Perception Based Decision-making for Public Transport Investments

Prawesh Brispat

Perception based decision-making

Research regarding the added value of modality perception based analysis for public transport investments.

By

P. Brispat

Student nr. 4190866

in partial fulfilment of the requirement for the degree of

Master of Science
in Transport, Infrastructure & Logistics

at the Delft University of Technology

Faculties of Civil Engineering & Geosciences (CITG),
Technology, Policy & Management (TPM)
and Mechanical, Maritime & Materials Engineering (3mE)

to be defended publicly on **Thursday 26th** October 2017 at **11:30**

Thesis Committee

Prof. dr. ir. Bart van Arem (Chair)	TU Delft CITG – Transport & Planning
dr. ir. N. van Oort	TU Delft CITG – Transport & Planning
dr. J.A. Annema	TU Delft TBM – Transport & Logistics
ir. V. Stevovic	Metropolitan region Rotterdam The Hague

An electronic version of this thesis is available at http://repository.tudelft.nl/

“ A developed country is not a place where
the poor have cars,

It’s where the rich use public transport “

-- Enrique Peñalosa Londoño

Mayor of Bogotá, Colombia

PREFACE

This thesis forms the end result of my graduation research, which finalizes the study Transport, Infrastructure and Logistics (TIL), a multi-faculty master at the Delft University of Technology. I would like to use this opportunity to thank the people that made all of this possible. Thankfully, I was very lucky with the supervision of a very professional and experienced committee. I want to thank the colleagues at MRDH and especially Vesna Stevovic, for the challenging discussions, not only regarding public transport but also interesting subjects like mobility, economic business climate and the influence on everyday life.

A special thanks to Jan Anne Annema, for his help starting from the first day we began as MSc. students, but most importantly for his feedback, tips and contribution during the last couple of months in my research. Our meetings really contributed in a great way to a satisfying result.

Thirdly I would like to thank, Niels van Oort, for providing me with this topic but also his guidance and enormous help throughout the process. Thank you, for providing me with honest criticism, advice and feedback regarding this research but also how to deal with barriers which I came across during the process.

I want to thank Bart van Arem, who has done me the honour as chair in my graduation committee and providing me with feedback during the formal meetings.

Of course, my fellow students, who also became my close friends. We really made some memorable moments, with early mornings and late nights working on our projects. Studying together but also motivating and helping each other to finally reach our end goal.

Finally, many thanks to my friends and family for their help and support during the last couple of years, for believing in me and for all the distractions at the right time. These moments are unforgettable and makes us remember the important things in life.

I can honestly say that I enjoyed my life as a student from the Delft University of Technology. However, sadly, all good things come to an end, and with great pleasure I can look back at one of the most important, memorable and enjoyable phases in life. It also feels great and I am kind of relieved to say that I am truly excited to finally start a new chapter in life with an amazing adventure. With great gratitude.

Prawesh Brispat

Delft, October 2017

EXECUTIVE SUMMARY

In the Netherlands it is mandatory to conduct a Cost-Benefit Analysis (CBA) for large transportation infrastructure projects. Although this method is widely used it still has disadvantages such as not taking into account all stakeholders and only using a utility-based approach. Another disadvantage is that CBA approaches decision-making only from a monetary point of view. Multi-criteria decision-making (MCDM) can be a solution to address these disadvantages because this analysis can include different stakeholders and non-monetary effects in the decision-making. Such a case can be made for public transport decision-making, where multiple important stakeholders are involved. Having the possibility to take into account the interests of the most important stakeholders, could potentially lead to better decision-making. There is a lack of research on the usefulness and applicability of MCDM for public transport projects in the related literature.

The objective of this research is to investigate whether a perception based method adds valuable information to the decision making process for governmental organizations. The following research question is formulated to achieve the objective of this research:

What is the added value for governmental authorities, of a perception-based mode choice method for public transport investments?

To answer the research question the following 5 sub-questions are identified:

1. Which MCDM method suits best for a perception based analysis?
2. Which criteria are important for comparison of public transport modalities and why?
3. How do the comparison factors score on level of importance for different stakeholders?
4. Which public transport system suits best for implementation according to the perceptions of the stakeholders?
5. To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

There are a number of steps required to answer these questions. First, a suitable MCDM method was selected. After this, relevant data and criteria were identified on which the different Public Transport modalities can be compared with each other. The weights represents the importance of the criteria and indicate the perceptions of the involved stakeholders. Third, the selected method and criteria was tested using general Public Transport information. This step investigated if the results are as expected and are able to answer the questions that need to be answered. After this phase, the model was applied on two case studies to obtain the perceptions of the important stakeholders and to evaluate with decision-makers if the method resulted in 'added value'.

After a thorough literature review, a comparison was conducted between the MCDM methods that were selected. MAMCA (Multi-actor multi-criteria analysis) was chosen to conduct a perception-based analysis. Mainly because it takes into account the perception of different stakeholders, which plays an important part in the decision-making process of public transport investments. To obtain weights for the criteria, the Best-worst

method (BWM) is chosen that served as input for the MAMCA. The BWM was chosen accounting for the following reasons:

- Less data is needed (compared to other methods)
- It leads to more consistent comparisons, which results in reliable results
- BWM can be combined with other MCDM methods
- BWM is a simple method to perform; comparisons are performed with integer numbers ranging from 1 to 9.

After the MCDM method was determined, the important stakeholders (Government, Passengers and Public Transport Operators), and important criteria for the stakeholders were identified. By conducting a literature review, desk research, and interviews (with 5 employees of each group and 15 passengers), a list of criteria is identified. These criteria are necessary when selecting upon different public transport projects. The important stakeholders, their criteria and the corresponding weights are presented in Table 1. These weights are used to indicate the perceptions of the stakeholders. They represent the importance of each criterion compared to the other ones as determined by each stakeholder.

TABLE 1. STAKEHOLDERS, CRITERIA AND THEIR CORRESPONDING WEIGHTS

Passengers	**Wp**	**Government**	**Wg**	**Operators**	**Wo**
Frequency	0.18	Operational costs	0.14	Frequency	0.13
Punctuality	0.11	Punctuality	0.06	Subsidy	0.12
Passenger Safety	0.10	Passenger safety	0.06	Passenger safety	0.11
Operational speed	0.18	Liveability inhabitants	0.08	Operational speed	0.11
Accessibility PT system	0.07	System Capacity	0.13	System Capacity	0.12
Travel information	0.09	Passenger Forecast	0.15	Passenger forecast	0.21
Image	0.05	Maintenance costs	0.12	~~Political consideration~~	---
Travel comfort	0.09	Flexibility	0.11	TCO	0.16
Ticket price	0.12	Investment costs	0.16	Ticket price	0.04
Sum	1.00		1.00		1.00

The criterion **Political Considerations** is one of nine of the most important criteria for the public transport operators. Despite the high importance of this attribute, this factor will not be taken into account in further analysis as it not easy to estimate accurately. The **Passenger Forecast** can be considered the most important criteria from the operator's perspective, followed by the **Total Cost of Ownership**. The **Ticket Price** is identified as least important criterion and attributing to the fact that the price per km is determined by law and independent of the system.

The criteria **Investment Costs** and **Passenger Forecast** can be characterized as the two most important criteria according to the government's point of view. The investment costs is the most important criterion because the government is responsible for the investment, maintenance and operational costs for the transport systems. The least important criteria, from the government's perspective, are **Punctuality** and **Passenger Safety**. The importance of the passenger forecast for both groups can be attributed to the fact that this represents expected passengers the system at least should be able to handle. When the demand is known, the system(s) that can cope with this demand can then be identified.

Table 1 indicates that the passengers highly value the criteria **Frequency** and **Operational speed**. On the contrary, criterion **Image**, which represents the idea passengers have regarding the system, is identified as the least important criterion. From these observations the following conclusion can be drawn:

Passengers appear to be indifferent with regards to the type of public transport system. The important characteristics of the system should include a high operational speed and a high frequency.

Through extensive literary research, the corresponding values (e.g. Investment costs, average operational speed, average frequency etc.) per public transport modality (e.g. bus, metro and so forth) for the criteria were determined.

After executing the MAMCA analysis and multiplying the above-mentioned values with the weights, the results shown in Table 2 are obtained. National data is used to calculate the perceptions. The bus is used as a benchmark to compare the different alternatives. A scale is used between -1000% and 1000% to display the preference of the systems. The table shows the perception of the modes and how these score for each stakeholder, compared to the bus. As seen from a passenger's point of view, the tram for example, is perceived (just 2%) lower than the bus.

For the Public Transport Operators, it can be concluded that, in general, the perception of systems with a dedicated infrastructure (LRT, BRT, Metro and Tram) are preferred over systems with mixed infrastructure (Bus and eBus). The bus scores low due to the low Passenger forecast, Earnings, System capacity, Operational speed and Frequency. The BRT scores high due to the higher earnings, high operational speed, low costs, average passenger forecast and system capacity. The LRT scores high because of high passenger forecast and therefore high earnings, the higher frequency but also the low passenger safety costs.

From the government's point of view, it can be concluded that, in general, they share the same opinion regarding BRT and LRT as the operators. The metro however, is perceived as lowest due to the high costs (investment, maintenance, operational and passenger safety). The BRT gets a high preference due to the low operational, investment and passenger safety costs. The high flexibility of the system and its average capacity also contribute to perception. The LRT is preferred highest from the governments perspective due to low operational costs, the high influence on the liveability the high passenger forecast and system capacity.

Furthermore, passengers appear to be rather indifferent regarding public transport systems. This observation in combination with the high preference for operational speed and frequency indicates that passengers value a system that has a high operational speed and frequency. The characteristics of the system (e.g. road- or rail-based) matter less.

TABLE 2. RESULTS GENERAL PERCEPTION ANALYSIS

Stakeholders\Modality	Bus	Tram	Metro	BRT	LRT	eBus
Passengers	0%	-2%	0%	-1%	-1%	1%
Government	0%	2%	-17%	4%	5%	1%
PT operators	0%	32%	37%	45%	49%	-4%

An interesting observation that can be derived from the table is that the eBus scores slightly higher compared to the bus from the passengers and governments point of view. However, this 1% difference, on a scale of [-1000%, 1000%] is negligible. It is expected that this very small perception difference occurs due to the better image of the system and the higher travel comfort. Using an electric bus positively contributes to the acceleration of the bus and a more sustainable system. The government perceives the eBus higher due to the lower operational costs compared to a conventional diesel bus. The Operators however, perceive the eBus lower than the bus. The reason for this is the lower system capacity (60 passengers eBus vs. 90 passengers Bus) and therefore also a lower passenger forecast.

Case Studies

After the general perceptions are calculated, the method was applied on two case studies. Figure 1 below shows on the left, a map of tramline 12 in The Hague (Case Study A) and on the right Bus line 44 in Rotterdam (Case Study B). With regards to the values of the case studies, a mix of general data and case specific data is used to calculate the perceptions.

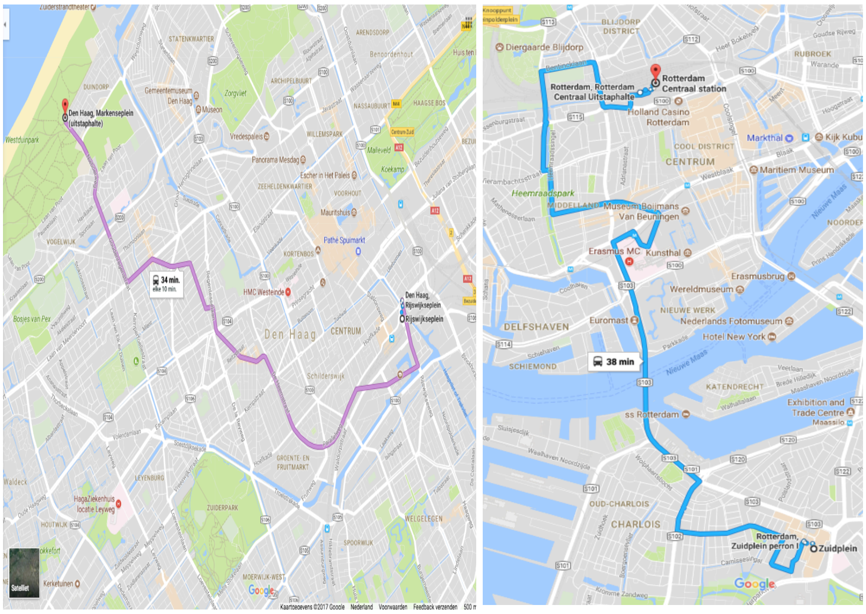


FIGURE 1. LEFT: TRAM LINE 12 HTM; RIGHT: BUS LINE 44 RET

The <u>first case study</u> examines tramline 12 of HTM where plans are to transform this line into a bus system. The tramline performs worse compared to average and governmental authorities are hesitant about the continuity of the tram system. The results shown in Table 3 describe two alternatives for the current tramline. In both alternatives a bus line will replace the current tramline. The first alternative will use a conventional bus of 12 meters while the other will make use of an 18-meter bus.

The results indicate that, from a passenger's point of view, the current scenario (tram) is preferred higher compared to the two bus alternatives. However, the general perception showed that passengers lightly prefer a bus system to a tram system. This is because the Passenger safety, Operational speed, accessibility of the system, Travel information, Image of the system, Travel comfort and Ticket price are perceived more positive in a bus system. In the case study however, the punctuality and operational speed are higher of a tram compared to a bus. Furthermore, the case study uses data from the MRDH region whereas for the general perception, national data is used. Therefore, the following criteria of the tram are perceived higher by the passengers: Punctuality, Passenger safety, Operational speed, Accessibility and Image of the system, Travel comfort and Ticket price.

With regards to the perception of the government and operators, the results from the first case study also tend to show a little contradictory information compared to the general perception. From the general perception, both stakeholders prefer the tram to the bus. In Case Study A however, both bus scenarios are preferred over the tram scenario.

The government prefers, in general, a tram to a bus because of lower operational costs, higher passenger forecast and a higher system capacity. In the first case study however, the government perceives a bus to a tram because of lower investment, maintenance and passenger safety costs. A higher forecast due to the frequency bonus and a higher flexibility of the system.

