables. The camera numbers at the edges of the city are omitted from the dataset and the remaining data is organized in the matrix tables. Organizing the remaining data is done by putting the remaining camera numbers on the horizontal and vertical axes (so omitting the cameras located at the edge of the city) and entering in every box the number of cars that travel the same route during the same time period. Then each box in the matrix table represents a certain route.

To sort the number of cars from every origin to every destination, the pivot table tool in Excel is used. This provides the opportunity to easily find the total number of cars travelling from a certain origin to all destinations in separate cells.

A remarkable detail of the matrix tables is that the closer the beginning and end of a route is to the Maastunnel, the more cars travel these specific routes. This could be caused by the fact that the data only consists of the routes that lead through the Maastunnel. The further away a camera is, the less likely it is that the car that passes that camera will drive through the Maastunnel.

3.2 Methodology

3.2.1 Relevant routes to find alternatives for

It is necessary to find out which routes are relevant to find alternatives for. For this research it is irrelevant and too time consuming to examine all the routes that are brought together in matrix tables. When many people use a route it is simple to cause congestion. As more people will be involved in this situation than in a situation where less people use a route. Finding alternatives for these busy routes will be beneficial for more people and thus more relevant for this research. Therefore the focus is on the busiest 25 routes of each matrix. These routes are found by using the 'conditional formatting' tool in Excel and applying the rule type: 'Format only top or bottom ranked values'. When 'top' and '25' are filled in, the top 25 busiest routes per matrix are found. These are the relevant routes for this research.

As mentioned above, it is assumed that the bicycle is a good alternative for the routes that are shorter than four kilometres. As riding a bicycle is free and the travel times from door-to-door do not deviate a lot for routes up this length. The Municipality of Rotterdam and Rijkswaterstaat should make an effort to provide information to people travelling these short routes every day by car. Certainly during the renovation of the Maastunnel it is important that these people change their mode of transportation to minimize congestion during peak hours. For these people it could also be satisfactory to stick to their ´new´ mode of transportation after the renovation is finished. To achieve this, it is of great importance to provide the correct information in the correct way. The routes that are shorter than four kilometres can be omitted from the busiest 25 routes.

The shortest ten routes of all the busiest routes are researched to find out how many people travel these routes and the size of the share these routes have relative to the average number of travellers of the routes.

3.2.2 Modes of transportation used in research as alternative modes

A mode of transportation can be seen as an appropriate alternative for the car when it can be easily used in a dense area such as a city centre. The modes of transportation that are used in this research a alternative are : the bicycle, public transport and the water taxi.

The bicycle can be used as an appropriate alternative mode of transportation because the city centre of Rotterdam is suitable for cyclists since the road system is equipped for cyclists with cycling trails along almost every street, traffic lights and storages for bicycles.

The public transport can serve as an appropriate alternative mode of transportation. The city has an extensive public transportation network, with buses, trams and subways that can carry many people at the same time to various places throughout the city centre and outside.

The water taxi is an ideal mode of transportation as alternative for the car to transport people from one place to the other when the origin and destination the route are close to the Maas river. Without traffic lights and congested streets, the water taxi deliver people at their destination manoeuvring across the Maas river between the ships that enter and exit the port of Rotterdam.

3.2.3 Distance and travel times per mode of transportation

For each route the distance and travel times are looked up. Knowing the distances and travel times gives insight in the actual situation on the roads and it makes it possible to compare this initial situation with situations when there is congestion due to road constructions.

In order to determine the distance and travel times under normal conditions by car and public transport for each route, the travel directions of Google Maps is used. With Google Maps it is possible to enter the GPS Coordinates of the camera locations that are provided in the data from the 'Verkeersonderneming'. As Google Maps provides multiple possible routes, it is assumed that the car followed de fastest route possible. For each route provided the distance and travel time is mentioned. For the distance and travel times by car the tab 'Driving' is used and for the distance and travel times by Public Transport the tab 'Transit' is used.

Car

The travel times by car during peak hours deviate from the travel times under normal conditions. The congestion during peak hours causes delay and therefore travel times will be longer. The increase in travel time compared to the normal condition is higher during the evening rush hour than during the morning rush hour. The increase in travel time during peak hours increases the travel time with a daily average of 19% (AD, 2017). The increase in travel times by car are displayed in table 2.

Additional travel time	Percentages
Daily average	19%
Morning rush hour	27%
Evening rush hour	32%

Table 2: Increase in travel times by car (AD,2017)

Public transport

Metros and trams have their own space on the road and are not hindered by other users of the transportation network. On busy routes, buses often have bus lanes where they can drive without being hindered by other traffic. However, sometimes buses are also stuck in the traffic just like car users. In this research the travel times by public transport during peak hours are assumed to stay equal.

Water taxi

For a very few routes the water taxi can be considered as an alternative for the car. The water taxis of Rotterdam can transfer people from one location to another via the Maas river, that flows through the centre of the city of Rotterdam. Watertaxi Rotterdam has about 50 landing stages where people can embark and disembark. The locations of the landing stages are divided in three zones: West, Centrum and Oost (see figure 11). The landing stages that are located in the western part of the city belong to the West zone, the landing stages that are located in the centre of the city belong to the Centrum zone and the landing stages that are located in the eastern part of the city belong to the Oost zone.

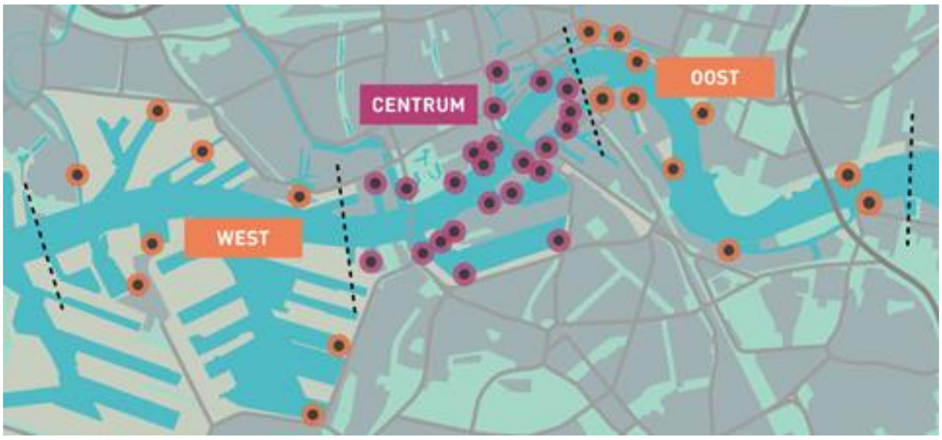

Figure 11: Landing stages of water taxis in the city of Rotterdam per zone (Watertaxi Rotterdam, 2017)

The travel times of the water taxi are obtained from the website of Watertaxi Rotterdam. Since the river is broad a lot of space is available for the water taxis to navigate from one location to another. It is therefore assumed that the travel times during peak hours are equal to the travel times during off-peak hours.

3.2.4 Travelling costs per mode of transportation

Car

The costs per kilometre of travelling by car are obtained from the ANWB website. On this website the ANWB distinguishes three categories of cars depending on size: small cars, small middle class cars and normal middle class cars. Each category has a different cost per kilometre. To determine an average cost per kilometre for all cars, the average of the different costs of each category is computed. The costs per kilometre per category and the average cost per kilometre are displayed in table 3. The actual costs of travelling by car are different for each individual and depends on the type of car, the type of fuel the car consumes and the driving style of the driver. However, it is for this research impossible to compute the actual costs per kilometre for each individual separately.

Type of car	Costs (per km)
Small car	€ 0,31
Medium car	€ 0,43
Large car	€ 0,49
Average costs of car	€ 0,41

Table 3: Travelling costs per kilometre by car (ANWB, 2017)

Public transport

The costs of travelling by public transport are obtained from the site of the RET, the main public transport operator in the city of Rotterdam. The costs of public transport consists of two parts: a basic fare and a kilometre fare. Every individual that uses the public transport pays the basic fare regardless of where the destination of the individual is. Additionally, a cost per kilometre is paid. The further an individual is travelling, the higher the total costs of travelling will be. The costs of travelling by public transport are displayed in table 4.

Travelling cost	Costs
Basic fare	€ 0,89
Kilometre fare Rotterdam metropolitan area	€ 0,137

Table 4: Travelling costs of public transport (RET, 2017)

Water taxi

The costs of travelling by water taxi are also obtained from the website of Watertaxi Rotterdam. The costs of travelling by water taxi depend on the locations of the landing stages where the water taxi departs and where it arrives. The fares are determined by the zones the origin and destination of the trip are (see table 5).

	Travelling costs water taxi Rotterdam (per zone)		
	West	**Centrum**	**Oost**
1 zone	€ 5,50	€ 4,50	€ 5,50
2 zones	€ 7,00		€ 7,00
3 zones	€ 10		

Table 5: Travelling costs per zone by water taxi (Watertaxi Rotterdam, 2017)

3.2.5 Route occupancy

The occupancy of the route during the peaks is calculated as a percentage of the route occupancy per day. The occupancy of a route per day is the total amount of cars that travel a specific route during a day. The occupancy of a route during the peaks is only the amount of cars that travel the specific route during a peak hour time period. The percentage of occupancy during the peaks is calculated by dividing the amount of cars that travelled a specific route during the peak hours by the total amount of cars that travelled the specific route on a certain day.

A distinction is made between a day of 24 hours and a day of 18 hours. A natural day has 24 hours. However, at night between 00:00 'o clock and 6:00 'o clock hardly any traffic is on the road and comparing the occupancy with a 18-hour day gives a better representation of the actual situation. In table 6 the critical values are displayed of the route occupancy during the peaks.

Length of Peak (hours)	Length of day (hours)	% peak hours of hours day
4	18	22%
4	24	17%

Table 6: Critical values road occupancy during peaks

The critical values are calculated by dividing the length of the peak in hours by the length of a day in hours. For an 18 hour day the average route occupancy during four hours is 22% of the total route occupancy during a day. This means that a route occupancy above 22% during a peak shows that the route is higher occupied than on average. For a 24 hour day the average route occupancy during four hours is 17% of the total route occupancy during a day. This means that a route occupancy above 17% during a peak shows that the route is more occupied than on average.

Now we know the relevant routes for this research, how the distances and travel times are obtained and the how the travelling costs of using each mode of transportation are calculated. With this information we can find for each route whether switching mode of transportation can be seen as a realistic alternative for using the car.

4. Empirical results for northern direction

In this chapter the results of this research are put forward of the routes for the traffic in the northern direction. A direction is separated in three parts: Throughout the whole day, morning peak and evening peak. Each part has different routes that are the busiest, as some routes are busy during the morning peak, while they are calm during the evening peak. For each part some routes are omitted from the 25 busiest routes: these routes are those that could be taken by bicycle because they are shorter than four kilometres. For the remaining routes the travel times, travelling costs and route occupancy are computed.

4.1 Travel times

The travel times per mode of transportation of the busiest routes are computed. First the travel times by car are computed, then the travel times by public transport and finally the travel times by water taxi. After the computation of the travel times of the several modes of transportation, these travel times will be compared with each other by means of ratios.

4.1.1 Throughout the whole day

4.1.1.1 Travel times per mode of transportation

Car

First the travel times by car throughout the whole day are calculated. To calculate the average travel times throughout the whole day, the additional travel time of 19% is added to the off peak travel times. The addition of this extra travel time creates a more realistic idea of these values for an average throughout the whole day. The travel times per kilometre are calculated by dividing the travel time of a route by the distance of that route. For example, if it takes 11,9 minutes to travel a route of 4,8 kilometres, dividing 11,9 by 4,8 gives a travel time of 2,05 minutes per kilometre. The distances and travel times of the busiest routes by car throughout the whole day can be seen in table 7.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
5	17	4,8	11,9	2,05
5	19	5,9	10,7	2,19
5	108	4,8	13,1	2,22
49	47	6,2	9,5	2,03
93	47	5,2	8,3	1,89
98	108	5,7	14,3	2,34
102	47	4,6	9,5	2,07
102	50	5,1	10,7	2,43
102	108	4,7	15,5	2,24
108	17	4,7	9,5	2,27
108	21	4,2	11,9	2,38
108	22	4,2	11,9	2,33
108	107	5	8,3	2,03
111	47	4,9	9,5	2,07
111	108	7,4	16,7	2,41

Table 7: The distances and travel times by car throughout the whole day

The average travel time per kilometre by car of the busiest routes throughout the whole day is 2,20 minutes, which means that travelling one kilometre will take 2 minutes and 12 seconds on average. Looking at the minutes per kilometre column, no abnormal values can be observed. All values of the travel times per minute are close to the average.

Public transport

For public transport the distances and travel times throughout the whole day of the alternative routes are computed and displayed in table 8. The distances in the table are the distances of the original route that would be taken by car. This is not really the case, as the distance of the route with public transport is longer than the route by car. Using the distances of the routes by car enables a good comparison of the travel times by public transport with the travel times by car. The travel times per kilometre are calculated in a similar way as the for the car, by dividing the travel time of a route by the distance of the route travelled by car.