In general, the Operators prefer, a Tram to a Bus because of the higher passenger forecast and earnings, higher system capacity, frequency and operational speed. In the first case study however, the bus is perceived higher due to the higher frequency. The increase in frequency leads more passengers due to the frequency bonus and therefore, higher earnings. Furthermore, the bus has lower costs (TCO and passenger safety costs).

In conclusion, the operators and government prefer both bus systems to the tram scenario. The passengers have a very slight preference for the tram scenario.

TABLE 3. RESULTS CASE STUDY A TRAM LINE 12 TO BUS HTM

Stakeholders	Tram Current	Bus 12m Scenario 1	Bus 18m Scenario 2
Passengers	0%	-2%	-9%
Government	0%	111%	118%
Government (- investments)	0%	29%	35%
Operators	0%	33%	28%

The second case study examines bus line 44 of the RET, where the plan is to transform this line into a tramline. This bus line overperforms compared average bus lines and governmental authorities are thinking about transforming the bus line into a tramline.

The results are shown in Table 4. The alternatives that are considered for this case are trams with different frequencies. The first alternative is a tram with frequency 3.2, whereas the second alternative is using a tram with frequency 4 and the last alternative, a tram with a frequency of 5. The bus in the current scenario has a frequency of 6.5.

All three stakeholders show a higher preference for the current bus system compared to the tram systems. Only the tram scenario with a frequency of 5 trams is preferred slightly higher from a passenger's point of view. This is because of the frequency bonus. The passengers perceive the punctuality, Passenger safety, Operational speed, Accessibility and Image of the system, Travel information, and Travel comfort of the tram higher compared to bus. Still, with a lower frequency, the system is not attractive enough.

The government prefers the current bus scenario to all tram scenarios because of a higher passenger forecast, lower passenger safety costs and a higher flexibility. Furthermore, the (extra and high) investment costs of the tram also contribute to a lower perception of the tram. The general perception however, shows that the government prefers the tram to a bus system. This is due to lower operational costs, higher passenger forecast and a higher system capacity.

As seen from the operator's perspective, in this case, the current bus scenario is preferred to all tram scenarios because of higher passenger forecast and earnings, higher frequency and lower costs (TCO and passenger safety). The general operators perception differs compared to that of the 2nd case study. In general however, the tram is preferred to a bus because of the higher passenger forecast and earnings, higher system capacity, frequency and operational speed.

In conclusion, the operators and government prefer the bus to the tram system. The passengers have a very slight preference for the tram scenario.

TABLE 4. RESULTS CASE STUDY B RET BUS LINE 44 TO TRAM

	Bus	Tram 3.2	Tram 4	Tram 5	Tram 8
Passengers	0%	-3%	1%	3%	11%
Government	0%	-18%	-19%	-18%	-31%
Operators	0%	-33%	-24%	-12%	-5%

Table 4 displays that the perception of the passengers and operators, positively changes when the frequency increases. The increase in frequency leads to a higher amount of passengers which results in higher revenues (earnings) for the operators. The benefits of a higher passenger forecast and higher revenues exceed the extra costs. The perception of the government however, changes more negatively with an increase in frequency. This is because of the higher costs. However, as shown in section 4.6, each public transport system has its own benefits and contributes on its own way to, for example, the economic development and/or accessibility of the region.

Table 5 shows for each system the corresponding benefits and the importance of the benefit. The "++" sign indicates highly positive compared to the other modalities while "+" sign indicates a positive contribution compared to the other modes. As can be seen, the economic development (of the surrounding region) of the metro and LRT is highest compared the other modalities.

TABLE 5. WIDER BENEFITS OF PUBLIC TRANSPORT

Benefits	Metro	Tram	Bus	eBus	LRT	BRT
Accessibility of the region	++	++			++	++
Emissions	++	++		++	++	
Flexibility			++	++		
High Earnings	+				+	+
High frequency	+	+			+	+
Economic development	++	+			++	+
Operational speed	++				++	+
Passenger safety			+	+		+
Property values	+				+	+
Punctuality	+	+			+	+
Travel comfort			+	+		
Walking distance to stop			++	++		+

Conclusions

In both case studies, the operators and government prefer the bus systems to the tram systems because of lower costs and more passengers. Resulting from the general perception analysis and the case studies analysis, it appears that passengers prefer a system with a high frequency and operational speed (and show indifference regarding the other characteristics of the system).

So, in this thesis a method is developed that enables to calculate the perceptions of important stakeholders in the decision-making process of public transport investments. The purpose of a new chosen public transport system is to maximize the level of satisfaction among the users. According to the policy advisors, who advise the policy decision-maker, the added value of this method could lead to other decisions. For that reason, MCDM can be used as an additional tool to provide more and other insights in the perceptions of the involved stakeholders and result in a more transparent decision-making process. Furthermore, the government and operators (who decide one the system) are able to use this information to maximize the satisfaction of the chosen system. By knowing which criteria affect the perception of the passengers, these criteria can be changed with the goal to positively change the perception.

It is more difficult to use this method as a decisive tool because of the following two reasons. Firstly, passengers do not have any financial resources and administrative powers. Secondly, passengers do not experience the negative impacts of the implementation of a wrong choice regarding public transport systems.

Furthermore, this research did not take into account the criterion, **political considerations**, but may be an important aspect for further research because there are still decisions made based on this factor. A practical recommendation is to increase the consistency in the KPI's on which the various operators are compared with each other. Additionally, when conducting this method it is recommended to use as much case-specific data as possible.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Public transportation keeps getting more and more important in daily life (APTA, 2016) (HSLHRT, 2013) (PTV, 2013). With different modalities becoming faster, safer, more comfortable, easier to access, more sustainable and widely available, the threshold to use these systems becomes even lower (Millard-Ball & Schipper, 2010). Taking into account the decrease in car ownership (Eenink & Vlakveld, 2013), the growth for mobility services and mass transit developments, it is no doubt that the level of decision-making processes, regarding investments for public transport systems, also should increase (Provincie Gelderland, 2016).

In general, the total costs for public transport exceed the revenues the operators earn (NZTA, n.d.) (Veeneman & Mulley, 2017). The majority of the earnings received from ticket revenues are not sufficient to cover all investment, maintenance and operational costs that come with public transport services. This means that the (local) governments almost always have to subsidize these systems to support the gap between costs and benefits to provide enough transport facilities (The International Association of Public Transport , 2013).

The last couple of years the total budget for public transport investments kept decreasing while management and maintenance costs of these systems kept increasing (MRDH-OV, 2013). This is quite beneficial for innovations in the transport sector because this motivates to come up with modern solutions for optimal utilization of the current infrastructure. However, lower availability of investments does not encourage design, implementation and construction of new public transport projects. This can be highly disadvantageous, especially for newly developed urban areas. The decision-making process regarding public transport investments needs to improve and taking into account that a great amount of stakeholders are involved, does not make this process easier.

This research will analyze the perception of important stakeholders regarding public transport investments and analyze whether this perception has any added value in the overall decision-making process regarding public transport investments. Section 1.1 will elaborate more on the problem definition and explain in more detail what exactly the problem is. Section 1.2 will propose a research objective, present the main research question and provide sub-questions, which will help to answer the main research question and reach the objective. Section 1.3 will explain the scientific and societal relevance of this research and section 1.4 will elaborate more on the scope of this research. An explanation will be provided in terms of why certain aspects are taken into account and why some of them are not. Section 1.5 will serve as a division where the report structure is presented. This chapter will finalize with section 1.6 where the thesis outline will be described.

1.1 PROBLEM DEFINITION

The increasing costs for public transport and lower budgets for investments makes the process regarding selection of public transport investments more and more difficult. When deciding upon public transport projects, decisions usually are supported by appraisal methods such as a Cost-benefit analysis (CBA) or a Multi-criteria analysis MCA (Bristow & Nellthorp, 2000). In the Netherlands it is, since 2000, mandatory to conduct a CBA for (large scale) infrastructure projects (Annema, Koopmans, & van Wee, 2007). However, as described by Annema et al. (2016), there is more and more evidence that a CBA only has limited impacts in the decision-making process. This immediately raises the question, why this analysis is still being used, with its limited impacts. Furthermore, this also makes you wonder what kinds of other appraisel methods exist, which are more suitable and possibly could have more influence in the policy process.

One major disadvantage of a CBA, as explained by Kopp, Krupnick & Toman (1997) and Kelman (1981), is the utility-based approach. This approach does not make any distinction in impact for every stakeholder. Individual preferences, whether they are positive or negative, are not taken into account. This asks for a method that can take different perceptions into account and is less utilitarian based. However, there is little information available about perception-based decision-analysis methods due to lack of research. Furthermore, monetization of some aspects may be difficult, especially effects with high uncertainty or ethical effects, which may result in inaccurate estimations. Another disadvantage of a CBA are the welfare gains. Effects are calculates by means of benefits in social welfare. However, this does not always mean that a policy should be implemented (Weisbach, 2014). When using different discount rates, the results of a CBA also can differ resulting in implementation of different policies.

To take into account the use of ethical, non-ethical and difficult effects, a multi-criteria decision-making (MCDM) method may be an alternative, as suggested by van Wee (2011). This method is also able to deal with the involvement of different stakeholders in the project (Thomopoulos, Grant-Muller, & Tight, 2009). MCDM also is a method often used for transport appraisal projects and projects with environmental or social effects (Lahdelma, Salkminen, & Hokkanen, 2000). However, there are also some downsides using this MCDM method. The weights assigned to the criteria can be subjectively determined which may question their accuracy. Another downside is the possibility for manipulations throughout the analysis, but this also can occur when conducting a CBA.

By making use of MCDM methods, different stakeholders involved in the projects and qualitative and quantitative data can be taken into account to determine different perceptions of groups regarding public transport systems. By making use of analytical models, MCDM structures and decomposes complex decision-making problems and makes the process manageable; to eventually provide enough information to make a decision (Scholten, Maurer, & Lienert, 2017).

Until now, it is unknown if and how perceptions of various stakeholders add any value in the decision-making process regarding public transport investments. Not much research can be found regarding this subject which leads to a (knowledge) gap regarding perception-based methods and their contribution to help governmental authorities in their decision-making process. To solve this problem and therefore close this gap, this thesis will investigate whether such a method adds valuable information in the process of public transport investments for various modalities. This research is conducted in collaboration with the Metropolitan Region Rotterdam The Hague (MRDH). Therefore, the results will be discussed with policy decision makers from this organization.

To obtain the perceptions of the important stakeholders in the decision-making process, a closer look is necessary at what perception actually is or how this term can be defined. This will contribute to interpret the perception-based information, which results from the analysis conducted in this thesis. The following definitions of perception can be found in literature: The Cambridge Dictionary defines perception as (Cambridge Dictionary, n.d.):

''A belief or opinion, often held by many people and based on how things seem ''

Two definitions of perception that can be found in the Oxford Dictionary (Oxford dictionary, n.d.):

'' The neurophysiological processes, including memory, by which an organism becomes aware of and interprets external stimuli ''

'' The way in which something is regarded, understood, or interpreted ''

The Free Dictionary's definition of perception is as follows (The Free Dictionary, n.d.):

'' An interpretation or impression; an opinion or belief ''

Perception as defined by Schacter, Gilbert & Wegner (2011) is the identification and interpretation of information, with the goal to represent and understand that information or its environment.

Most of the definitions seem to have various aspects in common such as, *interpretation, understanding* and *opinion* with regards to what perception actually is. Applying these aspects on public transport from a customers point gives a more understandable meaning on what exactly can be understood from perception in public transport. Keeping in mind the three above-mentioned characteristics of perception results in the customers' interpretation and opinion about their experience and understanding of the service quality of public transport.

Perception of public transport as seen from the government's point of view differs compared to that of the passengers. By collecting the opinion of many passengers about public transport and how they experience different modalities, a perception of that specific group and how they experience public transport can be created.

The government provides subsidies to the public transport operators and decides upon the location, design and implementation of transport systems. With regards to the perception of the government, public transport needs to be able to transport passengers in a clean, safe and efficient way and contribute positively to the image of the environment. Hence, the government will take into account other aspects when deciding which public transport system suits best, compared to the other stakeholders. The same applies for the public transport operators. As described in section 4.2, the goal of the PT operators is to transport their passengers in the fastest, safest, cheapest way possible.

1.2 RESEARCH OBJECTIVES

The objective of this research is to investigate whether a perception based method adds any valuable information in the decision making process for governmental organizations. This thesis will elaborate more on the different multi-criteria analyses and select the one that is most suitable representing perceptions of different stakeholders. After the important stakeholders are determined, a list of criteria is constructed which will serve as comparison factors for public transport modalities. These comparison factors are criteria upon which public transport systems can be compared with each other. Each stakeholder decides which system suits best based on their own set of criteria. When the important criteria are determined and assigned to each stakeholder, the weights corresponding with the criteria can be determined. The weights will be determined by conducting surveys at each stakeholder. These weights indicate the importance of each criterion compared to the others. By multiplying the weights with the values of the criteria, the preference of each system can be determined. Furthermore, by making use of a case study, the selection method will be presented and the results will be discussed and validated with policy decision-makers.

The objective of this research will be reached by answering the following research question:

What is the added value for governmental authorities, of a perception-based mode choice analysis for public transport investments?

To solve this problem, this research will obtain the perceptions of the important stakeholders in the decision-making process and discuss the results with a policy decision-maker. This discussion will provide more insights regarding, if and how this information can be used in the decision-making process.

To help answer the main research question, a set of sub-research questions are formulated which will provide supportive knowledge and structure the research. The first sub-question will compare which MCDM (Multi-Criteria Decision-Making) methods currently are used for public transport appraisal and which one suits best for a perception-based analysis. A more detailed explanation of how this method is chosen is explained in chapter 3 and Appendix II. The following sub-question will help to provide the correct information:

1. Which MCDM method suits best for a perception based analysis?

Furthermore, before selecting a public transport mode, it is important to know the strengths and weaknesses for each modality. This is done by comparing the modalities on different criteria. The second sub-question helps to find a suitable list of comparison factors using the 5xE framework developed by van Oort, van der Bijl & Maartens (2016). This list presents the costs and benefits of public transport on which the modalities can be compared with each other.