As can been seen in table 8, not every route has an alternative route by public transport. The fact that there is no alternative route by public transport means that it takes more time to travel from origin to destination by public transport than by foot.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
5	17	5,8	21	3,62
5	19	4,9	26	5,31
5	108	5,9	-	-
49	47	4,7	15	**3,19**
93	47	4,4	34	7,73
98	108	6,1	20	3,28
102	47	4,6	22	4,78
102	50	4,4	30	6,82
102	108	6,9	23	3,33
108	17	4,2	36	**8,57**
108	21	5	31	6,20
108	22	5,1	33	6,47
108	107	4,1	-	-
111	47	4,6	30	6,52
111	108	6,9	25	3,62

Table 8: The distances and travel times of the alternative routes by public transport throughout the whole day

The average travel time per kilometre by public transport throughout the whole day is 5,43 minutes, which means it takes on average 5 minutes and 26 seconds on average to travel a kilometre by public transport. It can be observed that the values per route fluctuate a lot. The longest travel time per kilometre is 8,57 minutes and the shortest 3,19 minutes.

Water taxi

No alternative routes have been found for the water taxi to replace the car as mode of transportation. Therefore it is not possible to compute travel times for this mode of transportation.

4.1.1.2. Comparing the travel times of the several modes of transportation

Now the travel times per kilometre throughout the whole day for each mode of transportation are known, it is possible to compare them with each other. The travel times are compared using ratios. A ratio is calculated by dividing the travel time by public transport by the travel time by car. A ratio of 176% is achieved by dividing 3,62 by 2,05. The value of 176% means that the travel time of travelling the route by public transport costs 176% of the time that it costs to travel the same route by car. The travel time is thus increased with 76%. The results of the comparison of the travel times by public transport and car are displayed in table 9.

Origin	Destination	Travel time per km by public transport (min)	Travel time per km by car (min)	Ratio
5	17	3,62	2,05	176%
5	19	5,31	2,19	243%
5	108	-	2,22	-
49	47	3,19	2,03	158%
93	47	7,73	1,89	**408%**
98	108	3,28	2,34	**140%**
102	47	4,78	2,07	231%
102	50	6,82	2,43	280%
102	108	3,33	2,24	149%
108	17	8,57	2,27	378%
108	21	6,20	2,38	261%
108	22	6,47	2,33	277%
108	107	-	2,03	-
111	47	6,52	2,07	315%
111	108	3,62	2,41	150%

Table 9: Comparison of travel times per km throughout the day by public transport and car

It is remarkable that all alternative routes by public transport take more time to travel than the routes by car, varying from an increase to 140% of the travel time by car to an increase to even over 400% of the travel time by car. The average ratio is 244%, which means that on average the travel times when travelling by public transport increase to 244% of the travel times when travelling by car.

The more time it costs to travel the route, the lower the willingness for people to change their mode of transportation. Throughout the whole day travelling by public transport costs more time than travelling by car. Looking only to the travel times and assuming people makes rational choices, it will be the case that no change will occur in the mode of transportation people use and all people will keep travelling by the car.

4.1.2 Morning peak

4.1.2.1 Travel times per mode of transportation

Car

The travel times by car of the busiest routes during the morning peak are calculated. To calculate the average travel times during the morning peak, the additional travel time of 27% is added to the off peak travel times. The distances and travel times by car during the morning peak can be seen in table 10.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
2	108	6,1	15,2	2,50
5	17	5,8	14,0	2,41
5	108	5,7	14,0	2,45
98	17	6,2	15,2	2,46
98	108	6,1	15,2	2,50
102	47	4,6	10,2	2,21
102	50	4,4	10,2	2,31
102	108	6,9	16,5	2,39
108	17	4,2	14,0	**3,33**
108	21	5	12,7	2,54
108	22	5,1	12,7	2,49
108	37	4,4	11,4	2,60
108	107	4,1	8,9	2,17
110	47	5,2	12,7	2,44
111	47	4,6	10,2	2,21
111	108	6,9	17,8	2,58

Table 10: The distances and travel times by car during morning peak

The average travel time per kilometre by car during the morning peak is 2,47 minutes, which means it takes 2 minutes and 28 seconds on average to travel one kilometre by car. A remarkable value is the route where it takes 3,33 minutes to travel one kilometre, which means it takes almost one minute extra to travel one kilometre.

Public transport

The travel times of the alternative routes by public transport during the morning peak are computed and displayed in table 11.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
2	108	6,1	25	4,10
5	17	5,8	21	3,62
5	108	5,7	-	-
98	17	6,2	34	5,48
98	108	6,1	24	3,93
102	47	4,6	25	5,43
102	50	4,4	29	6,59
102	108	6,9	23	**3,33**
108	17	4,2	34	**8,10**
108	21	5	32	6,40
108	22	5,1	34	6,67
108	37	4,4	35	7,95
108	107	4,1	-	-
110	47	5,2	29	5,58
111	47	4,6	29	6,30
111	108	6,9	32	4,64

Table 11: The distances and travel times of the alternative routes by public transport during morning peak

The average travel time per kilometre by public transport during the morning peak is 5,58 minutes, which means it takes 5 minutes and 35 seconds on average to travel one kilometre. Observing table 11, with a highest value of 8,10 minutes per kilometre and a lowest value of 3,33 minutes per kilometre, it can be seen that the travel times per kilometre fluctuate upwards as well as downwards.

Water taxi

The water taxi can be an alternative mode of transportation for one route. Its travel time is displayed in table 12. The travel time per kilometre is calculated similarly as the travel times per kilometre by car and public transport, by dividing the travel time of a route by the distance of that same route.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
108	37	4,4	10	2,27

Table 12: The distance and travel time of the alternative route by water taxi during morning peak

In figure 12 the alternative route of the water taxi from origin 108 to destination 37 during the morning peak is displayed.

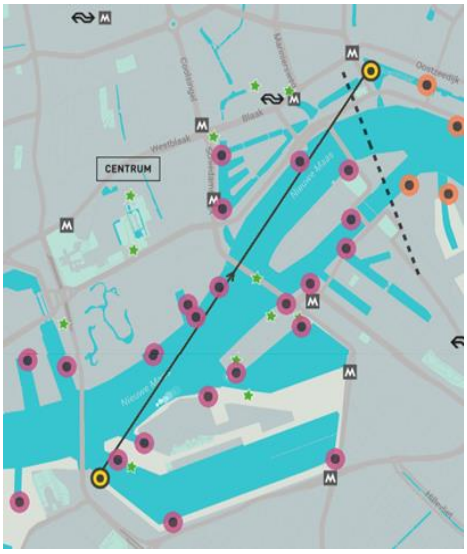

Figure 12: Alternative route during morning peak by water taxi (Watertaxi Rotterdam, 2017)

4.1.2.2. Comparing the travel times of the several modes of transportation

Now the travel times per kilometre during the morning peak for each mode of transportation are known, it is possible to compare them with each other.

Comparison public transport and car

The results of the comparison of travel times of the busiest routes during the morning peak by public transport and car are displayed in table 13.

Origin	Destination	Travel time per km by public transport (min)	Travel time per km by car (min)	Ratio
2	108	4,10	2,50	164%
5	17	3,62	2,41	150%
5	108	-	2,45	-
98	17	5,48	2,46	223%
98	108	3,93	2,50	157%
102	47	5,43	2,21	246%
102	50	6,59	2,31	285%
102	108	3,33	2,39	**139%**
108	17	8,10	3,33	243%
108	21	6,40	2,54	252%
108	22	6,67	2,49	268%
108	37	7,95	2,60	**306%**
108	107	-	2,17	-
110	47	5,58	2,44	228%
111	47	6,30	2,21	285%
111	108	4,64	2,58	180%

Table 13: Comparison of travel times per km during the morning peak by public transport and car

As well as with the comparison of the travel times of the busiest routes throughout the whole day, comparing the travel times of the busiest routes during the morning peak also results in the ratios being all above 100%. This means that all alternative routes by public transport take longer to travel than travelling from and to the same origin and destination by car. With a smallest increase to 139% of the travel time by car and a largest increase to 306% of the travel time by car, there is quite a difference between the travel times of both modes of transportation. However, with a value of 223%, the average increase in travel time using public transport during the morning peak is lower than the average increase in travel time using public transport throughout the whole day. Based on these travel times, people will still not be willing to change their mode of transportation, as a person itself will not benefit from it.

Comparison water taxi and car

The results of the comparison of travel times of the busiest routes during the morning peak by water taxi and car are displayed in table 14.

Origin	Destination	Travel time per km by water taxi (min)	Travel time per km by car (min)	Ratio
108	37	2,27	2,60	87%

Table 14: Comparison of travel times per km during the morning peak by water taxi and car

Comparing the travel time of the alternative route by water taxi with the travel time by car of the same route during the morning peak gives a ratio of 87%. This means the travel time by water taxi is shorter than the travel time by car. Based only on the travel time, when people are rational they will be willing to change their mode of transportation as it costs less time to travel from origin to destination by water taxi than by car.

4.1.3 Evening peak

4.1.3.1 Travel times per mode of transportation

Car

The travel times by car of the busiest routes during the evening peak are calculated. To calculate the average travel times during the evening peak, the additional travel time of 27% is added to the off peak travel times. The distances and travel times of the busiest routes by car during the evening peak can be seen in table 15.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
5	17	5,8	14,5	2,50
5	19	4,9	11,9	2,42
5	108	5,7	14,5	2,55
49	47	4,7	10,6	2,25
93	47	4,4	10,6	2,40
93	108	6,7	17,2	2,56
102	19	6,1	15,8	2,60
102	47	4,6	9,2	**2,01**
102	108	6,9	17,2	2,49
108	17	4,2	10,6	2,51
108	21	5	13,2	2,64
108	22	5,1	13,2	2,59
108	37	4,4	13,2	**3,00**
108	107	4,1	9,2	2,25

Table 15: The distances and travel times by car during evening peak

The average travel time per kilometre by car during the evening peak is 2,48 minutes, which means that travelling one kilometre with the car takes 2 minutes and 29 seconds on average. Most values of the travel times per kilometre are close to the average value, except for two routes. One route with an travel time per kilometre of 2,01 is somewhat shorter than the average. The other route, with a travel time of 3,00 minutes per kilometre is rather larger than the average of 2,48.

Public transport

The travel times of the alternative routes by public transport during the evening peak are computed and displayed in table 16.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
5	17	5,8	21	3,62
5	19	4,9	26	5,31
5	108	5,7	-	-
49	47	4,7	-	-
93	47	4,4	34	7,73
93	108	6,7	21	**3,13**
102	19	6,1	28	4,59
102	47	4,6	25	5,43
102	108	6,9	25	3,62
108	17	4,2	37	**8,81**
108	21	5	32	6,40
108	22	5,1	34	6,67
108	37	4,4	35	7,95
108	107	4,1	-	-

Table 16: The distances and travel times of the alternative routes by public transport during evening peak

The average travel time per kilometre by public transport during the evening peak is 5,75 minutes, which means it takes 5 minutes and 45 seconds on average to travel one kilometre. The values differ a lot from each other as the lowest value is 3,13 minutes per kilometre and the highest value is 8,81 minutes per kilometre.

Water taxi

As well as during the morning peak, during the evening peak the water taxi could be used as an alternative instead of the car for one route. The route is similar to the route during the morning peak and so are its distance and travel time. The distance and travel time can be found in table 12 of section 4.1.2.1 and in figure 12 of the same section the alternative route of the water taxi is displayed.

4.1.3.2. Comparing the travel times of the several modes of transportation

Comparison public transport and car

The results of the comparison of travel times of the busiest routes during the evening peak by public transport and car are displayed in table 17.

Origin	Destination	Travel time per km by public transport (min)	Travel time per km by car (min)	Ratio
5	17	3,62	2,50	145%
5	19	5,31	2,42	219%
5	108	-	2,55	-
49	47	-	2,25	-
93	47	7,73	2,40	322%
93	108	3,13	2,56	**122%**
102	19	4,59	2,60	177%
102	47	5,43	2,01	271%
102	108	3,62	2,49	146%
108	17	8,81	2,51	**350%**
108	21	6,40	2,64	242%
108	22	6,67	2,59	258%
108	37	7,95	3,00	265%
108	107	-	2,25	-

Table 17: Comparison of travel times during the evening peak by public transport and car

The phenomenon that the travel times to travel from origin to destination using public transport are higher than the travel times using the car repeats itself again during the evening peak. All ratios are again higher than 100%, which means that for all routes it takes longer to travel the routes using public transport than to travel the routes using the car. The average ratio is 229%, which is practically equal to the average ratio of the comparison of public transport and the car during the morning peak and lower than the average ratio throughout the whole day. With the lowest value of 122% and the highest value of 350%, the values are further away from the mean compared to the highest and lowest value during the morning peak, which were respectively 139% and 306%. Based on these travel times, people will still not be willing to change their mode of transportation.

Comparison water taxi and car

The results of the comparison of travel times of the busiest routes during the evening peak by water taxi and car are displayed in table 18.

Origin	Destination	Travel time per km by water taxi (min)	Travel time per km by car (min)	Ratio
108	37	2,27	3,00	76%

Table 18: Comparison of travel times during the evening peak by water taxi and car

Comparing the travel time of the alternative route by water taxi with the travel time by car of the same route during the evening peak gives a ratio of 76%. This means the travel time by water taxi is shorter than the travel time by car. Comparing this ratio with the ratio of the travel time by water taxi divided by the travel time by car during the morning peak, it can be seen that the value is lower during the evening peak. Based only on the travel time, when people are rational they will be willing to change their mode of transportation as it costs less time to travel from origin to destination by water taxi than by car.

4.2 Travelling costs per mode of transportation

The travelling costs per mode of transportation of the busiest routes are computed. The routes of which the travelling costs are computed are the same as the routes of which the travel times are computed. First the travelling costs of travelling by car are computed, then the travelling costs of travelling by public transport and finally the travelling costs of travelling by water taxi. After the computation of the travelling costs of the several modes of transportation, these travelling costs will be compared with each other by means of ratios.

4.2.1 Throughout the whole day

4.2.1.1 Travelling costs per mode of transportation

Car

The total costs of travelling by car and the travelling costs per kilometre for the busiest routes are displayed in table 19.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
5	17	5,8	€ 2,38	€ 0,41
5	19	4,9	€ 2,01	€ 0,41
5	108	5,9	€ 2,42	€ 0,41
49	47	4,7	€ 1,93	€ 0,41
93	47	4,4	€ 1,80	€ 0,41
98	108	6,1	€ 2,50	€ 0,41
102	47	4,6	€ 1,89	€ 0,41
102	50	4,4	€ 1,80	€ 0,41
102	108	6,9	€ 2,83	€ 0,41
108	17	4,2	€ 1,72	€ 0,41
108	21	5	€ 2,05	€ 0,41
108	22	5,1	€ 2,09	€ 0,41
108	107	4,1	€ 1,68	€ 0,41
111	47	4,6	€ 1,89	€ 0,41
111	108	6,9	€ 2,83	€ 0,41

Table 19: The travelling costs of the busiest routes by car throughout the whole day

The total costs of travelling a route by car are calculated by multiplying the distance by the costs per kilometre of using a car. The costs of using a car rise proportionally with the distance the car travels. Therefore the costs per kilometre are fixed and thus are the travelling costs per kilometre for each route equal and they have a value of €0,41. Logically, the average costs per kilometre of travelling by car are also €0,41.

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes throughout the whole day are displayed in table 20. Routes with the missing values have no alternative for public transport.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
5	17	5,8	€ 1,68	€ 0,29
5	19	4,9	€ 1,56	€ 0,32
5	108	5,9	-	-
49	47	4,7	€ 1,53	€ 0,33
93	47	4,4	€ 1,49	€ 0,34
98	108	6,1	€ 1,73	€ 0,28
102	47	4,6	€ 1,52	€ 0,33
102	50	4,4	€ 1,49	€ 0,34
102	108	6,9	€ 1,84	€ 0,27
108	17	4,2	€ 1,47	€ 0,35
108	21	5	€ 1,58	€ 0,32
108	22	5,1	€ 1,59	€ 0,31
108	107	4,1	-	-
111	47	4,6	€ 1,52	€ 0,33
111	108	6,9	€ 1,84	€ 0,27

Table 20: The travelling costs of the busiest routes by public transport throughout the whole day

The total costs of travelling a route by public transport are calculated by adding a tariff per kilometre to a basic fare that every person has to pay when using public transport despite the distance that will be travelled. The costs rise disproportionally with the distance. The longer the route, the less an extra kilometre will cost. The costs per kilometre therefore will decrease if this distance increases.

The average travelling costs per kilometre throughout the whole day using public transport is €0,31. All values have a deviation of €0,04 per kilometre or less.

Water taxi

The water taxi has no alternative routes to replace the car as mode of transportation. Therefore it is impossible to compute its travelling costs.

4.2.1.2 Comparing travelling costs of the several modes of transportation

Now the travelling costs per kilometre throughout the whole day for each mode of transportation are known, it is possible to compare them with each other. The travelling costs are compared using ratios. The ratios are calculated by dividing the costs of travelling by a specific mode of transportation by the costs of travelling by another mode of transportation. In this case the costs of travelling by public transport is divided by the costs of travelling by car. For example, when a ratio of the costs of travelling a specific route is 71%, this is achieved by dividing €0,29 by €0,41. The value of 71% means that the costs of travelling the route by public transport are 71% of the costs of travelling the same route by car. The costs of travelling the specific route are thus 29% lower when using public transport as mode of transportation. The results of the comparison of the costs of travelling by public transport and car are displayed in table 21.

Origin	**Destination**	**Travelling costs per km of public transport**	**Travelling costs per km of car**	**Ratio**
5	17	€ 0,29	€ 0,41	71%
5	19	€ 0,32	€ 0,41	78%
5	108	-	€ 0,41	-
49	47	€ 0,33	€ 0,41	80%
93	47	€ 0,34	€ 0,41	83%
98	108	€ 0,28	€ 0,41	69%
102	47	€ 0,33	€ 0,41	81%
102	50	€ 0,34	€ 0,41	83%
102	108	€ 0,27	€ 0,41	**65%**
108	17	€ 0,35	€ 0,41	**85%**
108	21	€ 0,32	€ 0,41	77%
108	22	€ 0,31	€ 0,41	76%
108	107	-	€ 0,41	-
111	47	€ 0,33	€ 0,41	81%
111	108	€ 0,27	€ 0,41	65%

Table 21: Comparison of travelling costs per km throughout the day by public transport and car

It is remarkable that all alternative routes have lower costs when travelling by public transport compared to the same routes travelling by car, varying from a decrease in costs of 15% when travelling by public transport to a decrease of 35%. The average ratio is 77%, which means that on average the costs of travelling when travelling by public transport decrease with 23% to 77% of the costs of travelling by car.

The less it costs to travel the route, the higher the willingness will be for people to change their mode of transportation. The costs of travelling by public transport are lower than the costs of travelling by car. Looking only to the costs of travelling and assuming people make rational choices, it will be the case that people will change their mode of transportation for every route throughout the whole day and switch from using the car to using public transport.

4.2.2 Morning peak

4.2.2.1 Travelling costs per mode of transportation

Car

The costs of travelling via the busiest routes by car during the morning peak are calculated. As we have seen already, the costs per kilometre of travelling by car are fixed at €0,41. Both the total travelling costs as well as the travelling costs per kilometre can be seen in table 22.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
2	108	6,1	€ 2,50	€ 0,41
5	17	5,8	€ 2,38	€ 0,41
5	108	5,7	€ 2,34	€ 0,41
98	17	6,2	€ 2,54	€ 0,41
98	108	6,1	€ 2,50	€ 0,41
102	47	4,6	€ 1,89	€ 0,41
102	50	4,4	€ 1,80	€ 0,41
102	108	6,9	€ 2,83	€ 0,41
108	17	4,2	€ 1,72	€ 0,41
108	21	5	€ 2,05	€ 0,41
108	22	5,1	€ 2,09	€ 0,41
108	37	4,4	€ 1,80	€ 0,41
108	107	4,1	€ 1,68	€ 0,41
110	47	5,2	€ 2,13	€ 0,41
111	47	4,6	€ 1,89	€ 0,41
111	108	6,9	€ 2,83	€ 0,41

Table 22: The costs of travelling the busiest routes by car during morning peak

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes during the morning peak are displayed in table 23.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
2	108	6,1	€ 1,73	€ 0,28
5	17	5,8	€ 1,68	€ 0,29
5	108	5,7	-	-
98	17	6,2	€ 1,74	€ 0,28
98	108	6,1	€ 1,73	€ 0,28
102	47	4,6	€ 1,52	€ 0,33
102	50	4,4	€ 1,49	€ 0,34
102	108	6,9	€ 1,84	€ 0,27
108	17	4,2	€ 1,47	€ 0,35
108	21	5	€ 1,58	€ 0,32
108	22	5,1	€ 1,59	€ 0,31
108	37	4,4	€ 1,49	€ 0,34
108	107	4,1	-	-
110	47	5,2	€ 1,60	€ 0,31
111	47	4,6	€ 1,52	€ 0,33
111	108	6,9	€ 1,84	€ 0,27

Table 23: The travelling costs of the busiest routes by public transport during morning peak

The average travelling costs per kilometre using public transport during the morning peak is €0,31, which is similar to the average value throughout the whole day. In this situation also all values are within a deviation of €0,04 per kilometre.

Water taxi

During the morning peak one route by water taxi can be seen as an alternative of using the car as mode of transportation. Its travelling costs is displayed in table 24. The travel time per kilometre is calculated in a similar way as the travel times per kilometre by car and public transport, by dividing the travelling costs of a route by the distance of that same route.

Origin	Destination	Distance (km)	Travelling costs of water taxi	Travelling costs per km of water taxi
108	37	4,4	€ 7,00	€ 1,59

Table 24: The travelling costs of the alternative route by water taxi during morning peak

In figure 12 of section 4.1.2.1 the alternative route of the water taxi from origin 108 to destination 37 during the morning peak is displayed.

4.2.2.2 Comparing travelling costs of the several modes of transportation

Comparison public transport and car

The travelling costs per kilometre during the morning peak for each mode of transportation are known and comparing them with each other is the next step. The results of the comparison of the costs of travelling by public transport and car are displayed in table 25.

Origin	Destination	Travelling costs per km of public transport	Travelling costs per km of car	Ratio
2	108	€ 0,28	€ 0,41	69%
5	17	€ 0,29	€ 0,41	71%
5	108	-	€ 0,41	-
98	17	€ 0,28	€ 0,41	68%
98	108	€ 0,28	€ 0,41	69%
102	47	€ 0,33	€ 0,41	81%
102	50	€ 0,34	€ 0,41	83%
102	108	€ 0,27	€ 0,41	**65%**
108	17	€ 0,35	€ 0,41	**85%**
108	21	€ 0,32	€ 0,41	77%
108	22	€ 0,31	€ 0,41	76%
108	37	€ 0,34	€ 0,41	83%
108	107	-	€ 0,41	-
110	47	€ 0,31	€ 0,41	75%
111	47	€ 0,33	€ 0,41	81%
111	108	€ 0,27	€ 0,41	65%

Table 25: Comparison of travelling costs of the busiest routes during the morning peak by public transport and car

During the morning peak all the busiest routes are cheaper to travel by public transport than to travel by car. All the ratios are lower than 100%. The ratios vary from 65% to 85%, which represents a decrease in costs of respectively 35% and 15%. This minimum and maximum are equal to the minimum and maximum of the decrease in costs throughout the whole day. However, the average ratio of the costs of travelling during the morning peak is 75%, a decrease in costs of 25%. This is two percent point more decrease in costs of travelling with public transport compared to car during morning peak in comparison with the costs of travelling throughout the whole day.

During the morning peak the costs of travelling by public transport are lower than the costs of travelling by car. Assuming people make rational choices, people will change their mode of transportation for every route during the morning peak. As a cost reduction will be the case when changing mode of transportation, people have an incentive to change their mode of transportation from using the car to using public transport.

Comparison water taxi and car

The results of the comparison of travelling costs of the busiest routes during the morning peak by water taxi and car are displayed in table 26.

Origin	Destination	Travelling costs per km of water taxi	Travelling costs per km of car	Ratio
108	37	€ 1,59	€ 0,41	388%

Table 26: Comparison of travelling costs per km during morning peak by water taxi and car

Comparing the travelling costs of the alternative route by water taxi with the travelling costs of car of the same route during the morning peak gives a ratio of 388%. This means the costs of travelling by water taxi are higher than the costs of travelling by car. An increase of the costs to 388% of the costs of travelling by car means that the costs are almost three times as high as the costs of travelling by car. Based only on these travelling costs, and assuming people are rational they will not be willing to change their mode of transportation.

4.2.3 Evening peak

4.2.3.1 Travelling costs per mode of transportation

Car

The costs of travelling via the busiest routes by car during the evening peak are calculated. As we have seen throughout the day and during the morning peak, it is also true for the evening peak that the costs per kilometre of travelling by car are fixed at €0,41. The total travelling costs and the travelling costs per kilometre can be seen in table 27.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
5	17	5,8	€ 2,38	€ 0,41
5	19	4,9	€ 2,01	€ 0,41
5	108	5,7	€ 2,34	€ 0,41
49	47	4,7	€ 1,93	€ 0,41
93	47	4,4	€ 1,80	€ 0,41
93	108	6,7	€ 2,75	€ 0,41
102	19	6,1	€ 2,50	€ 0,41
102	47	4,6	€ 1,89	€ 0,41
102	108	6,9	€ 2,83	€ 0,41
108	17	4,2	€ 1,72	€ 0,41
108	21	5	€ 2,05	€ 0,41
108	22	5,1	€ 2,09	€ 0,41
108	37	4,4	€ 1,80	€ 0,41
108	107	4,1	€ 1,68	€ 0,41

Table 27: The costs of travelling the busiest routes by car during evening peak

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes during the evening peak are displayed in table 28.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
5	17	5,8	€ 1,68	€ 0,29
5	19	4,9	€ 1,56	€ 0,32
5	108	5,7	-	-
49	47	4,7	-	-
93	47	4,4	€ 1,49	€ 0,34
93	108	6,7	€ 1,81	€ 0,27
102	19	6,1	€ 1,73	€ 0,28
102	47	4,6	€ 1,52	€ 0,33
102	108	6,9	€ 1,84	€ 0,27
108	17	4,2	€ 1,47	€ 0,35
108	21	5	€ 1,58	€ 0,32
108	22	5,1	€ 1,59	€ 0,31
108	37	4,4	€ 1,49	€ 0,34
108	107	4,1	-	-

Table 28: The costs of travelling the busiest routes by public transport during evening peak

The average travelling costs per kilometre using public transport during the evening peak is €0,31, which is similar to the average values using public transport throughout the whole day and during the morning peak. In this situation also all values are within a deviation of €0,04 per kilometre.