2. Which criteria are important for comparison of public transport modalities and why?

When the comparison factors are known, weights are assigned with the goal to illustrate the importance of each criterion compared to the other ones. Some criteria are more important compared to others and by assigning weights to them this will compensate for the unbalance. Furthermore, some stakeholders will assign different values to different criteria because of their perception of each mode. The third sub-question results in a list of criteria and their weights for each stakeholder.

3. How do the comparison factors score on level of importance for different stakeholders?

Once the important comparison factors are known, together with their weights, the method can be tested. By multiplying the weights with the values corresponding with the criteria a perception of the important stakeholders and the modalities is obtained. After testing the method, the case study is executed. The case study serves as the final quantification step in the method where the weights and criteria are applied and multiplied with the scores (information) from the case. This generates an output where a value is assigned to each modality on which they are compared. From this comparison analysis, one of the public transport systems is depicted as the most desirable for each group. This information then, is presented and discussed with the policy decision-maker to investigate whether and how this adds any value to the decision-making process.

One of the requirements the case has is that it has to be a Dutch transport project, preferably in the Randstad region. The MRDH operates mainly in the Rotterdam–The Hague region. For this reason, a project for the case study is chosen within this area. Furthermore, there should be enough and up-to-date data available. Also, recent data needs to be available and because transport projects, on average, take 30-40 years before they are put into service. The project for the case study, therefore, should not be older than 30-40 years. Projects in this area are projects with a complex environment where different modalities are involved, especially compared to other areas within the country:

4. Which public transport system suits best for implementation according to the perceptions of the stakeholders?

Finally, the results of the case study are discussed and validated with two policy decision-maker. This step is executed to check if and how this information contributes to the decision-making process regarding the selection of public transport investments. The final and following sub-question will be answered:

5. To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

1.3 SCIENTIFIC AND SOCIETAL RELEVANCE

The scientific relevance of this research is to give insight in the fact, whether a MCDM method can be used in decision-making process compared to the conventional CBA. Furthermore, this research provides an answer how MCDM can be used to visualize perceptions of important stakeholders regarding different public transport systems, which also contributes to the scientific relevance.

By providing information about, if and how perceptions of various stakeholders add any value in the decision-making process of public transport investments, contributes to the societal relevance.

Furthermore, by developing a perception-based model, the selection method for public transport investments, for governmental authorities might become easier. Secondly, this research will visualize the benefits of public transport. By providing more insight in the stakeholders perceptions, a more transparent decision-making process could be obtained. Better decisions eventually lead to higher qualitative public transport facilities. Not only local governments, but also inhabitants and surrounding companies, will profit from higher quality public transport facilities. Finally, this research will use the 5xE framework developed by van Oort, van der Bijl & Maartens (2016) to visualize the costs and benefits of public transport (modalities).

1.4 SCOPE

This entire research is executed from the perspective of MRDH. The main focus of the MRDH and its activities lies in this metropolitan region (Figure 2). For this reason, the geographical scope of this research lies within the metropolitan area Rotterdam The Hague. This area also develops the majority of the public transport projects in The Netherlands, which should provide more than enough of the necessary knowledge and information. Furthermore, this area has a complex network making it more interesting to conduct a case study. Finally, the MRDH also mainly works together with regional public transport operators. For this reason, the scope of this research will only focus on regional public transport.

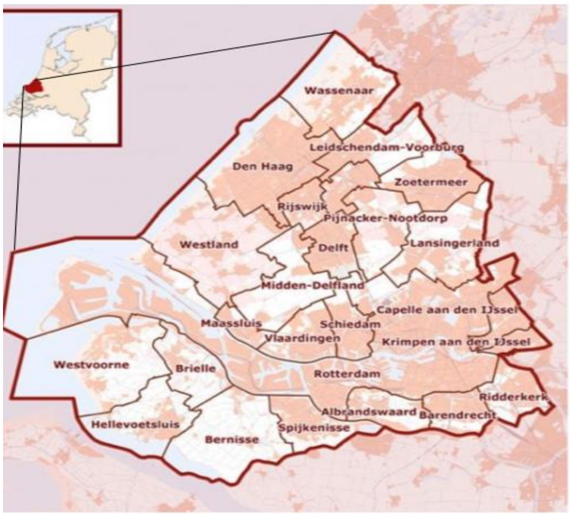


FIGURE 2. OPERATIONAL AREA MRDH

1.5 REPORT STRUCTURE & THESIS OUTLINE

Figure 3 shows the report structure and methodological steps used in this research. In the problem definition, the introduction of the problem is introduced together with the main research questions and sub-questions.

Secondly, in the Literature review phase, information is gathered regarding various Multi-criteria Decision Making (MCDM) methods to determine the method that suits best to tackle the problem (Chapter 3). This will provide an answer for the first sub-question.

After the method is selected, relevant data and criteria need to be identified making comparison possible between the different modalities.

Now that the selected method and criteria are defined, the model is going to be validated in chapter 4, using general Public transport information. This chapter investigates if the results are as expected and can answer the questions that need to be answered and gives an answer to the third sub-question.

After validation, chapter 5 applies the model on two case studies to obtain the perceptions of the important stakeholders and the modalities. Calculating the perceptions, gives insight in which factors need to be changed to make the system more attractive. This chapter will provide an answer to the fourth sub-question.

The final step of this research is to discuss the results with the decision makers (chapter 6) to investigate if and how the perception based analysis adds any value in their decision-making process. This chapter will elaborate more on this discussion and by serving as a validation for the policy decision-makers an answer will be provided to the last, fifth, sub-question.

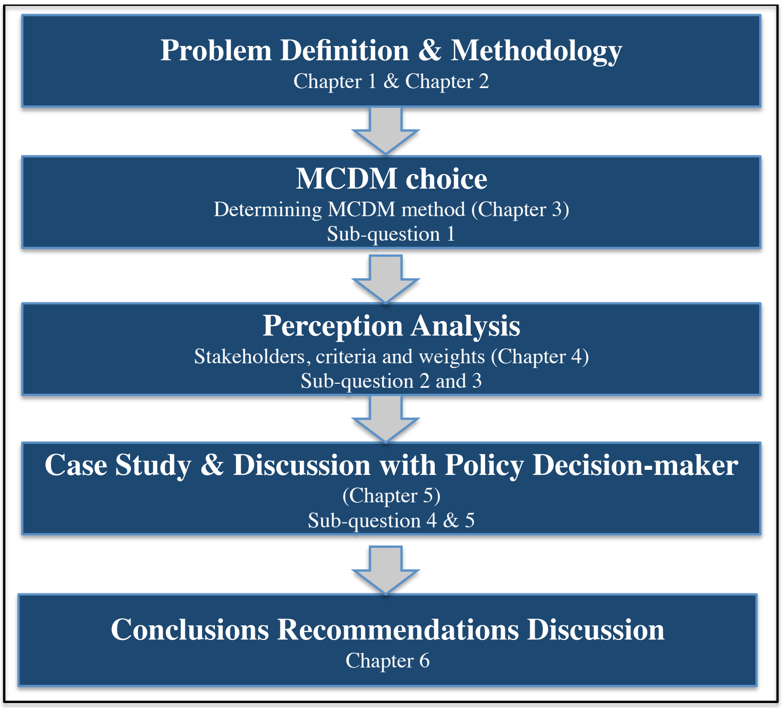


FIGURE 3. REPORT STRUCTURE

CHAPTER 2. METHODOLOGY

This chapter gives a description about the methodology and approach used in this research to find an answer to the main research question. This also gives insight in the kind of information that is used, where it is gathered from, why this needs to be analyzed and how it contributes to this research.

2.1 RESEARCH METHODS

To reach the objective of this research and answer both the main research question and sub-questions, different kind of methods are used. Besides using personal observations, different methodologies are used for gathering and analyzing data. Below are different methodologies described, which were used in this research:

1. Literature review
2. Desk Research
3. Interviews
4. Surveys
5. Data analysis
6. Multi-criteria decision making
7. Case study

2.2 LITERATURE REVIEW

Firstly an important part of this research is the literature review. The literature review is used to answer the first sub-question (1. Which MCA method suits best for a perception based analysis?). In combination with a desk research and interviews, an answer is provided for the second sub-question (2. Which criteria are important for comparison of public transport modalities and why?). This part focuses on gathering literature about existing analysis that is used for the decision-making process regarding investments of public transport systems. This method also gives insight in what kind of research already is conducted and what kind of research is necessary to close the scientific gaps. Data needed for a literature review are gathered from newspaper articles, published reports and scientific papers from different online databases such as: Google Scholar, Scopus, ScienceDirect, Researchgate, World Transit Research and Springer, but also papers from the THREDBO-15 Conference (Thredbo, 2017). The following keywords were used:

Public transport investments, public transport assessment methods, mcdm, mca, multi-criteria, decision-making, transit investment, cba, mamca, macharis, stakeholders, razei, bwm, best-worst method, public transport comparison, bus, tram, metro, BRT, LRT, image, transport image, public transport image, public transport methods, multicriteria evaluation, van Oort, Bart van Arem, Annema, 5xE framework, public transport evaluation, wider benefits of public transport, benefits of ownership, costs of ownership, TCO, public investment, transport costs, transport benefits, assessment methods, Evaluation framework, MAMCA vs. BWM, AHP, PROMETHEE, ELECTRE, Weighted Product Model, Weighted Sum Model, TOPSIS, Mode-choice, perception analysis, transport investments, public transport subsidy, earnings public transport, modalities, modality, public transport impacts, economic value public transport, perception, MAAS Mobility as a service, TAAS Transport as a Service, Life cycle costs LCC, electric bus, electric vehicles, mode share. Furthermore, an extensive search is conducted by searching using all criteria, all modalities and a combination between them, like BRT safety, as keywords.

2.3 DESK RESEARCH

Desk research is a method where information specifically is gathered from documents and information that the MRDH has at its disposal. This method is used, together with the literature review and interviews, to provide an answer for the second sub-question (2. Which criteria are important for comparison of public transport modalities and why?). The difference between a Literature review and a Desk research is the source of information. Literature review can be characterized as gathering literature from anywhere, whereas a Desk research only uses information, documents and data from the organization. A Desk research therefore, will have more practical relevance and cannot be conducted by everyone and from everywhere due to privacy limitations. The information gathered via a literature review however, can be gathered from almost everywhere at any time.

2.4 INTERVIEWS

Conducting interviews with different stakeholders provides insight in different perspectives of stakeholders and what they think is important and can be seen as benefits and costs. By conducting interviews in combination with a literature review and desk research, the first sub-question is answered (1. Which MCA method suits best for a perception based analysis?). The final sub-question is also answered conducting an interview with a policy decision-maker to investigate how the perception results add value in the decision-making process (5. To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?). These two sub-questions, together with the other ones, finally provide an answer the main research question.

By interviewing different important decision-makers from different organizations, a perspicuous image will be constructed regarding the importance and difference in criteria used for implementation decisions by various organizations. This also leads to conclusions why certain decisions are made with regards to public transport projects and why they take certain aspects into account or why not. The data needed for conducting these interviews is derived from a stakeholder analysis. This analysis (Appendix I) gives insight in which stakeholders are involved, how they can influence the project and how they should be treated. When the important stakeholders are identified (Chapter 4.2), the interviews are conducted and help to understand which methods are used nowadays and where they can be improved. Chapter 4.4 describes more information regarding the interviewed decision-makers and passengers. The functions are also presented in that section and the findings can be found in Appendix VI. The final step of this research is to investigate if the perceptions of the important groups have an influence or add any value in the decision-making process of public transport investments. Together with a policy decision-maker, the results of this perception analysis are discussed via an interview to give an answer to the main research question.

2.5 SURVEYS

To obtain a realistic perception of the different modalities and different stakeholders, a survey is conducted (Appendix III). The data from the surveys will be used for the calculation of the weights for the criteria answering the third sub-question (3. How do comparison factors score on level of importance for different stakeholders?). A survey is used to get insight regarding the way how certain people or groups think about certain aspects. This method will also contribute to construct weights for the criteria and gain an understanding in how the weights score against each other. The survey is executed by asking decision-makers from the important stakeholders to rate the criteria. In general, only a few (1 or 2) people in an organization make the final decisions. However, these decision-makers always get their information from their advisors, who make the analysis and provide suggestions and recommendations. By gathering data from only one or two decision-makers, there is a high likelihood that certain weights are biased. To lower this subjectiveness, the surveys for the governmental authorities and operators are presented to more people. For each group, 5 advisors/decision-makers are asked to fill in the survey, which provides information regarding the weights of the criteria. With regards to the passengers group, in total 15 respondents were asked to fill in the survey. More information can be found in chapter 4.4 and Appendix III. In chapter 7.3 is reflected on the surveys, responses and results.

2.6 DATA ANALYSIS

Besides gathering data in this research, data analysis is also an important part. By doing so, an answer is provided, together with a case study, for the fourth sub-question (4. Which public transport system suits best for implementation according to the perceptions of the stakeholders?). Analyzing data with regards to investment decisions, conducted for past projects, gives insight in the calculations, assumptions and factors that are taken into account in a public transport study. Furthermore, data analysis also helps to identify and understand problematic issues. The data needed is gathered from different sources such as (BRT Data speed, 2017), (Clean fleets, 2015), (FTA, 2001), (Kennisplatform CROW, 2017), (MRDH, 2017) and many more (see also Appendix VII). An example of analyzing data is the calculation of the total cost of ownership, which consists of the investment costs, maintenance costs and operational costs of a system measured in € per year (Appendix VII, section B and Section I).

2.7 MULTI-CRITERIA DECISION MAKING

Decision-making is important aspect in daily life. Everyday the average adult makes about 35,000 decisions (Hoomans, 2015). With that many decisions only on a daily basis, decision-making almost can be seen as an art. When various alternatives or options are available, the decision-maker needs to find an optimal result and choose the most suiting alternative (Foreman & Sally, 2001). By using a multi-criteria decision-making analysis (MCDM), several alternatives are compared with each other using multiple weights. According to Saaty & Vargas (2012), decision-makers try to find a way to assign weights to the criteria, where each alternative is compared on to eventually find the best one. This method is used to provide an answer to the third sub-question (3. How do the comparison factors score on level of importance for different stakeholders).