Water taxi

As well as during the morning peak, during the evening peak the water taxi could be used as an alternative instead of the car for one route. The route is similar to the route during the morning peak and so are its costs of travelling. The costs of travelling can be found in table 24 in section 4.2.2.1 and in figure 12 of section 4.1.2.1 the alternative route of the water taxi is displayed.

4.2.3.2 Comparing travelling costs of the several modes of transportation

Comparison public transport and car

The travelling costs per kilometre during the evening peak for each mode of transportation are known and now they can be compared with each other. The results of the comparison of the costs of travelling by public transport and car during the evening peak are displayed in table 29.

Origin	Destination	Travelling costs per km of public transport	Travelling costs per km of car	Ratio
5	17	€ 0,29	€ 0,41	71%
5	19	€ 0,32	€ 0,41	78%
5	108	-	€ 0,41	-
49	47	-	€ 0,41	-
93	47	€ 0,34	€ 0,41	83%
93	108	€ 0,27	€ 0,41	66%
102	19	€ 0,28	€ 0,41	69%
102	47	€ 0,33	€ 0,41	81%
102	108	€ 0,27	€ 0,41	**65%**
108	17	€ 0,35	€ 0,41	**85%**
108	21	€ 0,32	€ 0,41	77%
108	22	€ 0,31	€ 0,41	76%
108	37	€ 0,34	€ 0,41	83%
108	107	-	€ 0,41	-

Table 29: Comparison of travelling costs of the busiest routes during the evening peak by public transport and car

What can be extracted from the table is that all ratios are lower than 100%, which means that all routes are cheaper to travel by public transport than by car. The highest ratio and thus the lowest cost reduction is 85%, a decrease in costs of 15%. The lowest ratio and thus the highest cost reduction is 65%, a decrease in costs of 35%. These extreme values of the travelling costs during the evening peak by public transport and car are equal to the extreme values of the costs of travelling by public transport and car during the morning peak and throughout the day. Though, there are differences in the other values of the table.

The average ratio of the costs to travel during the evening peak is 76%, a cost decrease of 24% relative to travelling by car. An average ratio of 76% is between the average ratios of the morning peak and throughout the whole day, which were respectively 75% and 77%.

As already seen in the comparison of the costs of travelling by public transport and car during the morning peak, during the evening peak the costs of travelling by public transport are also lower than the costs of travelling by car. When assuming people make rational choices, people will switch from modality and use public transport instead of the car for every route during the evening peak.

Comparison water taxi and car

The results of the comparison of travelling costs of the busiest routes by water taxi and car during the evening peak are displayed in table 30.

Origin	Destination	Travelling costs per km of water taxi	Travelling costs per km of car	Ratio
108	37	€ 1,59	€ 0,41	388%

Table 30: Comparison of travelling costs per km during evening peak by water taxi and car

Comparing the travelling costs of the alternative route by water taxi with the travelling costs of the route travelling by car that has the same origin and destination gives us a ratio of 388%. Since this is the same route as seen as alternative route during the morning peak and the costs are equal, the consequences will be similar. The costs of travelling by water taxi are almost three times as high as the costs of travelling by car. So based only on these travelling costs, and assuming people are rational they will not be willing to change their mode of transportation.

4.3 Route occupancy during peak hours

Since many people travel at the same time during the peaks, the expectation rises that the route occupancy on the busiest routes during these peaks are higher than the average route occupancy of these routes throughout the day. By comparing the occupancy of the routes of the morning and evening peak with the average occupancy throughout the day, it is possible to find out whether the routes are more than average occupied during the peaks. For this section the same routes are used as the routes in the previous sections of chapter 4.

4.3.1 Morning peak

Dividing the amount of cars that travelled during the morning peak by the total amount of cars travelled during the day gives the percentage of route occupancy during the morning peak relative to the route occupancy throughout the whole day. In table 31 the route occupancy during the morning peak as percentage of the total route occupancy throughout the whole day is displayed.

Origin	Destination	% Morning peak
2	108	26
5	17	17
5	108	16
98	17	29
98	108	15
102	47	24
102	50	35
102	108	26
108	17	18
108	21	16
108	22	16
108	37	19
108	107	13
110	47	27
111	47	25
111	108	25

Route occupancy above 18h average of 22%	(dark orange)
Route occupancy above 24h average of 17%	(light orange)

Table 31: Route occupancy of the routes during morning peak as percentage of an 18 and 24 hour day

Half of the routes have an occupancy during the morning peak that is higher than the average route occupancy of an 18 hour day. Two more routes have an occupancy that is higher than the 24 hour day average and lower than the 18 hour average. The average occupancy of the busiest routes during the morning peak is 21,69%.. This value is 4 percent point higher than the average route occupancy of an 24 hour day. The percentage of 21,69% is lower than the average route occupancy of an 18 hour day although with less than one percent point difference it is close to it. What is remarkable is that the route occupancy deviates a lot per route. The highest percentage of occupancy during the morning peak is 35%, which is 13 percent point higher than the average occupancy of an 18-hour day and 18 percent point higher than a 24-hour day occupancy average. The lowest percentage of occupancy during the morning peak is 13%, which is almost 10 percent point lower than the average occupancy of an 18-hour day. It is even lower than the 24-hour day occupancy average, which is 4 percent point.

4.3.2 Evening peak

The percentage of route occupancy during the evening peak relative to the route occupancy throughout the whole day is calculated the same way as it is done during the morning peak, but with the amount of cars travelled the routes during the evening peak. In table 32 the route occupancy during the evening peak as percentage of the total route occupancy throughout the whole day is displayed.

Origin	Destination	% Evening peak
5	17	24
5	19	22
5	108	22
49	47	19
93	47	24
93	108	28
102	19	23
102	47	20
102	108	22
108	17	22
108	21	22
108	22	18
108	37	40
108	107	17

Route occupancy above 18h average of 22%	(dark orange)
Route occupancy above 24h average of 17%	(light orange)

Table 32: Route occupancy of the routes during evening peak as percentage of an 18 and 24 hour day

Remarkable is that all of the routes have an occupancy during the evening peak that is higher than the average route occupancy of a 24-hour day, except one route. A third of the routes have an occupancy higher than the average route occupancy of an 18-hour day. More than half of the routes have an occupancy that is between the average route occupancy of a 24-hour day and an 18-hour day. The average occupancy of the busiest routes during the evening peak is 23,07%. This is six percent point higher than the average route occupancy of a 24-hour day. Unlike during the morning peak, during the evening peak the average route occupancy is also higher than the average route occupancy of an 18-hour day although the difference is only one percent point. Another difference between the route occupancy during the morning peak and the evening peak is that whereas the values of the route occupancy during the morning peak deviate a lot, the values during the evening peak are rather stable. One outlier of 40% is an exception to the stable values. This value is 18 percent point higher than the average occupancy of an 18-hour day and 23 percent point higher than a 24-hour day occupancy average. The lowest percentage of occupancy during the evening peak is 17%, which is five percent point lower than the average occupancy of an 18-hour day. It is even equal to the 24-hour day occupancy average.

5. Empirical results for southern direction

In this chapter the results of this research are put forward of the routes for the traffic in the southern direction. This direction is also separated in three parts: Throughout the whole day, morning peak and evening peak. The routes differ per part in terms of occupancy, since some routes are busy during the morning peak, while they are calm during the evening peak and vice versa. As seen in the previous chapter, routes that are shorter than four kilometres are omitted from the 25 busiest routes, because the can be taken by bicycle. The travel times, travelling costs and route occupancy for the remaining routes are computed.

5.1 Travel times

The travel times per mode of transportation of the busiest routes are computed. First the travel times by car are computed, then the travel times by public transport and finally the travel times by water taxi. After the computation of the travel times of the several modes of transportation, these travel times will be compared with each other by means of ratios.

5.1.1 Throughout the whole day

5.1.1.1 Travel times per mode of transportation

Car

First the travel times by car throughout the whole day are calculated. To create a more realistic idea of these values, the off peak travel time is increased with 19%. Which is on average the extra time it costs to travel by car throughout the whole day. The distances and travel times of the busiest routes by car throughout the whole day can be seen in table 33.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
16	107	4,8	10,7	2,23
20	100	5,9	13,1	2,22
20	105	4,8	11,9	2,48
23	105	6,2	14,3	2,30
23	107	5,2	10,7	2,06
26	100	5,7	13,1	2,30
26	105	4,6	10,7	2,33
39	107	5,1	13,1	2,57
49	47	4,7	9,5	2,03
49	95	4,7	10,7	2,28
49	96	4,2	9,5	2,27
49	97	4,2	9,5	2,27
49	100	5	13,1	2,62
49	101	4,9	11,9	2,43
49	103	7,4	15,5	2,09
55	107	4,6	13,1	**2,85**
108	107	4,1	8,3	2,03

Table 33: The distances and travel times by car throughout the whole day

The average travel time per kilometre by car of busiest the routes throughout the whole day is 2,31 minutes, which means that travelling one kilometre of this route will take 2 minutes and 19 seconds on average. Looking at the minutes per kilometre column, most values are close to the average. However, the travel time per kilometre of the route from origin 55 to destination 107 (2,85) differs somewhat from the average as it takes more than half a minute longer to travel one kilometre.

Public transport

For public transport the distances and travel times throughout the whole day of the alternative routes are computed and displayed in table 34.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
16	107	4,8	31	6,46
20	100	5,9	40	6,78
20	105	4,8	33	6,88
23	105	6,2	30	4,84
23	107	5,2	28	5,38
26	100	5,7	40	7,02
26	105	4,6	33	**7,17**
39	107	5,1	31	6,08
49	47	4,7	-	-
49	95	4,7	30	6,38
49	96	4,2	24	5,71
49	97	4,2	23	5,48
49	100	5	24	4,80
49	101	4,9	23	4,69
49	103	7,4	21	**2,84**
55	107	4,6	26	5,65
108	107	4,1	-	-

Table 34: The distances and travel times of the alternative routes by public transport throughout the whole day

The average travel time per kilometre by public transport throughout the whole day is 5,74 minutes, which means it takes on average 5 minutes and 44 seconds on average to travel a kilometre by public transport. It can be observed that the values per route are rather spread. The longest travel time per kilometre is 7,17 minutes and the shortest is 2,84 minutes.

Water taxi

The water taxi can be an alternative mode of transportation for two routes. The travel times are displayed in table 35. The travel times per kilometre are calculated similarly as the travel times per kilometre by car and public transport, by dividing the travel time of a route by the distance of that same route.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
39	107	5,1	10	1,96
55	107	4,6	10	2,17

Table 35: The distance and travel time of the alternative route by water taxi throughout the whole day

The average travel time by water taxi is 2,07. However, the average value consists of two values and might not provide a lot of information. In figure 13 the alternative routes of the water taxi throughout the whole day are displayed.

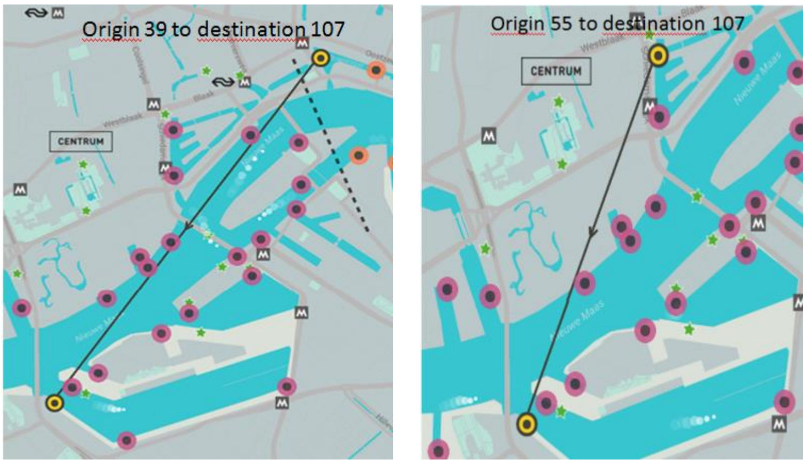

Figure 13: Alternative routes throughout the whole day by water taxi (Watertaxi Rotterdam, 2017)

5.1.1.2 Comparing the travel times of the several modes of transportation

The travel times per kilometre throughout the whole day for each mode of transportation are known, so it is possible to compare them with each other. The travel times in the southern direction are compared in the same way as in the northern direction using ratios.

Comparison public transport and car

The results of the comparison of the travel times by public transport and car are displayed in table 36.

Origin	Destination	Travel time per km by public transport (min)	Travel time per km by car (min)	Ratio
16	107	6,46	2,23	289%
20	100	6,78	2,22	306%
20	105	6,88	2,48	277%
23	105	4,84	2,30	210%
23	107	5,38	2,06	261%
26	100	7,02	2,30	306%
26	105	7,17	2,33	**308%**
39	107	6,08	2,57	237%
49	47	-	2,03	-
49	95	6,38	2,28	280%
49	96	5,71	2,27	252%
49	97	5,48	2,27	242%
49	100	4,80	2,62	183%
49	101	4,69	2,43	193%
49	103	2,84	2,09	**136%**
55	107	5,65	2,85	199%
108	107	-	2,03	-

Table 36: Comparison of travel times per km throughout the day by public transport and car

All ratios of the travel times are higher than 100%, which means that for all routes it takes longer to travel from an origin to its destination by public transport than by car. The ratios vary from 136% to 308%. The lowest increase of travel time by public transport is 36% and the highest increase is 208%, which means more than twice the travel time is added to the travel time by car. The average ratio is 245%, which means that on average the travel times when travelling by public transport increase to 245% of the travel times when travelling by car.

Taking only the travel times of the routes into account and assuming people make rational choices, people will not have an incentive to change their mode of transportation. All travel times by public transport take longer than the travel times by car. It will be the case that no change will occur in the mode of transportation people use and all people will keep travelling by the car.

Comparison water taxi and car

The results of the comparison of travel times of the busiest routes throughout the whole day by water taxi and car are displayed in table 37.

Origin	Destination	Travel time per km by water taxi (min)	Travel time per km by car (min)	Ratio
39	107	1,96	2,57	76%
55	107	2,17	2,85	76%

Table 37: Comparison of travel times per km throughout the whole day by water taxi and car

Comparing the travel times of the alternative routes by water taxi with the travel time by car of the same routes throughout the while day gives ratios of 76%. The travel times by water taxi are shorter than the travel times by car. Based only on the travel time people are willing to change their mode of transportation and travel by water taxi instead of the car, assuming people are rational.

5.1.2 Morning peak

5.1.2.1 Travel times per mode of transportation

Car

The travel times by car of the busiest routes during the morning peak are calculated. The average travel times during the morning peak in the southern direction are calculated in the same way as the average travel times in the northern direction, including the additional travel time of 27%. The distances and travel times by car during the morning peak can be seen in table 38.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
16	107	4,8	11,4	2,38
20	98	5,4	14,0	2,59
20	106	4,8	11,4	2,38
23	107	5,2	11,4	2,20
26	100	5,7	15,2	2,67
39	107	5,1	12,7	2,49
49	47	4,7	10,2	2,16
49	95	4,7	11,4	2,43
49	97	4,2	10,2	2,42
49	100	5	14,0	2,79
49	101	4,9	14,0	2,85
49	103	7,4	17,8	2,40
53	107	5,4	16,5	**3,06**
55	107	4,6	14,0	3,04
107	100	6,4	16,5	2,58
107	103	8,8	19,1	**2,16**
107	105	5,2	12,7	2,44
108	107	4,1	8,9	2,17

Table 38: The distances and travel times by car during morning peak

The average travel time per kilometre by car during the morning peak is 2,51 minutes, which means it takes 2 minutes and 31 seconds on average to travel one kilometre by car. With a highest value of 3,06 minutes it takes slightly more than half a minute extra to travel a kilometre than the average value. With a lowest value of 2,16 minutes it takes 21 seconds less than the average time to travel one kilometre.

Public transport

The travel times of the alternative routes by public transport during the morning peak are computed and displayed in table 39.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
16	107	4,8	31	6,46
20	98	5,4	36	6,67
20	106	4,8	32	6,67
23	107	5,2	28	5,38
26	100	5,7	40	7,02
39	107	5,1	31	6,08
49	47	4,7	-	-
49	95	4,7	41	**8,72**
49	97	4,2	28	6,67
49	100	5	29	5,80
49	101	4,9	28	5,71
49	103	7,4	26	3,51
53	107	5,4	29	5,37
55	107	4,6	26	5,65
107	100	6,4	25	3,91
107	103	8,8	22	**2,50**
107	105	5,2	22	4,23
108	107	4,1	-	-

Table 39: The distances and travel times of the alternative routes by public transport during morning peak

The average travel time per kilometre by public transport during the morning peak is 5,65 minutes, which means it takes 5 minutes and 39 seconds on average to travel one kilometre. From table 39 can be seen that with a value of 8,72 minutes per kilometre the highest value is an outlier as it exceeds the average by more than three minutes per kilometre, where the second highest value (7,02) exceeds the average travel time with 1,37 minutes. The lowest value is 2,50 minutes per kilometre, which is less than half the average travel time per kilometre. It can be seen that the travel times per kilometre fluctuate upwards as well as downwards.

Water taxi

The water taxi can be an alternative mode of transportation for three routes. The travel times of these routes are displayed in table 40. The travel times per kilometre are calculated similarly as the travel times per kilometre by car and public transport.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
39	107	5,1	10	1,96
53	107	5,4	10	1,85
55	107	4,6	10	2,17

Table 40: The distance and travel time of the alternative route by water taxi during morning peak

The average travel time per kilometre is 1,99 minutes. In figure 13 of section 5.1.1.1 the alternative routes of the water taxi during the morning peak are displayed. The route from origin 53 to destination 107 has the same embarking and disembarking stages as the route from origin 39 to destination 107.

5.1.2.2. Comparing the travel times of the several modes of transportation

After computing the travel times per kilometre during the morning peak for each mode of transportation, it is possible to compare them with each other.

Comparison public transport and car

The results of the comparison of travel times of the busiest routes during the morning peak by public transport and car are displayed in table 41.

Origin	Destination	Travel time per km by public transport (min)	Travel time per km by car (min)	Ratio
16	107	6,46	2,38	271%
20	98	6,67	2,59	258%
20	106	6,67	2,38	280%
23	107	5,38	2,20	245%
26	100	7,02	2,67	262%
39	107	6,08	2,49	244%
49	47	-	2,16	-
49	95	8,72	2,43	**359%**
49	97	6,67	2,42	276%
49	100	5,80	2,79	208%
49	101	5,71	2,85	200%
49	103	3,51	2,40	146%
53	107	5,37	3,06	176%
55	107	5,65	3,04	186%
107	100	3,91	2,58	151%
107	103	2,50	2,16	**115%**
107	105	4,23	2,44	173%
108	107	-	2,17	-

Table 41: Comparison of travel times per km during the morning peak by public transport and car

All ratios are above 100%, which we have seen already at the comparison of the travel times of the busiest routes throughout the whole day. This means that all alternative routes by public transport have longer travel times than the same routes by car. With a smallest increase to 115% of the travel time by car and a largest increase to 359% of the travel time by car, a substantial difference exist in the travel times of both modes of transportation. However, with a value of 222%, the average increase in travel time using public transport during the morning peak is lower than the average increase in travel time using public transport throughout the whole day. Based on these travel times, people will not be willing to change their mode of transportation.

Comparison water taxi and car

The results of the comparison of travel times of the busiest routes during the morning peak by water taxi and car are displayed in table 42.

Origin	Destination	Travel time per km by water taxi (min)	Travel time per km by car (min)	Ratio
39	107	1,96	2,49	79%
53	107	1,85	3,06	60%
55	107	2,17	3,04	71%

Table 42: Comparison of travel times per km during the morning peak by water taxi and car

Comparing the travel times of the alternative routes by water taxi with the travel times by car of the same routes during the morning peak shows that all values are lower than 100%. The travel times by water taxi are shorter than the travel times of the same routes by car. The average ratio is 70%. The average ratio during the morning peak is lower compared to the average ratio throughout the whole day. Based only on the travel times, rational people are willing to change their mode of transportation as it costs less time to travel from origin to destination by water taxi than by car.

5.1.3 Evening peak

5.1.3.1 Travel times per mode of transportation

Car

The travel times by car of the busiest routes during the evening peak are calculated. To calculate the average travel times during the evening peak, the additional travel time of 27% is added to the off peak travel times. The distances and travel times of the busiest routes by car during the evening peak can be seen in table 43.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
19	107	4,8	14,5	3,03
20	100	4,9	18,5	**3,77**
23	107	5,2	13,2	2,54
26	100	5,7	17,2	3,01
26	105	4,6	11,9	2,58
39	107	5,1	14,5	2,84
49	47	4,7	10,6	2,25
49	95	4,7	11,9	2,53
49	96	4,2	10,6	2,51
49	97	4,2	10,6	2,51
49	100	5	14,5	2,90
49	101	4,9	14,5	2,96
49	103	7,4	18,5	2,50
49	109	5,2	11,9	2,28
55	107	4,6	14,5	3,16
107	100	6,4	18,5	2,89
107	103	8,8	19,8	2,25
108	107	4,1	9,2	2,25

Table 43: The distances and travel times by car during evening peak

The average travel time per kilometre by car during the evening peak is 2,71 minutes, which means that travelling one kilometre with the car takes 2 minutes and 43 seconds on average. Most values of the travel times per kilometre are close to the average value. One route with a travel time of 3,77 minutes per kilometre has a rather high travel time per kilometre.

Public transport

The travel times of the alternative routes by public transport during the evening peak are computed and displayed in table 44.

Origin	Destination	Distance (km)	Travel time (min)	Travel time per km (min)
19	107	4,8	32	6,67
20	100	4,9	37	7,55
23	107	5,2	28	5,38
26	100	5,7	40	7,02
26	105	4,6	33	7,17
39	107	5,1	31	6,08
49	47	4,7	-	-
49	95	4,7	42	**8,94**
49	96	4,2	35	8,33
49	97	4,2	29	6,90
49	100	5	30	6,00
49	101	4,9	29	5,92
49	103	7,4	27	3,65
49	109	5,2	27	5,19
55	107	4,6	26	5,65
107	100	6,4	25	3,91
107	103	8,8	22	**2,50**
108	107	4,1	-	-
19	107	4,8	32	6,67

Table 44: The distances and travel times of the alternative routes by public transport during evening peak

The average travel time per kilometre by public transport during the evening peak is 6,05 minutes, which means it takes 6 minutes and 3 seconds on average to travel one kilometre. The values differ a lot from each other. The lowest value is 2,50 minutes per kilometre and the highest value is 8,94 minutes per kilometre, which results in a range of 6,44 minutes.

Water taxi

The routes that can be travelled by water taxi instead of the car during the evening peak are the same as the routes that can be travelled by water taxi throughout the whole day. Therefore the results of the distances and travel times of these routes can be found in table 35 of section 5.1.1.1. In figure 13 of the same section the alternative routes of the water taxi are displayed.

5.1.3.2. Comparing the travel times of the several modes of transportation

Comparison public transport and car

The results of the comparison of travel times of the busiest routes during the evening peak by public transport and car are displayed in table 45.

Origin	Destination	Travel time per km of public transport (min)	Travel time per km of car (min)	Ratio
19	107	6,67	3,03	220%
20	100	7,55	3,77	200%
23	107	5,38	2,54	212%
26	100	7,02	3,01	233%
26	105	7,17	2,58	278%
39	107	6,08	2,46	247%
49	47	-	2,25	-
49	95	8,94	2,53	**354%**
49	96	8,33	2,51	331%
49	97	6,90	2,51	275%
49	100	6,00	2,90	207%
49	101	5,92	2,96	200%
49	103	3,65	2,50	146%
49	109	5,19	2,28	227%
55	107	5,65	3,16	179%
107	100	3,91	2,89	135%
107	103	2,50	2,25	**111%**
108	107	-	2,25	-

Table 45: Comparison of travel times during the evening peak by public transport and car

As seen in all comparisons between public transport and car this time again all ratios are higher than 100%, which means that for all routes it takes longer to travel the routes using public transport than to travel the routes using the car. The average ratio is 222%, which is equal to the average ratio of the comparison of public transport and the car during the morning peak, but lower than the average ratio throughout the whole day. The lowest value is 111% and the highest value is 354%. The range of these values is almost as large as the range of the values during the morning peak, which were respectively 115% and 359%. Based on these travel times, rational people have no willingness to change their mode of transportation.

Comparison water taxi and car

The results of the comparison of travel times of the busiest routes during the evening peak by water taxi and car are displayed in table 46.

Origin	Destination	Travel time per km of water taxi (min)	Travel time per km of car (min)	Ratio
39	107	1,96	2,46	80%
55	107	2,17	3,16	69%

Table 46: Comparison of travel times during the evening peak by water taxi and car

Comparing the travel times of the alternative routes by water taxi with the travel times by car of the same routes during the evening peak gives an average ratio of 75%. This means the travel time by water taxi is shorter than the travel time by car. Comparing the average ratio of the travel times during evening peak with the average ratio of the travel times during the morning peak, it can be seen that the average value is higher during the evening peak. Based only on the travel time, when people are rational they will be willing to change their mode of transportation as it costs less time to travel from origin to destination by water taxi than by car.

5.2 Travelling costs per mode of transportation

The travelling costs per mode of transportation of the busiest routes are computed. As seen for the northern direction, the routes of the southern direction of which the travelling costs are computed are the same as the routes of which the travel times are computed. First the travelling costs of travelling by car are computed, then the travelling costs of travelling by public transport and finally the travelling costs of travelling by water taxi. Afterwards, the travelling costs of the modes of transportation will be compared with each other by means of ratios. All values of the southern direction are calculated in a similar way as the values of the northern direction, unless indicated otherwise.