MCDM can be seen as a tool to support the decision-maker to compare alternatives. The alternatives are compared with each other using different kind of criteria. Some criteria are more important to others and by assigning weights to them, their degree of importance is indicated. A MCDM analysis is conducted in this research to compare different kinds of modalities (alternatives) and to obtain a perception of various stakeholders. MCDM is often used in the transport sector: (Pineda, Liou, Hsu, & Chuang, 2017), (Annema, Mouter, & Razaei, 2015), (Boujelbene & Derbel, 2015), (Keyvan-Ekbatani & Cats, 2015), (Zak, 2010).

2.8 CASE STUDY

The case study serves as the final quantification step in the method and together with the data analysis provides an answer to the fourth sub-question ((4) Which public transport suits best for implementation?). After determining the weights and perceptions of the stakeholders, the data is combined with data from the case study where a value is assigned to each transport system. This makes comparison of the systems easier to finally select a public transport system for implementation.

One of the requirements the case has is that it has to be a Dutch transport project. Furthermore, there should be enough and up-to-date data available. Finally, the MRDH operates in the Rotterdam – The Hague region. The project should, therefore, not be older than 30-40 years and it has to be a Metropolitan area project. Projects in this area of the Netherlands are projects with a complex environment where different modalities are involved, especially compared to other areas within the country.

CHAPTER 3. MULTI CRITERIA DECISION MAKING METHODS

This chapter will elaborate more on the different MCDM methods, explained in Appendix II. MCDM, Multi-criteria decision-making is also referred to as Multi-criteria analysis (MCA) or Multi-criteria decision–making analysis (MCDA). In this research, MCDM is used for clarity sake.

By comparing their advantages and disadvantages and by comparing them on different criteria, one of the methods will be chosen that suits best to conduct a perception-based analysis. Furthermore, this chapter will serve as a path to answering the following sub-question:

(1) Which MCDM method suits best for a perception based analysis and why?

The following MCDM methods are widely used and therefore chosen for comparison (Mulliner, Malys, & Maliene, 2015), (Serrai, Abdelli, Mokdad, & Hammal, 2017), (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016) and (Triantaphyllou, 2000):

1. Best-Worst Method
2. Weighted Sum Model
3. Weighted Product Model
4. Multi-Actor Multi-Criteria Analysis
5. TOPSIS
6. AHP
7. PROMETHEE
8. ELECTRE

After giving a short description of all the methods, section 3.9 will decide which MCDM method suits best for a perception based analysis. The criteria on which the methods are tested are based on own analysis. This could be considered a weak point and is further elaborated on in the Discussion in chapter 7.3. A more detailed analysis of the MCDM evaluation can be found in Appendix II.

3.1 MCDM COMPARISON CRITERIA

This research focuses on a perception-based analysis. The perceptions of different stakeholders are taken into account to investigate if this adds any value in the decision-making process. For example, it is important that the chosen MCDM method contains an aspect where different stakeholders are taken into account. Besides coping with stakeholders, the MCDM methods are compared on the following criteria:

1. Stakeholders
2. Transparency
3. Year
4. Data Needed
5. Quality (of the weights)

1. Stakeholders. This criterion will indicate whether the method is taking into account stakeholders in the analysis.
2. Transparency. The extent and ease in which the method is understood. Some methods are hard to understand while others are rather easy. This criterion indicates whether the method is easy to understand and therefore easy applicable.
3. Year. This aspect is taken into account to just to clarify the age of the method. The advantage of using a method that was developed a long time ago is that this method has been in use a very long time which proves its reliability and results. However, times change and in this dynamic environment, a younger method may be more beneficial compared to older ones.
4. Data needed. The amount of data that is needed also is an important factor to take into account. The less data that is needed to obtain reliable results, the higher the method will score on this aspect.
5. Quality (of the weights) will be used to assess the pairwise comparison result. By comparing criteria with each other, a more reliable perception can be realized. This factor firstly will test if the method uses pairwise comparison and consequently if the method can cope with recurring inconsistencies, in such a way that the quality of the weights is sufficient.

3.2 BEST-WORST METHOD

The Best-worst method is a vector based multi-criteria decision-making method developed by Dr. Jafar Razaei (Rezaei, 2014). This method can be characterized as a pairwise comparison between a set of criteria. From this set of criteria, the participant chooses one criterion which in his or her opinion is most important (best) and one that is least important (worst). The best-criterion is then compared with the remaining criteria and the same is done for the worst-criterion. The benefits of the Best-worst method, compared to other Multi-criteria decision-making methods are:

- BWM requires less comparison data
- It leads to more consistent comparisons, which results in reliable results
- BWM can be combined with other MCDM methods
- BWM is a simple method to perform; comparisons are performed with integer numbers ranging from 1 to 9.

It seems that BWM may be one of the best methods to use when deciding on weights for parameters (Serrai, Abdelli, Mokdad, & Hammal, 2017). This is because not only the best and worst criteria are predefined by the users, but also the comparison of the other elements to them. Furthermore, this method is not that hard to understand (average) and the requirement of less data makes this method attractive to use.

3.3 WEIGHTED SUM MODEL

One of the most common and easy-to-use MCDM methods is the Weighted Sum Model, WSM (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). This method is easily applicable and easy to use in combination with other methods. The WSM method compares alternatives, based on a given set of criteria, with each other. Each criterion is given a certain weight and by multiplying the weight of the criteria with the score of the alternatives, an optimal solution is given.

3.4 WEIGHTED PRODUCT MODEL

The Weighted Product Model method is a MCDM method that has many similarities compared to the WSM (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). The biggest difference however, with the WSM is that a WPM used a product to calculate the optimal solution instead of a sum (Triantaphyllou, 2000). The equation below shows a comparison between the alternatives A_K and A_L. If R exceeds 1, this means that alternative A_K, is preferred compared to alternative A_L. Just like the WSM, this method is also quite easy to understand and to conduct, resulting in a high transparency.

3.5 MULTI-ACTOR MULTI-CRITERIA ANALYSIS

MAMCA is a Multi-Actor Multi-Criteria Analysis developed by Prof. Dr. Cathy Macharis (Macharis C. , 2005). This method can be characterized as a multi-criteria decision analysis that enables decision-makers a simultaneous evaluation of various projects (Macharis, de Witte, & Turcksin, 2010). One of the most important benefits of MAMCA compared to other MCDM methods is that MAMCA explicitly takes into account the opinion of different stakeholders. This is of high importance deciding which public transport investment will be most efficient. Involving stakeholders early in the process will give policy decision-makers not only and understanding and insight in their own problem but will also allow them to gain an understanding in the perspective of other stakeholders. MAMCA is a method that is not hard to understand, and has the most amount of (7) steps. Due to the fact that there are 7 easy-to-use and easy-to-understand steps, the transparency of this method can be characterized as average.

3.6 TOPSIS

The TOPSIS (Technique for Order Preference by Similarities to Ideal Solution) method is used broadly in various research fields (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016) and developed by Hwang and Yoon (1981). This method uses the Euclidean distance to find the best solution as close as (shortest distance) possible to the ideal alternative and at the same time as far away (longest distance) from the most negative solution. Both the best and the most negative solution result from this method and each criterion can lead to a change in utility (Triantaphyllou, 2000). The change in utility for every criterion eventually can lead to an ideal solution and a non-ideal solution and an optimal alternative within this range. However, by making use of the Euclidean distance, any correlation that may occur between criteria is not taken into account and could have difficulty to weight Qualitative parameters (Serrai, Abdelli, Mokdad, & Hammal, 2017). This method is harder and takes slightly more time to understand compared to the above-mentioned methods, resulting in a lower transparency.

3.7 ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process, AHP method (Triantaphyllou, 2000) is developed by Saaty almost 40 years ago (1980). This method is mostly applied in problems with conflicting criteria and in the energy planning sector (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). There even is a case where an AHP based method is developed which can cope with problems where uncertain data is available (Cobuloglu & Büyüktahtakın, 2015). The AHP method used a hierarchy structure and pairwise comparison to decide upon complex decision-making problems. This method also is not that hard to understand and to conduct. With 4 steps, the transparency of AHP method is around the same level of the Best-worst method.

3.8 PROMETHEE

The Preference Ranking Organization Method for Enrichment Evaluation method is created by Brans in 1985 (Brans & Vincke, 1985), (Brans, Vincke, & Marescha, 1986) and is widely used for problems in the energy sector (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). By using pairwise comparison, the method provides an overall ranking of the alternatives based on positive and negative outranking flows. PROMETHEE is an easy to use method, especially compared to other MCDM methods (Tuzkaya, Gulsun, Kahraman, & Ozgen, 2010). One of the advantages of PROMETHEE is that it can deal with qualitative and quantitative factors simultaneously (Serrai, Abdelli, Mokdad, & Hammal, 2017).

Two main categories of information PROMETHEE needs are:

1. Weights of the criteria
2. Preference of the decision-makers if applicable

This means that a specific method to determine the weights is not provided, which can be seen as a disadvantage. When dealing with a higher number of criteria (eight or higher), this can make things quite difficult for the decision-maker (Serrai, Abdelli, Mokdad, & Hammal, 2017). According to section 3.3, all three groups have a number of 9 criteria for comparison. This will make it difficult for the PROMETHEE method to obtain a reliable realistic perception of the stakeholders. Finally, the transparency can be categorized as lower compared to the above-mentioned methods because of the difficulty level.

3.9 ELECTRE

The Elimination and Choice Translating Reality method was first introduced around 1966 by Bernard Roy can also be characterized as a pairwise comparison method (Benayoun, Roy, & Sussman, 1966). ELECTRE is executed by comparing two alternatives on each criterion. This makes ELECTRE not always able to classify the most interesting alternative, which can be a great disadvantage depending on the goal of the problem (Triantaphyllou, 2000). However, when a situation occurs with few criteria and a huge amount of alternatives (Lootsma, 1990), ELECTRE may be a great choice to use to compare the different solutions. This method can also deal with both qualitative and quantitative factors simultaneously. However, because ELECTRE can be characterized as a complex decision making method, a great amount of data is required to perform a worthy analysis.

This method can be applied in many various fields to determine which alternatives are preferred considering a set of criteria (Vahdani, Haji, Jabbari, Roshanaei, & Zandieh, 2010). Due to the comprehensive explanation the transparency of this method is lower compared to the first methods.

3.10 MCDM EVALUATION

Summarizing the above (and appendix II) analysis, the table below, table 5 can be obtained. The methods are assessed on the criteria shown in the first row of the table. The methods are shown in the first column. These criteria and their scores are based on own analysis. This can be indicated as a weak point and will be more elaborated on in chapter 7.3.

The following scale is used when scoring the methods on the criteria:

--	not available or highly negative
-	negative
+/-	neutral
+	positive
++	highly positive

TABLE 6. MCDM METHOD EVALUATION

MCDM	Stakeholders	Transparency	Year	Data needed	Quality (weights)
1. BWM	--	+/-	2014	++	++
2. WSM	--	++	1967	++	--
3. WPM	--	++	1969	++	--
4. MAMCA	++	+/-	2005	--	--
5. TOPSIS	--	-	1981	+/-	--
6. AHP	--	+/-	1980	+/-	+
7. PROMETHEE	--	--	1985	+/-	+
8. ELECTRE	--	--	1966	+/-	+

To obtain a perception of stakeholders regarding public transport investments, there is only one MCDM method that may be able to take different stakeholders into account. As stated in section 4.5, the MAMCA method explicitly takes into account the interests of different stakeholders in the analysis. In the decision-making process, one of the most important parts is to take into account the interests of the stakeholders involved in the process. For this reason, the MAMCA is chosen as the method to determine the perceptions.

Step 3 of the MAMCA analysis is to determine the important criteria and their weights. By making use of another MCDM method, in combination with the MAMCA analysis, weights can be assigned to the criteria. To assign weights, a comparison method is needed that allows fair and accurate comparison of the criteria. By making use of pairwise comparison more accurate results can be achieved due to the fact that, each time, only two factors are compared with each other.

However, most of the pairwise comparison methods, such as ELECTRE, PROMOTHEE and AHP, are unable to cope with recurring inconsistencies. The main reason these inconsistencies occur is because of the unstructured method the comparisons are derived from. This results in inconsistent matrices and a solution for these inconsistencies is to revise the comparison in such a way that the matrix becomes consistent (Karapetrovice & Rosenbloom, 1999). Therefore, a method is needed where less of these inconsistencies appear. The BWM method uses a different kind of pairwise comparison which enables more consistent results with less information. This is done using the following method: By comparing the best criterion to the others and the others against the least preferred criterion the weights are determined.

One of the important benefits of BWM is that in some cases, a multi-optimal result can be established. Different alternatives can be chosen as the optimal solution, based on different sets of weights for the criteria. MCDM methods with multi-optimal solution can be highly beneficial for most kind of policy decision-making problems. These problems are known for their extensive decision-making process where debating plays an essential part (Simons, Pelled, & Smith, 1999). Another benefit of MCDM methods with multi-optimal solutions is that decision-makers are also provided with information that cannot be modelled.

For these reasons, the BWM is chosen as the method in this research to determine the weights for the important criteria. By combining the MAMCA with the BWM, the BWM will determine the weights for the criteria, which then will be used as input for the MAMCA.

3.11 CONCLUSION MCDM

The goal of this chapter was to analyse the popular MCDM methods and decide which method will be used to conduct a perception-based analysis. After describing all the methods and evaluating them, the following conclusion can be drawn, which directly answers the sub-question:

(1) Which MCDM method suits best for a perception based analysis and why?

Looking at table 5, stakeholders are a highly important aspect to take into account in the decision-making process for public transport investments. The method that is suitable to conduct an analysis, taking into account different stakeholders is the MAMCA.

The third step of the MAMCA is to determine important criteria and weights. This indicates that another method is needed, which determines the important criteria and weights to compare the alternatives. The only method that has a very high quality of the weights (explained in chapter 3.2) and where few amounts of data are needed, is the Best-worst method (BWM.) Therefore, this method is chosen because of the combination of the quality of the weights, less data that is needed to obtain highly reliable results, fewer inconsistencies between criteria and average transparency of the method.