5.2.1 Throughout the whole day

5.2.1.1 Travelling costs per mode of transportation

Car

The total costs of travelling by car and the travelling costs per kilometre for the busiest routes are displayed in table 47.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
16	107	4,8	1,97	€ 0,41
20	100	5,9	2,42	€ 0,41
20	105	4,8	1,97	€ 0,41
23	105	6,2	2,54	€ 0,41
23	107	5,2	2,13	€ 0,41
26	100	5,7	2,34	€ 0,41
26	105	4,6	1,89	€ 0,41
39	107	5,1	2,09	€ 0,41
49	47	4,7	1,93	€ 0,41
49	95	4,7	1,93	€ 0,41
49	96	4,2	1,72	€ 0,41
49	97	4,2	1,72	€ 0,41
49	100	5	2,05	€ 0,41
49	101	4,9	2,01	€ 0,41
49	103	7,4	3,03	€ 0,41
55	107	4,6	1,89	€ 0,41
108	107	4,1	1,68	€ 0,41

Table 47: The travelling costs of the busiest routes by car throughout the whole day

The total costs of travelling a route by car in southern direction are calculated the same way as they were calculated for the northern direction. As explained in section 4.2.1.1 the value of the costs per kilometre for travelling by car have a value of €0,41. Therefore, the average costs per kilometre of travelling by car are also €0,41.

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes throughout the whole day are displayed in table 48.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
16	107	4,8	€ 1,55	€ 0,32
20	100	5,9	€ 1,70	€ 0,29
20	105	4,8	€ 1,55	€ 0,32
23	105	6,2	€ 1,74	€ 0,28
23	107	5,2	€ 1,60	€ 0,31
26	100	5,7	€ 1,67	€ 0,29
26	105	4,6	€ 1,52	€ 0,33
39	107	5,1	€ 1,59	€ 0,31
49	47	4,7	-	-
49	95	4,7	€ 1,53	€ 0,33
49	96	4,2	€ 1,47	**€ 0,35**
49	97	4,2	€ 1,47	**€ 0,35**
49	100	5	€ 1,58	€ 0,32
49	101	4,9	€ 1,56	€ 0,32
49	103	7,4	€ 1,90	**€ 0,26**
55	107	4,6	€ 1,52	€ 0,33
108	107	4,1	-	-

Table 48: The travelling costs of the busiest routes by public transport throughout the whole day

The average travelling costs per kilometre throughout the whole day using public transport is €0,31. The lowest value is €0,26 per kilometre and the highest value is €0,35 per kilometre. Thus, all values have a deviation of €0,05 per kilometre or less.

Water taxi

Throughout the day for two routes the water taxi can be seen as alternative for using the car as mode of transportation. The travelling costs are displayed in table 49.

Origin	Destination	Distance (km)	Travelling costs of water taxi	Travelling costs per km of water taxi
39	107	5,1	€ 7,00	€ 1,37
55	107	4,6	€ 4,50	€ 0,98

Table 49: The travelling costs of the alternative route by water taxi throughout the whole day

The average travelling costs per kilometre of the routes by water taxi are €1,18. In figure 13 of section 5.1.1.1 the alternative routes of the water taxi throughout the whole day are displayed.

5.2.1.2 Comparing travelling costs of the several modes of transportation

Comparison public transport and car

Now the travelling costs per kilometre throughout the whole day for each mode of transportation are known, it is possible to compare them with each other. The travelling costs are compared using ratios. The results of the comparison of the costs of travelling by public transport and car are displayed in table 50.

Origin	Destination	Travelling costs per km of public transport	Travelling costs per km of car	Ratio
16	107	€ 0,32	€ 0,41	79%
20	100	€ 0,29	€ 0,41	70%
20	105	€ 0,32	€ 0,41	79%
23	105	€ 0,28	€ 0,41	68%
23	107	€ 0,31	€ 0,41	75%
26	100	€ 0,29	€ 0,41	71%
26	105	€ 0,33	€ 0,41	81%
39	107	€ 0,31	€ 0,41	76%
49	47	-	€ 0,41	-
49	95	€ 0,33	€ 0,41	80%
49	96	€ 0,35	€ 0,41	85%
49	97	€ 0,35	€ 0,41	**85%**
49	100	€ 0,32	€ 0,41	77%
49	101	€ 0,32	€ 0,41	78%
49	103	€ 0,26	€ 0,41	**63%**
55	107	€ 0,33	€ 0,41	81%
108	107	-	€ 0,41	-

Table 50: Comparison of travelling costs per km throughout the whole day by public transport and car

It is remarkable that all alternative routes have lower costs when travelling by public transport compared to the same routes travelling by car, varying from a decrease in costs of 15% when travelling by public transport to a decrease of 37%. The average ratio is 76%, which means that on average the costs of travelling when travelling by public transport decrease with 24%. Travelling by public transport throughout the whole day is cheaper by public transport than by car, so looking only to the costs of travelling and assuming people make rational choices, it will be the case that people will change their mode of transportation for every route throughout the whole day and switch from using the car to using public transport.

Comparison water taxi and car

The results of the comparison of travelling costs of the routes during the evening peak by water taxi and car are displayed in table 51.

Origin	Destination	Travelling costs per km of water taxi	Travelling costs per km of car	Ratio
39	107	€ 1,37	€ 0,41	334%
55	107	€ 0,98	€ 0,41	239%

Table 51: Comparison of travelling costs per km during evening peak by water taxi and car

Comparing the travelling costs of the alternative routes by water taxi with the travelling costs of car of the same routes during the evening peak gives an average ratio of 287%. This means the costs of travelling by water taxi are on average almost three times as high as the costs of travelling the same route by car. Based only on these travelling costs, and assuming people are rational they will not be willing to change their mode of transportation.

5.2.2 Morning peak

5.2.2.1 Travelling costs per mode of transportation

Car

The costs of travelling via the busiest routes by car during the morning peak are calculated. As we have seen already, the costs per kilometre of travelling by car are fixed at €0,41. Both the total travelling costs as well as the travelling costs per kilometre can be seen in table 52.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
16	107	4,8	€ 1,97	€ 0,41
20	98	5,4	€ 2,21	€ 0,41
20	106	4,8	€ 1,97	€ 0,41
23	107	5,2	€ 2,13	€ 0,41
26	100	5,7	€ 2,34	€ 0,41
39	107	5,1	€ 2,09	€ 0,41
49	47	4,7	€ 1,93	€ 0,41
49	95	4,7	€ 1,93	€ 0,41
49	97	4,2	€ 1,72	€ 0,41
49	100	5	€ 2,05	€ 0,41
49	101	4,9	€ 2,01	€ 0,41
49	103	7,4	€ 3,03	€ 0,41
53	107	5,4	€ 2,21	€ 0,41
55	107	4,6	€ 1,89	€ 0,41
107	100	6,4	€ 2,62	€ 0,41
107	103	8,8	€ 3,61	€ 0,41
107	105	5,2	€ 2,13	€ 0,41
108	107	4,1	€ 1,68	€ 0,41

Table 52: The costs of travelling the busiest routes by car during morning peak

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes during the morning peak are displayed in table 53.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
16	107	4,8	€ 1,55	€ 0,32
20	98	5,4	€ 1,63	€ 0,30
20	106	4,8	€ 1,55	€ 0,32
23	107	5,2	€ 1,60	€ 0,31
26	100	5,7	€ 1,67	€ 0,29
39	107	5,1	€ 1,59	€ 0,31
49	47	4,7	-	-
49	95	4,7	€ 1,53	€ 0,33
49	97	4,2	€ 1,47	**€ 0,35**
49	100	5	€ 1,58	€ 0,32
49	101	4,9	€ 1,56	€ 0,32
49	103	7,4	€ 1,90	€ 0,26
53	107	5,4	€ 1,63	€ 0,30
55	107	4,6	€ 1,52	€ 0,33
107	100	6,4	€ 1,77	€ 0,28
107	103	8,8	€ 2,10	**€ 0,24**
107	105	5,2	€ 1,60	€ 0,31
108	107	4,1	-	-

Table 53: The travelling costs of the busiest routes by public transport during morning peak

The average travelling costs per kilometre using public transport during the morning peak is €0,31, which is similar to the average value throughout the whole day. The lowest value is €0,24 per kilometre, which is €0,07 lower than the average costs per kilometre. The highest value is €0,35 per kilometre, which is €0,04 higher than the average costs per kilometre.

Water taxi

During the morning peak one route by water taxi can be seen as an alternative of using the car as mode of transportation. Its travelling costs is displayed in table 54. The travel time per kilometre is calculated in a similar way as the travel times per kilometre by car and public transport, by dividing the travelling costs of a route by the distance of that same route.

Origin	Destination	Distance (km)	Travelling costs of water taxi	Travelling costs per km of water taxi
39	107	5,1	€ 7,00	€ 1,37
53	107	5,4	€ 4,50	€ 0,83
55	107	4,6	€ 4,50	€ 0,98

Table 54: The travelling costs of the alternative route by water taxi during morning peak

The average travelling costs per kilometre are €1,06. In figure 13 of section 5.1.1.1 the alternative routes of the water taxi during the morning peak are displayed. As mentioned before, the route from origin 53 to destination 107 has the same embarking and disembarking stages as the route from origin 55 to destination 107.

5.2.2.2 Comparing travelling costs of the several modes of transportation

Comparison public transport and car

The travelling costs per kilometre during the morning peak for each mode of transportation are known, so they can be compared to each other. The results of the comparison of the costs of travelling by public transport and car are displayed in table 55.

Origin	Destination	Travelling costs per km of public transport	Travelling costs per km of car	Ratio
16	107	€ 0,32	€ 0,41	79%
20	98	€ 0,30	€ 0,41	74%
20	106	€ 0,32	€ 0,41	79%
23	107	€ 0,31	€ 0,41	75%
26	100	€ 0,29	€ 0,41	71%
39	107	€ 0,31	€ 0,41	76%
49	47	-	€ 0,41	-
49	95	€ 0,33	€ 0,41	80%
49	97	€ 0,35	€ 0,41	**85%**
49	100	€ 0,32	€ 0,41	77%
49	101	€ 0,32	€ 0,41	78%
49	103	€ 0,26	€ 0,41	63%
53	107	€ 0,30	€ 0,41	74%
55	107	€ 0,33	€ 0,41	81%
107	100	€ 0,28	€ 0,41	67%
107	103	€ 0,24	€ 0,41	**58%**
107	105	€ 0,31	€ 0,41	75%
108	107	-	€ 0,41	-

Table 55: Comparison of travelling costs of the busiest routes during the morning peak by public transport and car

During the morning peak all the routes are cheaper to travel by public transport than to travel by car, because all the ratios are lower than 100%. The ratios vary from 58% to 85%, which represents a decrease in costs of respectively 42% and 15%. The lowest ratio during the morning peak is 5 percent point lower than the lowest ratio throughout the whole day. The highest ratio is equal to the highest ratio throughout the whole day. However, the average ratio of the costs of travelling during the morning peak is 74%, a decrease in costs of 26%. This is a decrease of two percent point of the ratio during the morning peak in comparison with the ratio of travelling throughout the whole day.

During the morning peak the costs of travelling by public transport are lower than the costs of travelling by car. Assuming people make rational choices, people will change their mode of transportation for every route during the morning peak. People will save money switching their mode of transportation, so they have an incentive to use public transport instead of the car.

Comparison water taxi and car

The results of the comparison of travelling costs of the routes during the morning peak by water taxi and car are displayed in table 56.

Origin	Destination	Travelling costs per km of water taxi	Travelling costs per km of car	Ratio
39	107	€ 1,37	€ 0,41	334%
53	107	€ 0,83	€ 0,41	202%
55	107	€ 0,98	€ 0,41	239%

Table 56: Comparison of travelling costs per km during morning peak by water taxi and car

Comparing the travelling costs of the alternative routes by water taxi with the travelling costs of car of the same routes during the morning peak gives an average ratio of 259%. This means the costs of travelling by water taxi are higher than the costs of travelling by car. The travelling costs of water taxi vary from two times as high as the travelling costs of car for the same route to well over three times as high as the costs of travelling by car. Based only on these travelling costs, and assuming people are rational they will not be willing to change their mode of transportation.

5.2.3 Evening peak

5.2.3.1 Travelling costs per mode of transportation

Car

The total travelling costs and the travelling costs per kilometre are displayed in table 57.

Origin	Destination	Distance (km)	Travelling costs of car	Travelling costs per km of car
19	107	4,8	€ 1,97	€ 0,41
20	100	4,9	€ 2,01	€ 0,41
23	107	5,2	€ 2,13	€ 0,41
26	100	5,7	€ 2,34	€ 0,41
26	105	4,6	€ 1,89	€ 0,41
39	107	5,1	€ 2,09	€ 0,41
49	47	4,7	€ 1,93	€ 0,41
49	95	4,7	€ 1,93	€ 0,41
49	96	4,2	€ 1,72	€ 0,41
49	97	4,2	€ 1,72	€ 0,41
49	100	5	€ 2,05	€ 0,41
49	101	4,9	€ 2,01	€ 0,41
49	103	7,4	€ 3,03	€ 0,41
49	109	5,2	€ 2,13	€ 0,41
55	107	4,6	€ 1,89	€ 0,41
107	100	6,4	€ 2,62	€ 0,41
107	103	8,8	€ 3,61	€ 0,41
108	107	4,1	€ 1,68	€ 0,41

Table 57: The costs of travelling the busiest routes by car during evening peak

Public transport

The total costs of travelling by public transport and the travelling costs per kilometre for the busiest routes during the evening peak are displayed in table 58.