CHAPTER 4. PERCEPTION ANALYSIS

Now that the methods are identified, this chapter will apply the methodology to determine the mode choice perceptions of each of the stakeholders. After the method is applied to obtain general perceptions of the stakeholders, the case study will be conducted, further explained in chapter 5. Both the MAMCA and BWM will be executed and the weights determined in the BWM, will be used as input for the MAMCA.

Section 4.1 (step 1 MAMCA) will introduce the alternatives, which in this case are the different modalities from which a selection can be made for a new public transport system. Section 4.2 (Step 2 MAMCA) will describe which stakeholders are of importance in the decision-making process and why they will and should be taken into account. Section 4.3, then will describe for each stakeholder their important criteria, after which 4.4 will apply the Best-worst method to find their weights. Now that the weights are determined section 4.5 will explain which values correspond with the criteria and calculate the perceptions for each stakeholder. This chapter will finalize in section 4.7 by describing the benefits of public transport categorized per mode.

Finally, this chapter will finalize by providing answers to the following sub-questions:

(2) Which criteria are important for comparison of public transport modalities and why?

(3) How do the comparison factors score on level of importance for different stakeholders?

4.1 ALTERNATIVE SELECTION

The first step of the MAMCA defines the problem and classifies possible alternatives. The problem, as defined in chapter 1, is the difficulty for policy decision-makers in selecting the right public transport system. This research will make use of the modalities used by the operators operating within the metropolitan area of Rotterdam The Hague. The following modalities are used by the operators, coherent with the main focus of the MRDH and the Metropolitan Region it focuses on (RET-b, n.d.), (HTM-b, n.d.), (Conexxion, 2017), (OV-magazine eBus, 2017):

TABLE 7. MODALITIES

Public transport system
1. Tram
2. Metro
3. Bus (Diesel)
4. Light Rail Transit - LRT
5. eBus
6. Bus Rapid Transit – BRT
~~7. Fast Ferry~~

The fast ferry (RET-ferry, n.d.) will not be taken into account due to the fact that this research focuses on the decision-making procedure for public transport. The characteristics of a ferry are widely different compared to that of the other modes, which results in the exclusion of the ferry in the comparison analysis and therefore, fall out of scope for this research.

4.2 STAKEHOLDER ANALYSIS

The second step of the MAMCA is to conduct a stakeholder analysis to determine the involved and important stakeholders. Macharis, de Witte and Turcksin (2010) define stakeholders as a group of people who have an interest in, or are affected by any decisions taken throughout the process. An extensive stakeholder analysis is presented in Appendix I. It is important to conduct such an analysis because information is gathered regarding the influence and interests of the involved groups. By knowing which groups have what kind of power in the decision-making process and what their interest is, the decision-maker exactly knows how to cope with them. Some stakeholders only need to be monitored or kept informed, while others, usually with a high influence, need to kept informed or managed closely.

This research will focus on the added value of a perception-based analysis for a policy decision-maker. Therefore, not all stakeholder information is necessary. The perception of the most important stakeholders will be taken into account to investigate whether this adds any value in the decision-making process.

When deciding upon public transport investments in the metropolitan region of Rotterdam The Hague, the stakeholders involved can be characterized by the quality triangle shown below, in Figure 4 (Aboo & Robertson, 2016).

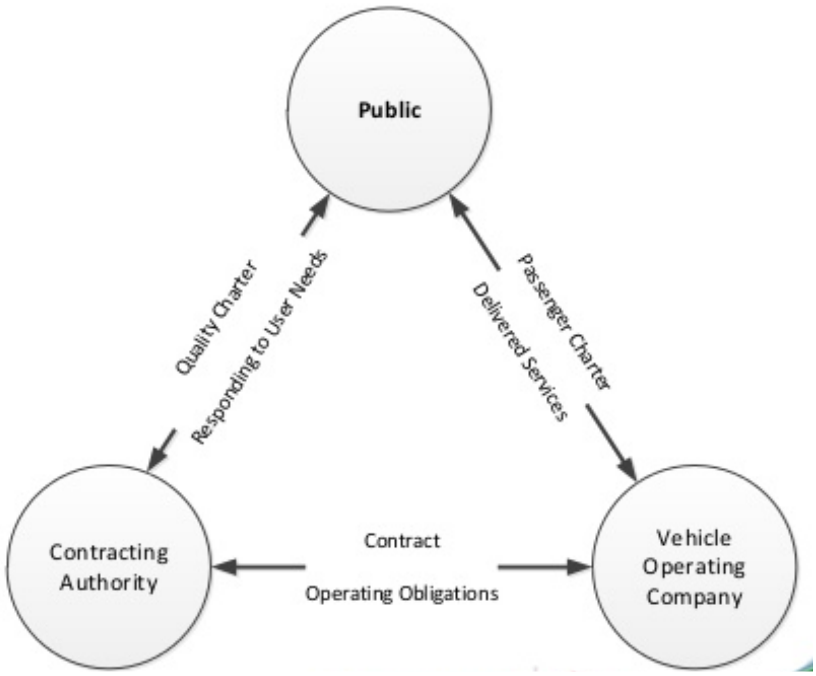


FIGURE 4. QUALITY TRIANGLE (ABOO & ROBERTSON, 2016)

The figure shows the three most important groups:

1. Contracting Authorities

The Contracting Authorities can be characterized as different governmental authorities making decisions regarding selecting and making agreements with the service provider(s). The role of the governmental agencies and institutions is to improve the quality of life, access and mobility in a clean, safe and sustainable environment (Government.nl , n.d.), (Gemeente Rotterdam, 2017), (Gemeente Den Haag).

The following governmental agencies and institutions play an important role regarding public transport investments:

- Province of South-Holland
- Ministry of Infrastructure and the Environment
  - Rijkswaterstaat (as executive organ for the Ministry)
- MRDH
- 23 Municipalities (represented by MRDH)

2. Vehicle Operating Companies,

The Vehicle Operating Companies, also public transport operators are the stakeholders that, despite they are competitors, share the following (same) goal (HTM, n.d.), (RET, Missie, 2017), (Carmen & Lidestam, 2016), (Conexxion, 2016):

> To provide high quality transport services to their passengers in the fastest, safest, cheapest way possible.

They work together with the governmental institutions to provide these transport services for the public and receive subsidy to operate and maintain the systems.

3. Public

The Public, also indicated as the passengers, is the final group in the triangle and is the group that is provided with public transport systems. The perception of the passengers has an important role due to the fact that this group actually consists of the users of the system. Summarizing the above-mentioned stakeholders together with the three important groups from the quality triangle, the following conclusion can be drawn:

The stakeholders, <u>government</u> and <u>public transport operators</u>, have an important role in the decision-making process regarding public transport investments (Pereira, Sennaa , & Lindaub, 2017). The perception of the <u>passengers</u> may give important insight regarding system choice. Their experience and choices are of great value and since the government wants to provide decent transportation and satisfy the Public. It is important to know how the Public experiences public transport. For this reason, the group of passengers is seen as an important group in the process and therefore, taken into account in the perception analysis.

4.3 CRITERIA SELECTION

The third step of the MAMCA is to select the important criteria and weights, which in this thesis is distinguished in chapter 4.3 (criteria) and 4.4 (weights). By using literature, desk research, interviewing (policy) decision-makers and personal communication, the list shown in Table 8 below, is composed. An explanation of some important criteria is written down below the table. Some criteria need to have an explicit explanation while other do not. An explanation of all the criteria can be found in Appendix XIII.

This list contains both costs (also financial attributes) and benefits of public transport (systems). The benefits are described using the 5xE framework developed by van Oort, van der Bijl & Maartens (2016) where they explain that the value of Public Transport is highly underestimated (van Oort, van der Bijl, & Verhoof, 2017). Therefore, they developed this framework to find alternative ways in which the value of public transport could be estimated and quantified (van Oort, van der Bijl, & Verhoof, 2017).

This 5xE framework consists of the following five elements:

E1. Effective mobility

The first element can be described as the effectiveness of the system or of public transport as a whole. The system should be able to transport passengers, in an effective, efficient, safe, clean, fast, reliable and comfortable manner.

E2. Efficient cities

This element can be described as the effective use of the urban area. Cities stay compact by implementing public transport systems while giving them a more attractive image. Public transport can transport a great amount of people in an effective manner to their destination while making use of limited space. By using public space more efficiently, the indirect societal value of public transport increases. This element also describes that public transport highly contributes to the business climate of the city.

E3. Economy

The Economy element is described as the increase in economic value of the surrounding land by means of public transport. Public transport leads to area development, also explained in the text underneath criteria 28, Land and Economic Development. Areas becoming more accessible lead to more potential clients, more investments, higher rents and higher real-estate prices.

E4. Environment

As can be seen in Figure 5, Public transport emits far less CO_2 compared to other transport modalities. Also shown by various research (Tamaki, Nakamkura, Fujii, & Managi, 2016), (Kunith, Mendelvitch, & Goehlich, 2017), (Zhang & Han, 2017), (Li & Tang, 2017). This element describes the influence and effects of transportation on the environment. Not only does public transport use less emissions, it also uses less energy compared to automobiles (Xylia & Silveira, 2017).

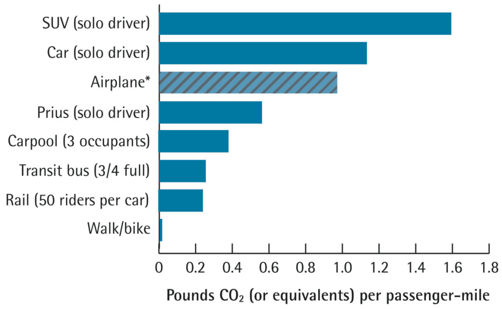


FIGURE 5. EMISSIONS PER MODE (SIGHTLINE, N.D.)

E5. Equity

The final element, equity, explains in what way the public transport services are accessible for whole society. This described the fact that public transport contributes in creating equal opportunities for inhabitants. It is available at all times for everyone and connects all parts of the city with each other, resulting in areas becoming available and accessible for people who are not able to make us of private transport. This factor explains that public transport functions as a service, making all kinds of facilities accessible for everyone.

4.3.1 MODE CHOICE CRITERIA

TABLE 8. COMPARISON FACTORS

Costs	Benefits – 5xE framework				
	E1. Effective Mobility	**E2. Efficient cities**	**E3. Economy**	**E4. Environment**	**E5. Equity**
Total Cost of Ownership – TCO	Robustness [vehicle loss hours]	Spatial quality [1-10]	Land development [€ per m²]	Emissions [CO_2/km]	Accessibility of PT system/stops [1-10]
a) Investments costs [€/yr.]	Operational speed [km/h]	Passenger forecast [passengers]		Environmental nuisance [dB]	Travel information [1-10]
b) Maintenance costs [€/yr.]	Travel comfort [1-10]	Livability inhabitants [1-10]		Parking availability at stops [1-10]	Drivers/staff interaction [1-10]
Operational costs [€/yr.]	Additional passenger services [1-10]	Possibility Autonomous [1-10]			Political considerations/pressure [N/A]
Earnings [€]	Flexibility [1-10]	Image [1-10]			Extra/Special luggage [1-10]
Ticket price [€/km]	Punctuality [%]	Life span [years]			
	Passenger safety [1-10]	Length of the system [km/stop]			
	Frequency				

	[dep./hr./dir.]
	Security level [1-10]
	System Capacity [passengers /vehicle]
	Extra/special luggage [1-10]

Some of the criteria may be unclear or need some more explanation. Below are a few of them explained in more detail. An explanation of all the criteria can be found Appendix XIII.

1. Image

This criterion is defined as the image of each public transport system in the eyes of public transport users (van Oort N. , 2011). It is expected that the image of a bus, for example, is different compared to that of a metro or tram. The image of a system is measure in a grade between [1-10], with 1 meaning really negative and 10 really positive.

2. Total cost of ownership - TCO

The total cost of ownership (TCO) is defined as the costs of a system over its life cycle. It is important to investigate which stakeholders are involved (section 3.2) and determine the costs they encounter throughout the total life cycle of the system (van Oort, van der Bijl, & Maartens, 2016). The total cost of ownership include Operational, Maintenance and Investment costs. The TCO can be measured as yearly cost per system [€/yr].

a) Operational costs

The operational costs are defined as the costs (in €) per km (MacKechnie, Bus and light rail costs, 2016). Information can be found regarding operating costs of public transport vehicles (United States Department of Transportation, 2016).

b) Investments costs

The investment costs is of high importance when comparing and deciding which public transport system suits best for implementation (Weisbrod, Mulley, & Hensher, 2016). The investment costs can be measured in € per year.

c) Maintenance costs

The maintenance costs can be divided into two different costs. The first one is preventive maintenance and can be defined as maintenance to prevent failure of the system (Schiavone, 2010). The second one is corrective maintenance and is conducted when there is a fault in the system (Stiles Machinery, 2012). The maintenance costs can be measured in € per year.

2. Passenger safety

Information regarding the safety of passengers will give some insight in how safe the passenger feels when using a specific transport mode. It is also important to investigate how the public transport operators are trying to keep the safety high (Gray, 1979). These safety measures can be different within the systems and therefore also have another feeling of safety. Measuring the passenger safety is different for the groups, based on their perception. The passengers for example, see safety as a how they feel or perceive safety in while using the transport system. The passenger safety, in this case, can be defined in a grade between [1-10], with a 1 meaning very unsafe and a 10 very safe. However, the public transport operators and the government invest in passenger safety and therefore, it can be measured in € invested in safety measurements per day [€/day] (explained more extensively in Appendix VII, Section M).

3. Punctuality

The punctuality is a measure to define the amount of times a vehicle arrives on time at the designated stop, according to its schedule (Rudnicki, 1997). This is an important factor because the punctuality contributes to the reliability of the system. A high punctuality means that the public transport vehicle, most of the time, if not always, arrives at the predefined time, making the system more reliable. The punctualities for the various modes are defined differently, dependent on each operator. This definition is dependent on the departure stations, important nodes, time-stations and transfer stations. Furthermore, the punctuality also depends on the difference in real-time departure compared to the departure time in the timetable. Some systems or operators use a margin of 3 minutes, while other ones use margin of maximum 2 minutes. This is further discussed in the recommendations and Appendix VII, Section E. The punctuality can be measured in percentage [0-100%], however, via a survey, an image can be obtained how the passengers perceive the punctuality.

4. Political considerations

Political considerations is also an important aspect which influences the decision-making process (Carmen & Lidestam, 2016). There are examples of non-profitable projects where no-one exactly knows why and how they are implemented (Rosenberg, 2016), (Sturm, 2008). Another aspect that can be decisive is the Alderman and his/her wishes. The influence of an Alderman on the process can be quite important especially if his/her intentions are to leave a landmark behind (Wijmenga, Veeneman, & Hirschhorn, 2017).

This factor can be characterized under the E5. Equity element of the 5xE framework, because this element describes the equality of public transport. This political pressure should serve as a tool to connect all parts of the city with each other and making facilities in and around the city as accessible as possible.

The political considerations factor is not taken into account, also explained in section 5.2, due to the difficulty in estimating this criterion. It is still a highly important factor, especially in the decision-making process. However, almost impossible to quantify and therefore will be left out of scope in this research.

5. Land and economic development

The factor land and economic development can also be seen as one of the wider economic benefits of public transport. As explained above, in the introduction of section 3.2.1, this factor measures, in what way the new public transport system contributes to land and economic development. One example can be derived from the observation made by Schafer & Viktor (1998), that faster modes of transport lead to people living further away from their work. Higher income leads to spending relatively more on travelling which results in increasing distances between home and work. If people commute further away from home and travel times decrease, cities become larger making more areas better accessible. This directly has a positive effect on the economic development of these and surrounding areas (van Oort & van der Bijl, 2014).

In literature, various effects can be found regarding the influence of public transport (systems) on the surrounding environment. Boarnet (2011) states that major transport infrastructure investments do contribute to the economic conditions and are powerful determinant of urban development patterns. Bollinger and Ihlanfeldt (1997) make two distinctions in land use impact:

1. Regional growth due to increased productivity
2. Local growth, around the station(s), due to higher accessibility

One example of the above-mentioned observations can be seen in a study conducted by by Catala, Reader and Perk (2012), the vast majority of the studies find positive impacts on property values from nearby rail transit. Another example was found by Mullins, Washington & Stokes (1987) that the BRT in Ottawa had some positive effect on land development in areas surrounding stations. In a report of the Federal Transit Authority, land use impacts of BRT are examined (FTA-BRT, 2009). They identified that property values near a BRT station (or system) increased between 7.6% and 14% in cities all over the world, from Los Angeles to Beijing. Other studies regarding the effect of LRT on property values found an increase in value between 7%-22% (Wienberger, 2001), (Mohammad, Graham, Melo, & Anderson, 2013). The land and economic development can be measured in [€ per m^2].

6. (Carrying of) extra and special luggage

Carrying extra or special luggage can also be a factor influencing the mode choice. This aspect mainly is applicable to passengers (Eisenkopf, Christian Burgdorf, & Andreas Knorr, 2017). One example is taking your bicycle in public transport. According to the RET for example, bikes are allows in busses and trams and only in the metro before 16:00 or after 18:30 (RET-fiets, n.d.). This factor is measured using a scale between [1-10] with a 1 meaning not allowed or possible in the system and 10 fully and always allowed.

4.3.2 CRITERIA PER STAKEHOLDER

From the stakeholder analysis (section 4.2 and Appendix I) the conclusion can be drawn that the following three groups can be defined as the most important stakeholders:

I. Passengers
II. Public transport operators
III. Government

These stakeholders play an important role in the decision-making process considering various public transport investments. This directly raises some curiosity if the perception of these groups, regarding public transport systems, has any added value in the overall decision-making process. The comparison list, presented in Table 8 is extensive and needs to be shortened. This will highly reduce the survey time which results in better, more reliable outcomes and less misinterpretation of (overlapping) criteria.

This sub-chapter will elaborate more on the important factors for each group with the goal to propose a shorter list of comparison factors for each group. These lists should be as complete as possible in such a way that the important comparison criteria for all three stakeholders are represented. This section will shorten the list for each stakeholder to a maximum of 9 criteria. The spatial working memory capacity of humans is 7 ± 2, meaning humans are, in generally, only able to compare 7 ± 2 attributes with each other (Glassman, Garvey, Elkins, Kasal, & Couillard, 1994) & (Miller G. A., 1955).

I. Passengers

Figure 6. Pyramid of Maslow for public transport Figure 6 below shows the Pyramid of Maslow for public transport. This pyramid exists of different layers representing the minimal requirements public transport systems should have. These requirements are determined by users of the systems. The lower part of the pyramid shows the dissatisfiers, which represent the minimum requirements a system must have. If Ease, Speed, Safety and Reliability are not sufficient, there is a high chance that passengers will not use the system and look for other transport modes or even not travel at all. The upper part of the pyramid, the satisfiers are criteria which can lead to choosing public transport over other transport modes (Peek & van Hagen, 2002).

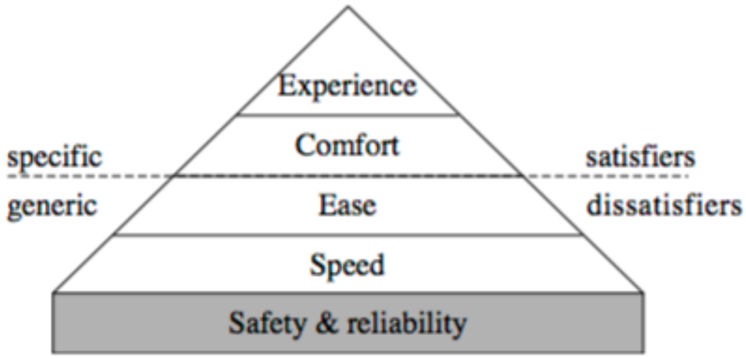


FIGURE 6. PYRAMID OF MASLOW FOR PUBLIC TRANSPORT (PEEK & VAN HAGEN, 2002)

Positioning this pyramid next to the criteria from Table 8, the diagram presented in Figure 7 is obtained. The figure shows on the left all the criteria and on the right the Pyramid of Maslow. The first level, Safety and Reliability, is coherent with the factors: Frequency, Punctuality and Passenger Safety. The 2nd and 3rd level, respectively Speed and Ease, are coherent with the Operational Speed, Accessibility of the PT system and Travel Information. The 4th level, Comfort, is coherent with the Travel comfort and the 5th and last level, Experience is coherent with the factors, Ticket Price, is the received quality worth the price, and Image, how does the passenger perceive and therefore experiences the system.

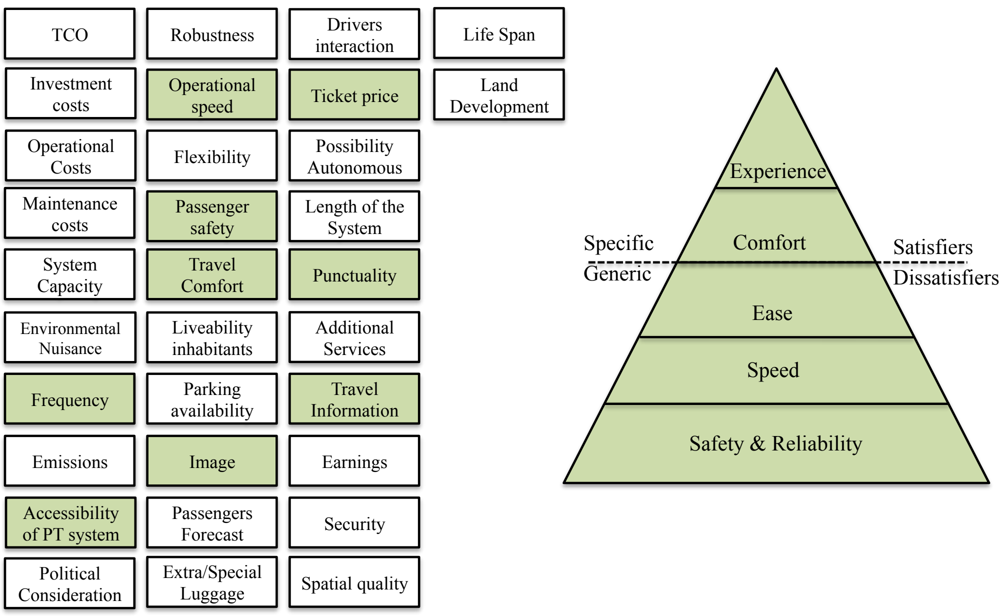


FIGURE 7. CRITERIA VS. PYRAMID OF MASLOW FOR PASSENGERS

The diagram shows the important criteria for the group: Passengers. As can be derived from Figure 7, the following criteria are important to take into account from the passenger's perspective when deciding upon public transport systems:

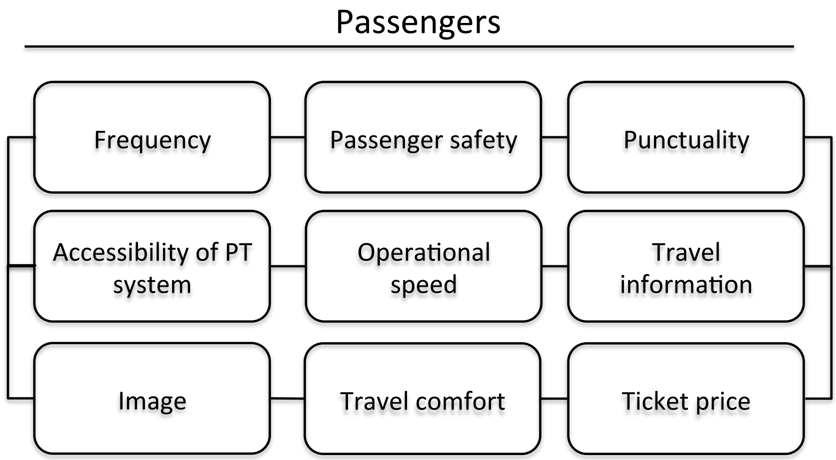


FIGURE 8. CRITERIA PASSENGERS

II. Public transport operators

Taking a seat in the public transport operators chair, immediately can be concluded that this group has other preferences compared to passengers and/or the government. The goal of the public transport operators to provide a perfectly organized public transport system with the highest (safe, reliable, efficient and comfortable) quality for the passenger (RET, Jaarverslag 2016, 2017) (HTM, n.d.). To provide these services, they need to have reliable materials and infrastructure but also think about the financial situation of the organization. This almost always means investing in infrastructure, materials and ways to stay operational most of the time, have high priorities just to keep providing qualitative transportation services to the passengers. With the decreasing subsidies, the operators need to have more (income from) passengers without changing the prices, while increasing the level of quality, efficiency and service (Wijmenga, Veeneman, & Hirschhorn, 2017).

When selecting upon public transport services, it makes sense that these organizations most likely would like to invest in flexible, sustainable and durable systems which requires few, if not any maintenance at all.

After conducting some research and more importantly, interviews with the public transport operators, the criteria presented in Figure 9 can be characterized as most important when deciding upon public transport investments.

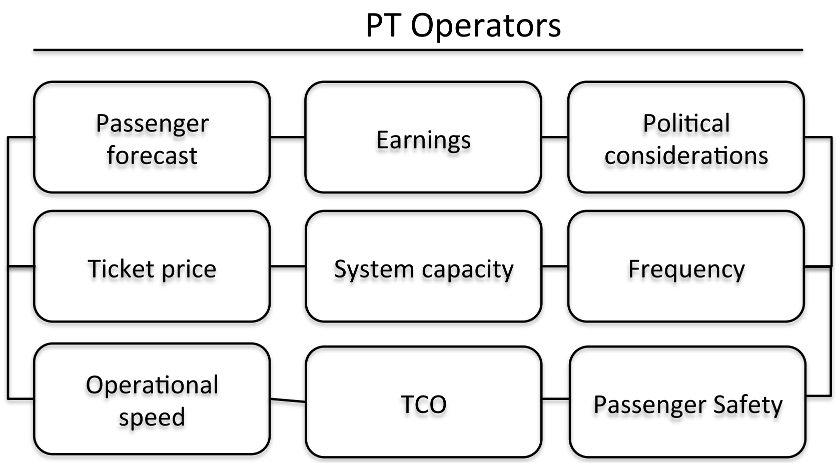


FIGURE 9. CRITERIA PT OPERATORS

TCO is an important criterion the public transport operators base their decision on. This factor indicates the life cycle costs and includes investment costs of infrastructure and materials, maintenance costs of both infrastructure and materials and operational costs.

The Operational speed is an important aspect for the public transport provider to take into account, as this indicates the operational speed, the vehicles are able to maintain. A bus for example, experiences the most amount of delays due to having the most amount of conflicts with other traffic users. This highly influences the operational speed.

The criterion Passenger Forecast is an important factor to take into account to help the public transport operators gain insight in the amount of personnel and material they need to have stand-by. Passenger Forecast is also an important aspect for the calculation for the earnings.

The Frequency is an important aspect with regards to use of assets. The higher the frequency, the more buses, trams or metros depart in an hour, the more material is needed. More tram/bus/metro lines per hour means more personnel, which will result in higher labor costs.

System capacity is an important factor to take into account due to the fact that materials need to be purchased. If the system is known together with the passenger forecast, a timetable can be created. This will provide knowledge of how the frequency and the amount of vehicles they need to own.

The Ticket price is an important criterion for the public transport operators because, together with the forecast information, the expected income can be calculated. These earnings/revenues are an important factor to minimize the operational costs. Despite the fixed ticket prices, determined by law (MRDH-OV, 2017), this criterion still is important for the operators to calculate the (expected) revenues.

Maybe of one the most important and least thought of aspects in public transport investments, is the political influence. As mentioned in section 3.1, the influence of, for example an Alderman on the process can be quite important especially if his/her intentions are to leave a landmark behind. This will put pressure on the public transport operators sometimes in such a way that their considerations and remarks are not even taken into account.