Origin	Destination	Distance (km)	Travelling costs of public transport	Travelling costs per km of public transport
19	107	4,8	€ 1,55	€ 0,32
20	100	4,9	€ 1,56	€ 0,32
23	107	5,2	€ 1,60	€ 0,31
26	100	5,7	€ 1,67	€ 0,29
26	105	4,6	€ 1,52	€ 0,33
39	107	5,1	€ 1,59	€ 0,31
49	47	4,7	-	-
49	95	4,7	€ 1,53	€ 0,33
49	96	4,2	€ 1,47	**€ 0,35**
49	97	4,2	€ 1,47	**€ 0,35**
49	100	5	€ 1,58	€ 0,32
49	101	4,9	€ 1,56	€ 0,32
49	103	7,4	€ 1,90	€ 0,26
49	109	5,2	€ 1,60	€ 0,31
55	107	4,6	€ 1,52	€ 0,33
107	100	6,4	€ 1,77	€ 0,28
107	103	8,8	€ 2,10	**€ 0,24**
108	107	4,1	-	-

Table 58: The costs of travelling the busiest routes by public transport during evening peak

The average travelling costs per kilometre using public transport during the evening peak is €0,31, which is similar to the average values using public transport throughout the whole day and during the morning peak. The lowest cost per kilometre is €0,24 and the highest cost per kilometre is €0,35. The largest deviation of the travelling costs compared to the average is thus €0,07.

Water taxi
During the evening peak the routes that can be travelled by water taxi as alternative for the car are the same as the routes with the water taxi as alternative throughout the day. Therefore the costs of travelling can be found in table 49 and in figure 13 of section 5.1.1.1 the alternative routes of the water taxi are displayed.

5.2.3.2 Comparing travelling costs of the several modes of transportation

Comparison public transport and car

The travelling costs per kilometre during the evening peak for each mode of transportation are known and they can be compared with each other. The results of the comparison of the costs of travelling by public transport and car during the evening peak are displayed in table 59.

Origin	Destination	Travelling costs per km of public transport	Travelling costs per km by car	Ratio
19	107	€ 0,32	€ 0,41	79%
20	100	€ 0,32	€ 0,41	78%
23	107	€ 0,31	€ 0,41	75%
26	100	€ 0,29	€ 0,41	71%
26	105	€ 0,33	€ 0,41	81%
39	107	€ 0,31	€ 0,41	76%
49	47	-	€ 0,41	-
49	95	€ 0,33	€ 0,41	80%
49	96	€ 0,35	€ 0,41	**85%**
49	97	€ 0,35	€ 0,41	**85%**
49	100	€ 0,32	€ 0,41	77%
49	101	€ 0,32	€ 0,41	78%
49	103	€ 0,26	€ 0,41	63%
49	109	€ 0,31	€ 0,41	75%
55	107	€ 0,33	€ 0,41	81%
107	100	€ 0,28	€ 0,41	67%
107	103	€ 0,24	€ 0,41	**58%**
108	107	-	€ 0,41	-

Table 59: Comparison of travelling costs of the busiest routes during the evening peak by public transport and car

What can be observed from the table is that all ratios are lower than 100%, which means that all routes are cheaper to travel by public transport than by car. The highest ratio and thus the lowest cost reduction is 85%, a decrease in costs of 15%. The lowest ratio and thus the highest cost reduction is 58%, a decrease in costs of 42%. These extreme values of the travelling costs during the evening peak by public transport and car are equal to the extreme values of the costs of travelling by public transport and car during the morning peak and throughout the day. Though, there are differences in the other values of the table.

The average ratio of the costs to travel during the evening peak is 75%, a cost decrease of 25% relative to travelling by car. An average ratio of 75% is between the average ratios of the morning peak and throughout the whole day, which were respectively 74% and 76%, although the differences are almost negligible.

As already seen in the comparison of the costs of travelling by public transport and car during the morning peak, during the evening peak the costs of travelling by public transport are also lower than the costs of travelling by car. Assuming people make rational choices, people will change their mode of transportation from the car to public transport for every route during the evening peak.

Comparison water taxi and car

The comparison of the travelling costs of the water taxi and the car during the evening peak is equal to the comparison of these modes of transportation throughout the day, because the routes are equal. Therefore, the values can be seen in table 51 of section 5.2.1.2.

5.3 Route occupancy during peak hours

As is done for the northern direction, now the occupancy of the routes of the morning and evening peak in southern direction are compared with the average occupancy throughout the day to find out whether the routes are more than average occupied during the peaks. The occupancy of the routes in southern direction are computed in the same way as the occupancy in the northern direction. For this section the same routes are used as the routes in the previous sections of chapter 5.

5.3.1 Morning peak

In table 60 the route occupancy during the morning peak as percentage of the total route occupancy throughout the whole day is displayed.

Origin	Destination	% Morning peak
16	107	21
20	98	9
20	106	10
23	107	13
26	100	14
39	107	25
49	47	10
49	95	18
49	97	10
49	100	14
49	101	6
49	103	12
53	107	24
55	107	19
107	100	16
107	103	13
107	105	16
108	107	13

Route occupancy above 18h average of 22%	
Route occupancy above 24h average of 17%	

Table 60: Route occupancy of the routes during morning peak as percentage of an 18 and 24 hour day

During the morning only a few routes have a higher occupancy than the average route occupancy of an 18-hour day. Most of the values are have a value that is close to the mean with only a few outliers. Of the five routes that have an higher occupancy than the average of an 24-hour day two have an occupancy that is even higher than the average occupancy of an 18-hour day. The average occupancy of the busiest routes during the morning peak is 14,61%. This value is 2,5 percent point lower than the average route occupancy of an 24-hour day. This value is even 7,5 percent point lower than the average route occupancy of an 18-hour day. What is remarkable is that the route occupancy is lower than the average, while theoretically the expectation is that during peak hours the occupancy would be higher than the average. The highest value is 25%, which is 3 percent point higher than the average of an 18-hours day and 8 percent point higher than the average of an 24-hour day. The lowest value is 6%, which is 16 percent point lower than the average of an 18-hour day and 11 percent point lower than the average of a 24-hour day.

5.3.2 Evening peak

In table 61 the route occupancy during the evening peak as percentage of the total route occupancy throughout the whole day is displayed.

Origin	Destination	% Evening peak
19	107	21
20	100	32
23	107	24
26	100	38
26	105	28
39	107	29
49	47	19
49	95	26
49	96	35
49	97	28
49	100	34
49	101	28
49	103	31
49	109	35
55	107	24
107	100	29
107	103	26
108	107	17

Route occupancy above 18h average of 22%	
Route occupancy above 24h average of 17%	

Table 61: Route occupancy of the routes during evening peak as percentage of an 18 and 24 hour day

Remarkable is that all of the routes have an occupancy during the evening peak that is higher than the average route occupancy of a 24 hour day, except one route. Of these routes only two have an occupancy between the 18- and 24-hour day, which means that all others have an occupancy above the 18-hour day average. Contrary to the morning peak, during the evening peak the average route occupancy is higher than the average route occupancy of a 24-hour day and an 18-hour day. The average occupancy of the busiest routes during the evening peak is 28,00%. This is six percent point higher than the average route occupancy of an 18-hour day and 11 percent point higher than the average of a 24-hour day. Most values are close to the mean, with a few outliers upwards as well as downwards. The lowest percentage and the only one that does not exceed the 24-hour day average is 17%, which equals the 24-hour day average.

6. Conclusion and policy recommendations

6.1 Conclusion

With all the results it is possible to find out the routes with the highest potential where local policy makers should focus on to persuade road users to switch from transport mode during the renovation of the Maastunnel. In order to do this, first the routes have been ordered with the ratios of the travel times as leading variable, because people will react more to travel time than to travelling costs. Also travel times are more difficult to compensate with policies than travelling costs. Conclusions will be drawn for the routes in northern direction and southern direction, after which a visual representation of the routes with the highest potential will be presented. Next, policy recommendations will be given to achieve the best traffic situation possible when the Maastunnel will be closed.

All routes that have been used in this research have one ratio above 100% and one ratio under 100%. On the one hand, a shorter travel time will be an incentive for people to switch their mode of transportation, but when switching mode of transportation involves additional costs. So the incentive to switch mode of transportation because of the shorter travel time will be diminished.

On the other hand, a travel time that is a little longer with another mode of transportation than the car, means that this route is cheaper with that mode of transportation. Although people find an increase in travel time annoying, saving money when using the other mode of transportation is an incentive to facilitate a real change.

Regarding travel times it is assumed that people might be willing to change their mode of transportation up to a travel time ratio of 150%, so the routes with a travel time ratio below this 150% are relevant. Policy measures must be taken for real switching mode of transportation. After a ratio of 150% the travel time loss is too large and change in travelling costs will not have any effect anymore. In the following tables, the relevant route are the ones below the bold lines.

6.1.1 Northern direction

Travel times and travelling costs

First the focus will be on the travelling times and travelling costs of routes in the northern direction. In table 62 the busiest routes throughout the whole day with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
5	108	-	-	Public transport
108	107	-	-	Public transport
93	47	408%	83%	Public transport
108	17	378%	85%	Public transport
111	47	315%	81%	Public transport
102	50	280%	83%	Public transport
108	22	277%	76%	Public transport
108	21	261%	77%	Public transport
5	19	243%	78%	Public transport
102	47	231%	81%	Public transport
5	17	176%	71%	Public transport
49	47	158%	80%	Public transport
111	108	150%	65%	Public transport
102	108	149%	65%	Public transport
98	108	140%	69%	Public transport

Table 62: Routes throughout the whole day with corresponding ratios of the travel times and travelling costs

In this period only three routes are relevant for switching mode of transportation without developing further policies.

In table 63 the busiest routes during the morning peak with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
5	108	-	-	Public transport
108	107	-	-	Public transport
108	37	306%	83%	Public transport
102	50	285%	83%	Public transport
111	47	285%	81%	Public transport
108	22	268%	76%	Public transport
108	21	252%	77%	Public transport
102	47	246%	81%	Public transport
108	17	243%	85%	Public transport
110	47	228%	75%	Public transport
98	17	223%	68%	Public transport
111	108	180%	65%	Public transport
2	108	164%	69%	Public transport
98	108	157%	69%	Public transport
5	17	150%	71%	Public transport
102	108	139%	65%	Public transport
108	37	87%	388%	Water taxi

Table 63: Routes during the morning peak with corresponding ratios of the travel times and travelling costs

In this period also only three routes are relevant for switching mode of transportation without developing further policies.

In table 64 the busiest routes during the evening peak with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
5	108	-	-	Public transport
49	47	-	-	Public transport
108	107	-	-	Public transport
108	17	350%	85%	Public transport
93	47	322%	83%	Public transport
102	47	271%	81%	Public transport
108	37	265%	83%	Public transport
108	22	258%	76%	Public transport
108	21	242%	77%	Public transport
5	19	219%	78%	Public transport
102	19	177%	69%	Public transport
102	108	146%	65%	Public transport
5	17	145%	71%	Public transport
93	108	122%	66%	Public transport
108	37	76%	388%	Water taxi

Table 64: Routes during the evening peak with corresponding ratios of the travel times and travelling costs

In this period four routes are relevant for switching mode of transportation without further policy measures.

What we can derive from these tables is that in this research for all periods **the water taxi has lower travel times than the car and public transport has higher travel times than the car**. This is the case, because all travel time ratios for public transport are higher than 100% and all travel time ratios for the water taxi are lower than 100%. For the travelling costs it is the other way around, the travelling costs ratios for public transport are for every route lower than 100% and for the water taxi they are all higher than 100%. It is remarkable that for all periods the routes with lower ratios of the travel times also have lower ratios of travelling costs. This is the case for the routes travelled by public transport as well as the water taxi.