Public transportation mainly is subsidized by the government due to the fact that the costs are higher than the earnings (Wijmenga, Veeneman, & Hirschhorn, 2017). This means that this subsidy, the public transport companies receive, is an important factor in system choice. The goal of this subsidy is to keep the operational costs as low as possible.

III. Government

Governmental institutions have a different perception when selecting upon public transport systems. The goal of the governments is to provide their inhabitants with a sustainable, livable environment (Stadsgewest Haaglanden, n.d.). However, this does not always mean selecting the fastest, most durable or most impressive transport system. Interviewing a handful of important decision-makers in the organization resulted in the criteria presented in Figure 10 (personal communication, August 2017). One important criterion to mention is the Earnings or Revenues, which are not of high importance for the government. This is because the earnings of tickets, regulated in the current concessions, go directly to the public transport operators.

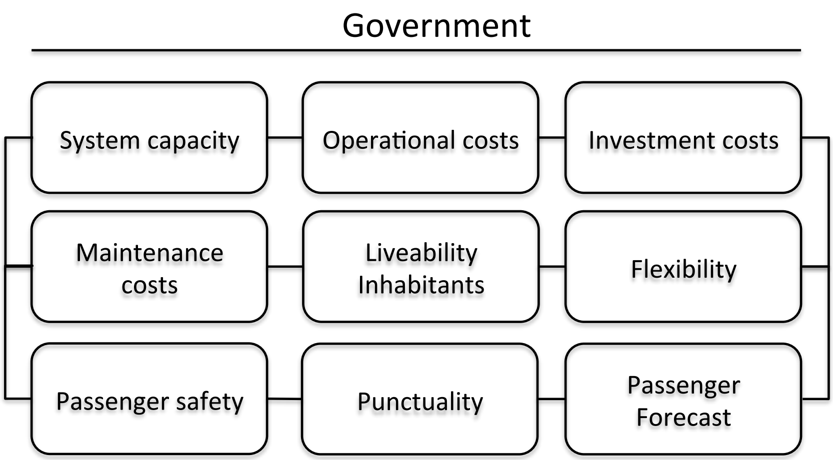


FIGURE 10. CRITERIA GOVERMENT

Investments costs can be divided into two categories. The first one is the most obvious and are the financial resources to build and implement the system. This is an important aspect from the government's side because they subsidize the public transport operators for managing and keeping the system operational. This is also the reason why the operational costs are an important factor for the government. Various agreements are made with regards to the service that is being delivered for the contracted price.

The second investment cost is also know as environment costs and defined as the loss of land that is necessary for the construction of the new transport system. Furthermore, the government is also responsible for the maintenance costs of the infrastructure of the systems. Due to this reason, the maintenance costs are an important aspect for the government to take into account when deciding upon public transport systems.

Flexibility is an important factor from the government's perspective and divided into the short- and long-term. Firstly, the short-term flexibility is characterized as the possibility of the system to cope with uncertainties and de-routes. The long-term flexibility is the possibility to transform/upgrade the system in terms of future opportunities.

Forecast is an important aspect to take into account also for the government because this may indicate the demand of (extra) facilities nearby the stops. The amount of (expected) passengers also gives an indication of the earnings (from tickets).

Passenger safety, Liveability of the inhabitants, and Punctuality are possibly the most important aspects from the government's perspective. The reason for this is because the goal of the government is to provide a qualitative, clean, safe and sustainable environment and improve access and mobility (Government.nl , n.d.). Coherent with this goal is a qualitative transport system to eventually attain satisfied travellers. Complaints regarding an insufficient transport system, will reach the municipality resulting in a negative image.

4.4 CRITERIA WEIGHTS

The important criteria and key stakeholders are defined, as described in the above-mentioned section. The second part of the third step is to assign weights to the important criteria and link them with each stakeholder. By conducting a Best-worst analysis, the weights for the important criteria are determined. The data gathered for the Best-worst analysis originates from the three groups, mentioned above.

The data is gathered from each group by conducting surveys (passengers group) and asking decision-makers (from governmental organisations and PT operators) to compare and rate criteria. These surveys can be found in Appendix IV. The respondents were asked to choose their best criteria, worst criteria and compare them against the other ones. This will result in a weight for each criterion. From a passenger's point of view, more data is needed (instead of 5 respondents) to obtain useful weights. For this reason, 15 respondents (passengers) are interviewed to represent the passengers perception. Conducting a survey with more than 15-20 passengers will result in an unequal contrast, comparing 5 decision-makers from the government and 5 from the operators against the perception of >15 passengers. To obtain a more realistic perception of the passengers, a member from the Metrocov organisation was asked to fill in the passenger survey (Appendix III). Metrocov is an organisation that represents the interests of the following four groups (Metrocov, 2015):

1. Students
2. Travellers with a limitation or disability.
3. Elderly travellers
4. Interests organisation ROVER

Table 9 below shows the diversity in the passengers group. In total, 15 respondents were interviewed to give their opinion about the preference of public transport systems. Chapter 7.3 will elaborate more on the results of the weights, with regards to the diversity of the group.

TABLE 9. DIVERSITY TABLE RESPONDENT: PASSENGERS

Gender	Male	73%	11	**Degree**	High School	0%	0
	Female	27%	4		MBO	0%	0
					HBO	13%	2
Age	12--18	0%	0		WO	87%	13
	19--26	27%	4		PhD	0%	0
	27--55	60%	9				
	56--65	13%	2	**Correspondence with PT sector**	Currently work in PT Sector	50%	7
	65+	0%	0		Have worked in PT	0%	0
					Study/research in PT	21%	3
Nationality	Dutch	80%	12		No, I only use PT	21%	3
	Indonesian	13%	2		No	7%	1
	Greek	7%	1		Other	0%	0

As can be derived from Table 9, the majority of the respondents have a Dutch nationality. This is beneficial for the survey because a perception needs to be obtained regarding public transport modalities in the Netherlands. Furthermore, the data shows that the majority of the respondents have an age between 27 and 55 and are currently active in the public transport sector. The goal of this survey for the passengers was to visualise the perception, as much as possible, of the average passenger using public transport in the metropolitan region.

From the governments' and public transport operators' group, data is needed from decision-makers concerning public transport investments. Usually, this only regards one or two policy managers. The problem with interviewing only one or two managers is the change in perception if another manager is in charge a few years later. His or her successor may have a different perception with regards to public transport investments. To obtain more valid results and to cope with this inaccuracy in change in perception, both for the government and public transport operators, 5 managers/decision-makers for each group are chosen.

Table 10 below shows the interviewed decision-makers from the operators and governmental organisations. A more detailed description regarding the interviews can be found in Appendix VI.

TABLE 10. DECISION-MAKERS PT OPERATORS AND GOVERNMENT

Public transport Operators	Government(al agencies)
1. RET- Manager Asset department	1. Strategic Advisor Assets
2. RET - Head of Strategy	2. Asset Manager
3. HTM – Concession Manager Assets	3. Strategic Advisor Public Transport
4. Conexxion – Head of Strategy	4. Senior Policy Developer
5. HTM – Product Manager Market exploration and Transport development	5. Senior Concession Manager

After comparing the best, worst and other criteria with each-other, the weights can be determined for each criterion. Figure 9 shows the two most important criteria for the public transport operators and the least important criteria. The weights of all the criteria are shown in Table 11.

An interesting observation with regards to the operators' perspective best-worst analysis, is that almost all of them identified **Ticket Price** as worst criteria. This is due to fact that this factor is legally determined and they cannot influence this. However, it still can be characterized as one of the most important because of the passenger-earnings, which contribute to how many subsidy they receive and how many (extra) costs they should make. The **Passenger forecast** is chosen as most important factor as seen from the operators' perspective. From this, the conclusion can be drawn that the operators find the passengers forecast the most important factor when deciding upon public transport systems. The second most important factor is the **Total costs of ownership**, which for the operators are the life cycle costs of the system.

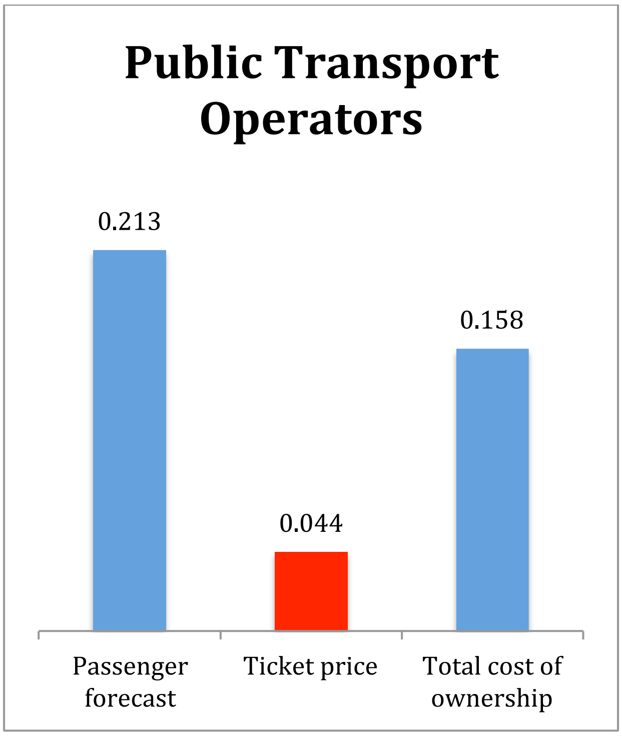


FIGURE 11. MOST AND LEAST IMPORTANT CRITERIA - OPERATORS

With regards to the perception of the government, the least important and three most important criteria are shown in Figure 11. As can be seen, the passenger safety is indicated as least important criteria. Because the safety needs to be at least on a certain level as long as the safety is on the required level, the added value of more safety is less important compared to the other criteria.

The most important criterion is the **Investment costs** followed closely by the **Passenger forecast** and **Operational costs**. The passenger forecast also is of high importance for the operators meaning, that the chosen system is highly dependent on the amount of expected passengers. The importance of investment and operational costs can be explained because the MRDH (government) subsidizes the investment costs (sometimes together with the municipalities). Furthermore, the MRDH is also responsible for the management and maintenance of the systems. Finally, they provide subsidy to cover the operational costs of the systems. This explains why the two, above-mentioned criteria are of high importance in the decision-making process, as seen from the governments perspective. One of the remarks that were made in the interview with the Strategic Advisor was that the government highly values this criterion. Figure 12 shows that the most important criterion for the government is the investment costs, confirming the remark made by the Strategic Advisor. This indicates that the weights indeed have a realistic value.

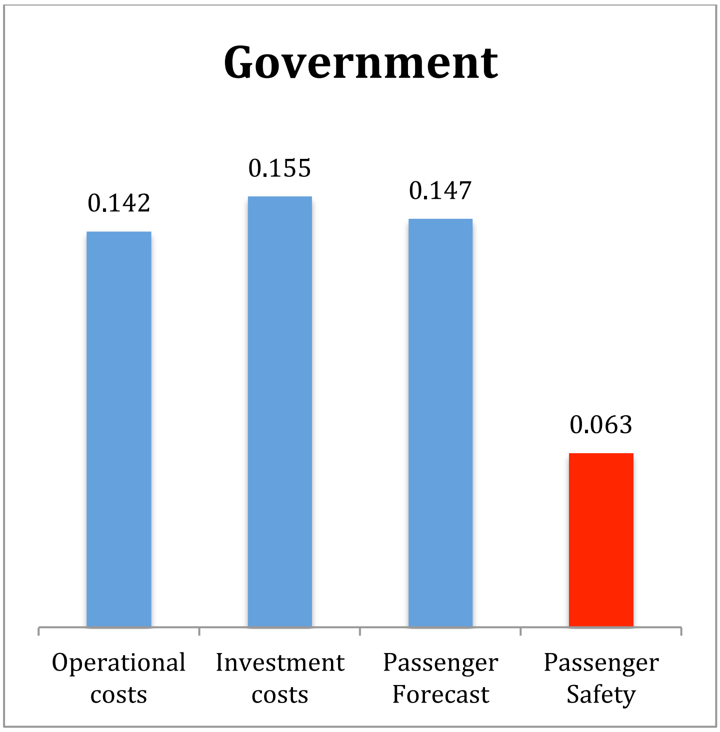


FIGURE 12. MOST AND LEAST IMPORTANT CRITERIA - GOVERNMENT

Figure 13, shows the two most important criteria for the passengers. The figure shows that **Frequency** and **Operational speed** can be characterized as highly important, from a passenger's perspective. Surprisingly, the criterion, **Image**, is chosen as the least important criterion. From these observations the following conclusion can be drawn: From a passenger's point of view, the type of system does not matter, as long at is fast (contributes to a short travel time) and has a high frequency.

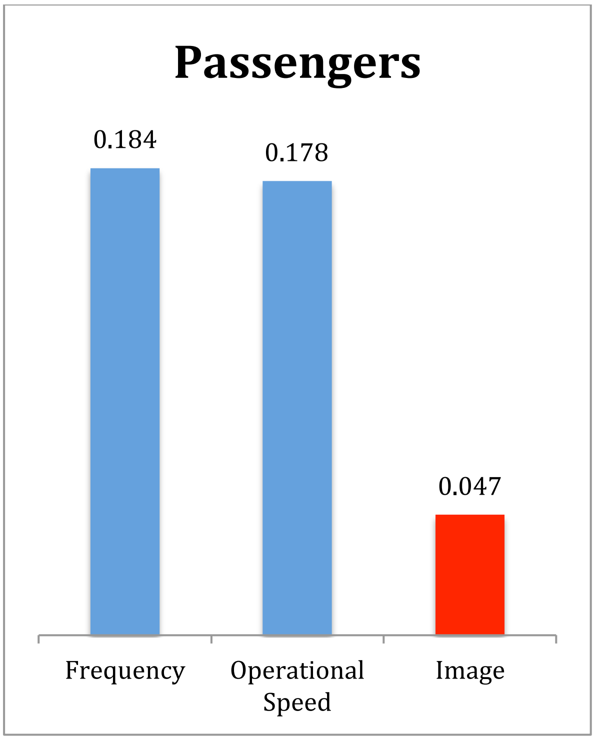


FIGURE 13. MOST AND LEAST IMPORTANT CRITERIA - PASSENGERS

All the criteria and weights for the three groups are shown in Table 11, a detailed analysis can be found in Appendix IV. Criteria marked blue indicates a duplicate within the other groups. For example, the **frequency** is a criterion that occurs both in the passengers as the operators group as important. From the interviews with decision-makers, the criterion: **passenger forecast**, is for both the government as the operators, an important factor. After conducting the Best-worst analysis, this statement can be validated, as this is the most important criterion for the operators and the 2nd most important one for the government.