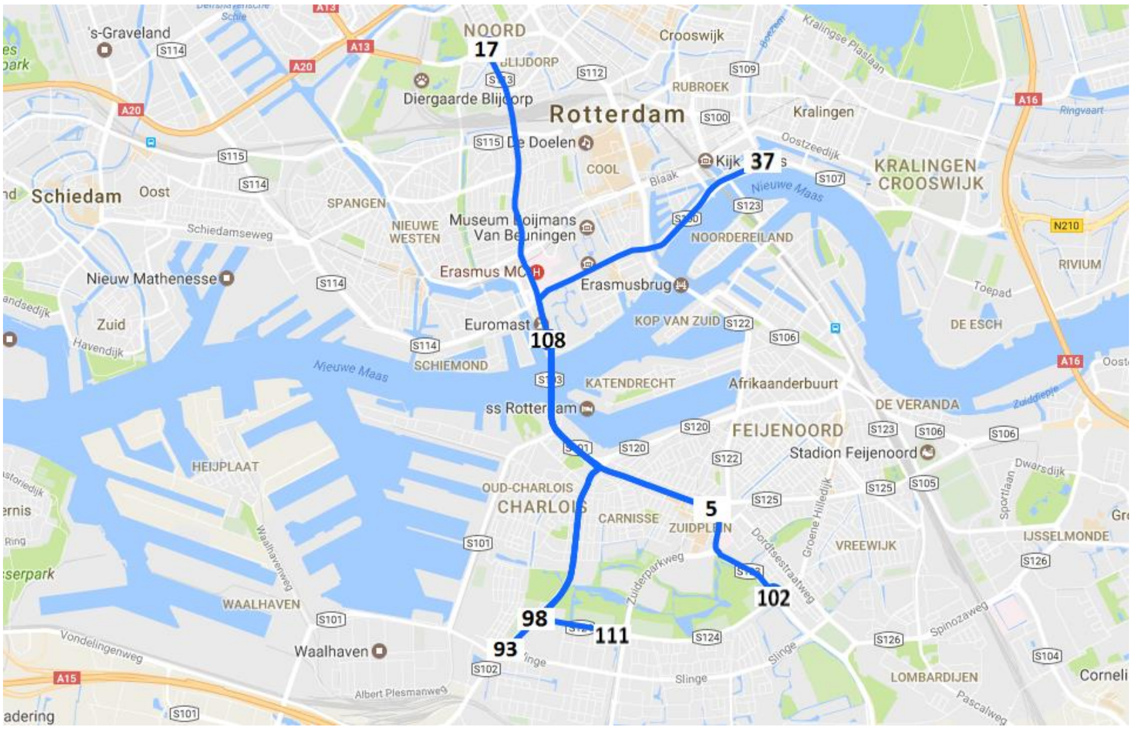

Figure 14: Routes in northern direction with the highest potential to switch mode of transportation (Google Maps)

Route occupancy

In table 65 the averages of the route occupancies of the morning and evening peak that we have seen in the results are displayed.

Morning peak occupancy average	Evening peak occupancy average
21,69%	23,07%

Table 65: Morning and evening peak occupancy averages

The values of the occupancy averages are both around the normal occupancy of a 18-hour day. The occupancy of the morning peak is slightly lower than the average of an 18-hour day and the occupancy of the evening peak is slightly higher. When searching for the best policies to develop, **priority should be given to the evening peak**, because this higher occupancy could cause problems that are more severe than the lower occupancy of the morning peak.

6.1.2 Southern direction

Now the focus is on the routes of the southern direction. In table 66 the busiest routes throughout the whole day with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
49	47	-	-	Public transport
108	107	-	-	Public transport
26	105	308%	81%	Public transport
20	100	306%	70%	Public transport
26	100	306%	71%	Public transport
16	107	289%	79%	Public transport
49	95	280%	80%	Public transport
20	105	277%	79%	Public transport
23	107	261%	75%	Public transport
49	96	252%	85%	Public transport
49	97	242%	85%	Public transport
39	107	237%	76%	Public transport
23	105	210%	68%	Public transport
55	107	199%	81%	Public transport
49	101	193%	78%	Public transport
49	100	183%	77%	Public transport
49	103	136%	63%	Public transport
39	107	76%	334%	Water taxi
55	107	76%	239%	Water taxi

Table 66: Routes throughout the whole day with corresponding ratios of the travel times and travelling costs

In this period only three routes are relevant for switching mode of transportation without developing further policies.

In table 67 the busiest routes during the morning peak with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
49	47	-	-	Public transport
108	107	-	-	Public transport
49	95	359%	80%	Public transport
20	106	280%	79%	Public transport
49	97	276%	85%	Public transport
16	107	271%	79%	Public transport
26	100	262%	71%	Public transport
20	98	258%	74%	Public transport
23	107	245%	75%	Public transport
39	107	244%	76%	Public transport
49	100	208%	77%	Public transport
49	101	200%	78%	Public transport
55	107	186%	81%	Public transport
53	107	176%	74%	Public transport
107	105	173%	75%	Public transport
107	100	151%	67%	Public transport
49	103	146%	63%	Public transport
107	103	115%	58%	Public transport
39	107	79%	334%	Water taxi
55	107	71%	239%	Water taxi
53	107	60%	202%	Water taxi

Table 67: Routes during the morning peak with corresponding ratios of the travel times and travelling costs

In this period five routes are relevant for switching mode of transportation without developing further policies.

In table 68 the busiest routes during the evening peak with the corresponding ratios of the travel times and travelling costs are displayed.

Origin	Destination	Ratio travel time	Ratio travelling costs	Mode of transportation
49	47	-	-	Public transport
108	107	-	-	Public transport
49	95	354%	80%	Public transport
49	96	331%	85%	Public transport
26	105	278%	81%	Public transport
49	97	275%	85%	Public transport
39	107	247%	76%	Public transport
26	100	233%	71%	Public transport
49	109	227%	75%	Public transport
19	107	220%	79%	Public transport
23	107	212%	75%	Public transport
49	100	207%	77%	Public transport
20	100	200%	78%	Public transport
49	101	200%	78%	Public transport
55	107	179%	81%	Public transport
49	103	146%	63%	Public transport
107	100	135%	67%	Public transport
107	103	111%	58%	Public transport
39	107	80%	334%	Water taxi
55	107	69%	239%	Water taxi

Table 68: Routes during the evening peak with corresponding ratios of the travel times and travelling costs

In this period, also five routes are relevant for switching mode of transportation without developing further policies.

What can be derived from the tables of the routes in southern direction is that in contrast to the northern direction the values of the ratios of the travelling costs are more spread when travelling by public transport. For travelling by water taxi this is not the case. Although the lowest travelling cost ratios are corresponding to the lowest travel time ratios, when looking at the higher travel time ratios no clear pattern seems to appear at the corresponding ratios of the travelling costs. Furthermore, as in northern direction, in southern direction all travel time ratios are above 100% when travelling by public transport, but below 100% when travelling by water taxi. This means that for the southern direction also **the water taxi has lower travel times and public transport has higher travel times than the car**. Also the ratios of the travelling costs of public transport are in every case lower than 100% and the ratios for the water are always above 100%.

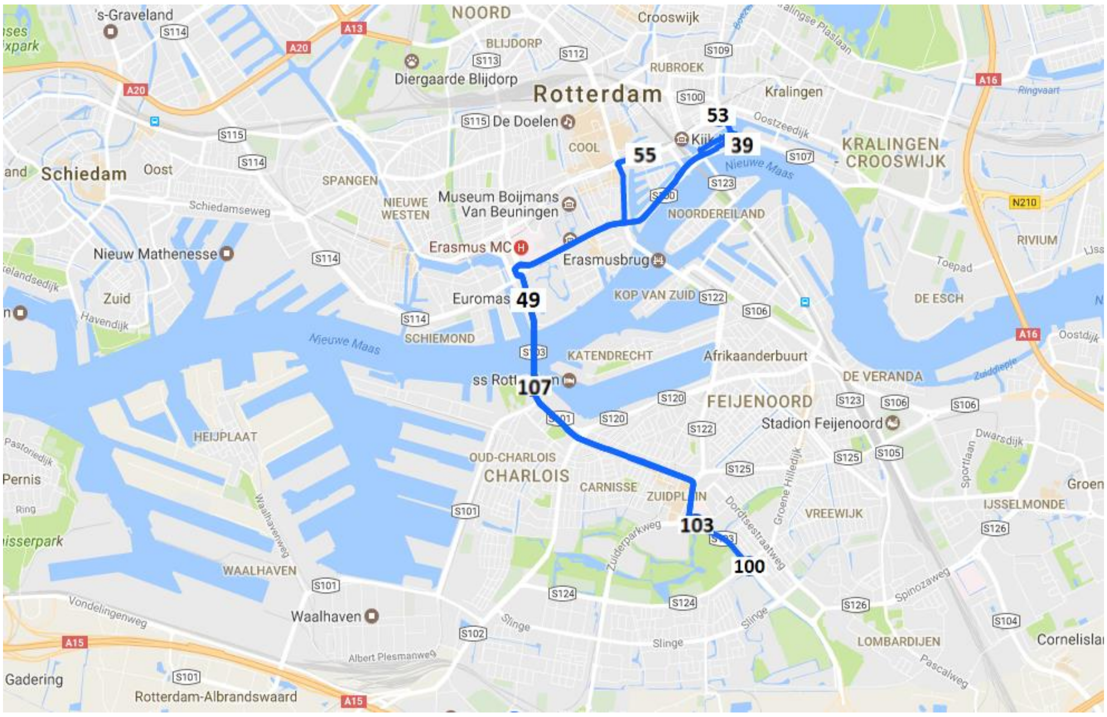

Figure 15: Routes in northern direction with the highest potential to switch mode of transportation (Google Maps)

Route occupancy

In table 69 the averages of the route occupancies of the morning and evening peak that we have seen in the results are displayed.

Morning peak average	Evening peak average
14,61%	28,00%

Table 69: Morning and evening peak occupancy averages

The values of the occupancy averages deviate a lot from the normal route occupancy of an 18-hour day. The occupancy of the morning peak is two third of the average of an 18-hour day and the occupancy of the evening peak is more than a quarter higher than this average. The difference between these values is 14 percent point, which means that when searching for the best policies to develop, priority should be given to the evening peak.

When looking at both table 65 and 69 it can be concluded that the occupancy is the highest is the evening peaks. Especially during the evening peak the routes in southern direction is highly occupied. Thus **the most important period to develop policies for is the evening peak in the southern direction**, as the occupancy average of this period is the highest.

6.2 Policy suggestions

It is now known which routes are of relevance in switching mode of transportation. The aim of this research was to find out which routes have the highest potential for a modal shift, not to find solutions how to achieve a modal shift for these routes. However, to make sure switching mode of transportation actually takes place, policy recommendations should be given. Next are some suggestions for policy recommendations that could be implemented.

Firstly, it is important to **make people aware** of the situation that will arise in general. So providing information about the closure of the Maastunnel is a first step to achieve this. Mass media, such as social media, regional broadcasting or newspapers, are good ways to reach greater audiences. When people are aware of the situation and understand the importance of it, they are more likely to cooperate and are willing to adapt their mode of transportation.

Secondly, the routes with the **water taxi** as alternative mode of transportation have a lower travel time, but rather high travelling costs. For some routes almost four times as high travelling by car. People will not be willing to change to this mode of transportation unless the travelling costs will be decreased. To meet these requirements, **the government could subsidise the use of the water taxi**. With lower travelling costs the high costs barrier is removed and people will switch to this mode of transportation.

Thirdly, to increase the amount of people that will switch their mode of transportation, the government could consider to **reduce the fares of public transport**. The cheaper public transport becomes, the higher the incentive is for people to switch to this mode of transportation. Depending on the governmental budget, offering public transport for free will cause the most people to switch their mode of transportation, which will minimize the congestion problems.

At last, routes shorter than four kilometre could be travelled by bike. Offering a bike sharing system in the city facilitates the choice for people to switch to the bicycle. It will become easier to travel from one place to the other. Also after the renovation of the Maastunnel is finished this bike sharing system could be beneficial when trying to reduce the already existing congestion in the city.

7. Limitations and recommendations for further research

Although this research has been executed thoroughly and with care, some limitations must be put forward.

Firstly, this research is based on data from January 2015. The results of this research could have seasonal effects. The choice of mode of transportation people make could be different during the winter than during other seasons. This could affect the results of the research when collecting and using data from other times of year and thus lead to a different outcome.

Also, the type of weather could affect the actual situation on the road when the Maastunnel will be closed. When the sun is shining, people could think it’s a beautiful day to take the bike for travelling, while when it is raining more people think of taking the car instead. In the data these weather effects could be present too.

For this research is chosen not to consider the cameras at the edge of the city to be sure people have started and finished their trip in the city of Rotterdam. However, it is not a hundred per cent watertight that all detected cars that have been used for this research started their journey in the city of Rotterdam. Some people might have taken back roads to enter the city and then they were detected for the first time by a camera that has been taken account in this research.

In this research is stated that routes with a length shorter than four kilometres can be taken by bicycle. However, there is awareness of the fact that not everyone has the opportunity to travel their trip by bicycle. Some people need a car because they are physically not capable of travelling by bicycle or because their need of a car is work related.

The travelling costs of public transport are based on the distance travelled by car. The actual distance of the routes travelled by public transport differs from the distance travelled by car. The routes travelled by public transport consists of actual travel time inside the mode of public transport and the travel time of walking from and to the station. The ratio of these two elements differ for each route. Therefore, the travelling distance by public transport that is paid for is for one route longer than the same route by car and for another route shorter than the distance by car.

At last is assumed that the costs per kilometre of using the car is based on the average of three sizes of cars. The costs per kilometre may vary per type of car, per type of fuel consumption and the amount of kilometres travelled yearly. For this reason the average cost per kilometre might not perfectly represent the actual cost per kilometre for each car.

With this research, the routes around the Maastunnel with the highest potential for modal split have been found. The findings of this thesis can be used as basis for further research on reducing traffic congestion during the closure of the Maastunnel. The impact of the several suggestions for policy recommendations can be researched to find out what is needed to actually achieve a modal shift and reduce the traffic congestion around the Maastunnel when it is closed for maintenance work.

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