TABLE 11. CRITERIA WEIGHTS

Passengers	**Wp**	**Government**	**Wg**	**Operators**	**Wo**
Frequency	0.18	Operational costs	0.14	Frequency	0.13
Punctuality	0.11	Punctuality	0.06	Subsidy	0.12
Passenger Safety	0.10	Passenger safety	0.06	Passenger safety	0.11
Operational speed	0.18	Liveability inhabitants	0.08	Operational speed	0.11
Accessibility PT system	0.07	System Capacity	0.13	System Capacity	0.12
Travel information	0.09	Passenger Forecast	0.15	Passenger forecast	0.21
Image	0.05	Maintenance costs	0.12	~~Political consideration~~	---
Travel comfort	0.09	Flexibility	0.11	TCO	0.16
Ticket price	0.12	Investment costs	0.16	Ticket price	0.04
Sum	1.00		1.00		1.00

With

Wp = Weights of the criteria for the passengers
Wg = Weights of the criteria for the government
Wv = Weights of the criteria for the public transport operators

As can be seen, **political considerations** is one of nine of the most important criteria for the public transport operators, which contributes to public transport investment decision-making. This observation was rather an important remark in almost all interviews, not only with the operators but also the government. Despite the high importance of this attribute, this factor will not be taken into account in further analysis as it too difficult to measure this unit. Trying and determining a measure, will only influence the results in a negative way and in consultation with various decision-makers, the conclusion is drawn to leave this factor out of scope. However, it is important to be aware that this is an extremely important factor, which can have a highly significant affect on the decision-making process.

As can be seen from Table 11, the weight for the criteria **frequency** and **punctuality** are higher from a passenger's perspective compared to the perspective of the government. This indicates that the passengers perceive frequency and punctuality as more important.

The table also shows that the 2nd most important criterion from the passengers perspective, **Operational speed**, is the 6th most important criterion as seen from the operators perspective.

Furthermore, as described below, the **Passenger safety** is the least important criterion from the government point of view. The same criterion is the 2nd least preferred criterion, as seen from the Operators point of view. The passenger safety is one of the factors that has a low preference in the decision-making process for both the government as the operators. In the passengers group however, this criterion is ranked 5th place in preference, which is about halfway.

4.5 INDICATORS AND ANALYSIS

Now that the important criteria and weights are known, a perception can be visualized. This is done by multiplying the weights with the factors. Table 12 shows the values corresponding with the passengers. these values are derived from the 'Ov-Klantenbarometer'(Customer Barometer) of 2016. This is a survey conducted by Kennisplatform Verkeer en Vervoer (KPVV) in the Netherlands which measures the experience, opinion and perception of passengers on public transport systems (CROW-KpVV, 2016)

TABLE 12. INDICATOR VALUES PASSENGERS

Passengers	Weight	Bus	Tram	Metro	BRT	LRT	eBus
Criterion		Factor	Factor	Factor	Factor	Factor	Factor
Frequency	0.18	7.2	7.3	7.5	7.3	7.4	7.2
Punctuality	0.11	7.2	7.2	7.5	7.2	7.4	7.2
Passenger Safety	0.10	7.9	7.6	7.4	7.9	7.5	7.9
Travel time	0.18	7.6	7.5	7.8	7.6	7.7	7.6
Accessibility of PT system	0.07	8.6	8.3	8.8	8.5	8.6	8.6
Travel information	0.09	7.7	7.4	7.9	7.6	7.7	7.7
Image	0.05	7.6	7.5	7.5	7.6	7.5	7.8
Travel comfort	0.09	7.5	7.2	7.1	7.4	7.2	7.9
Ticket price	0.12	5.6	5.1	5.1	5.4	5.1	5.6

Multiplying the weights with the factors the following results are obtained (Table 13), a scale is used between -1000% and 1000% to display the preference of the systems:

TABLE 13. PASSENGERS PERCEPTION

Passengers	Bus	Tram	Metro	BRT	LRT	eBus
Criterion	Factor	Factor	Factor	Factor	Factor	Factor
Frequency	0%	1%	4%	1%	3%	0%
Punctuality	0%	0%	4%	0%	2%	0%
Passenger Safety	0%	-4%	-6%	-1%	-5%	0%
Travel time	0%	-1%	3%	-1%	1%	0%
Accessibility of PT system	0%	-3%	2%	-2%	-1%	0%
Travel information	0%	-4%	3%	-2%	-1%	0%
Image	0%	-1%	-1%	-1%	-1%	3%
Travel comfort	0%	-4%	-5%	-2%	-5%	5%
Ticket price	0%	-9%	-9%	-4%	-9%	0%
Result	0%	-2%	0%	-1%	-1%	1%

As can be seen from the passenger Table 13, this group is rather indifferent regarding their system choice. The metro scores equally as the bus and the eBus ranks highest among all systems. The tram scores lowest, mainly because passengers feel more unsafe, perceive the tram as more expensive and have the feeling that the tram offers a lower travel comfort and less information.

With regards to ticket price, all rail-based, are experienced as more expensive compared to the road-based systems. On first thought, this seems strange, as the price per km is legally determined. On the other hand, rail-based systems usually overpass higher distances, resulting in a higher price per trip.

Table 15 and Table 16 below show the values for each criteria for the government. As can be seen, the first column presents the criteria and the second column their weights. The weights shown in red indicate a negative factor. When the values of these factor increase, they will have a negative effect on the perception of the government. For example, if the **passenger safety costs** increase for a modality, the more negative this modality will score. A more detailed explanation of all of the following criteria and their values, is described in Appendix VII. For the calculation of the investment, maintenance, operational costs and the TCO, a life span of 50 years is assumed and a length of 10 km infrastructure. Table 14, shows the TCO calculation, used for the Operators, but also the investment, maintenance and operational costs.

The operational costs (Appendix VII, section B) of a bus system for example, are calculated by using the following information, in € mln per year.

- Amount of buses needed in a 50 year life span
- Amount of km's an average bus drives per year
- The energy costs per km of a bus (CROW-KpVV factors, 2016).
- Salary of a bus driver per km (CROW-KpVV factors, 2016).

The life span of different modalities differ and therefore, to aim for a fair comparison, a time horizon of 50 years is assumed to calculate the investment and maintenance costs.

As can be seen, the investment and maintenance costs are shown in million euro per year. For the bus, for example, this means that the maintenance costs for a bus system is €0.16 mln. per year per km.

The maintenance costs (€mln. per year) are calculated by summing the maintenance costs of infra per km per year and the maintenance costs of vehicles per km per year, both derived from the 'kengetallen' report published by KpVV (CROW-KpVV factors, 2016). For example, for the calculation of maintenance costs for a bus system the calculation is made using the following information:

- Amount of vehicles needed for a period of 50 years
- Average km driven by a bus per year (MRDH-kmBus, 2017)
- Maintenance costs of bus per km (CROW-KpVV factors, 2016)
- Maintenance costs of bus infrastructure per km per year (CROW-KpVV factors, 2016)

With regards to the investments costs, the following information is used:

- Amount of vehicles needed for a period of 50 years
- Price for one vehicle per year (CROW-KpVV factors, 2016)
- Investments costs of bus infrastructure per km (CROW-KpVV factors, 2016)

The investment costs then are calculated by summing the total investment costs of the vehicle with the investment costs of infrastructure and are measured in investment costs per year.

TABLE 14. TCO CALCULATION

€ in millions per year	Bus	Tram	Metro	BRT	eBus	LRT
Vehicles needed	5	2	2	5	5	2
Investment costs	**€0.51**	**€4.92**	**€65.32**	**€1.90**	**€0.62**	**€24.96**
Investment infra	€0.48	€4.80	€65.12	€1.85	€0.56	€24.80
Investment vehicles	€0.03	€0.12	€0.20	€0.05	€0.06	€0.16
Maintenance costs	**€0.87**	**€3.07**	**€7.69**	**€0.89**	**€0.89**	**€6.46**
Maintenance infra	€0.79	€2.90	€7.65	€0.79	€0.87	€6.30
Maintenance vehicles	€0.08	€0.17	€0.04	€0.10	€0.02	€0.16
Operational costs	**€0.40**	**€0.24**	**€0.14**	**€0.44**	**€0.31**	**€0.14**
TCO	**€1.78**	**€8.23**	**€73.16**	**€3.22**	**€1.83**	**€31.57**

The Liveability of the inhabitants is defined as the influence of the public transport system on the environment. For a detailed explanation and analysis can be found in Appendix VII, Section J. This criterion is measured by the following three factors:

1. Emissions which are derived from (Brogt, 2013) and (Puchalsky, 2005).

2. Property values, derived from from (Dewees, 1976), (Sun, Wang, & Li, 2016), (Agostini & Palmucci, 2008), (Lloyds Bank, 2017), (FTA-BRT, 2009), (Stokenberga, 2014), (Wagner, Komarek, & Martin, 2017)

3. Accessibility of the region, derived from the amount of passengers that can be transferred and reached, defined by the passenger forecast.

The Passenger Forecast (Appendix VII, section G) is calculated by multiplying the average frequencies (RET-vervoerplan 2018, 2016) with the system capacities (RET-Bus, 2017).

The Punctuality is calculated by taking the average of the punctuality of the different systems of the operators (Appendix VII, section E). The punctualities can be found in the 'Concessiemonitor' report of the MRDH for all operators per mode (MRDH-concessie, 2017).

For the calculation of the passengers safety costs the following information is used (Appendix VII, section M):

- Passengers safety costs per year
- Amount of passengers per day

The Flexibility, also extensively explained in Appendix VII, Section K, is based on rough estimated and own analysis. Chapter 6.2 will elaborate more on this. All the rail-based system score very low on flexibility because they are 100% dependent on their infrastructure and therefore their route. The road systems are far less dependent regarding this subject. The BRT is a little more dependent compared to a bus, however, it still can take detours without a problem. The eBus is a little more dependent on its infrastructure due to the charging stations at each stop and at the depot.

The system capacities can be found on the websites of the different operators (RET-Bus, 2017), (Appendix VII, section A).

The table (Table 15) shows that the operational costs of a bus exceed the costs of a metro and tram. This can be explained due to the life span of the system and the amount of vehicles needed. But also, the fuel costs of a bus are higher compared to the energy costs of a metro or tram (Appendix VII, Section B and Section I). The red criteria indicate a negative impact on the overall perception, if the value increases. For example if the investment costs increase, the more negative the perception of the government.

TABLE 15. INDICATOR VALUES GOVERNMENT PART 1

Government		Bus	Tram	Metro	
Criterion	Weight	Factor	Factor	Factor	Unit
Operational costs	0.142	0.40	0.24	0.14	€mln./yr.
Investments costs	0.155	0.51	4.92	65.32	€mln./yr.
Maintenance costs	0.117	0.87	3.07	7.69	€mln./yr.
Liveability inhabitants	0.083	6	8	9	[1-10]
Forecast	0.147	337.5	1001	1500	Pass/hr.
Punctuality	0.063	85.82	91.3	94	%
Passenger safety	0.063	1276	3784	5670	€/day
Flexibility	0.107	8	1	1	[1-10]
System Capacity	0.125	90	182	250	Passengers

TABLE 16. INDICATOR VALUES GOVERNMENT PART 2

Government		BRT	LRT	eBus	
Criterion	Weight	Factor	Factor	Factor	Unit
Operational costs	0.142	0.44	0.14	0.31	€mln./yr.
Investments costs	0.155	1.90	24.96	0.62	€mln./yr.
Maintenance costs	0.117	0.89	6.46	0.89	€mln./yr.
Liveability inhabitants	0.083	7	9	7	[1-10]
Forecast	0.147	1136	1080	225	Pass./hr.
Punctuality	0.063	90	95	85.82	%
Passenger safety	0.063	4294	4082	851	€/day
Flexibility	0.107	6	1	7	[1-10]
System Capacity	0.125	142	216	60	Passengers

With regards to the Public Transport Operators, the corresponding values and the weights are shown in Table 17 and Table 18. A more detailed analysis can be found in Appendix VII. As can be seen, the TCO and passenger safety (costs) are shown in red. The higher this value, the more this negatively influences the perception.

The Earnings (Revenues) are calculated using the ticket price per km and the passenger forecast. The ticket price is determined by law, however, the more passengers are using the system, the higher the earnings. The ticket price (Appendix VII, section D) is based on a base tariff and a price per km. for each mode.

The operational speed of the systems is based on the information found in the 'Subsidiebeschikking' of the operators (MRDH-RailHTM, 2017), (MRDH-RailRET, 2017). This indicates the average speed of a system.

The frequency of the systems is derived from information from the 'Vervoersplan' of the different operators and describes the average frequency of the system (RET-vervoerplan 2018, 2016), (Conexxion-vervoerplan 2018, 2016), (HTM-vervoerplan 2018, 2016), (HTM-vervoerplan rail 2018, 2016). These documents describes in detail, the plans of the operators for the upcoming year (Kenniscentrum InfoMil, n.d.).

As can be seen, the metro can transfer almost 5 times the amount of passengers per hour compared to a bus, by having a higher average frequency and higher average system capacity. The capacity of the eBus is less compared to a conventional bus, most likely due to the batteries within the vehicle (RET, 2017).

As can be seen, the TCO of the metro is highest, followed by the LRT and Tram. From this observation, the conclusion can be derived that in general, all rail-based systems are more expensive compared to the road-based systems. The LRT is almost 10x more expensive compared to the most expensive road-system. The metro more than 22x more expensive and the tram almost 3x as expensive compared to the most expensive road-based system (BRT). The system capacity however, of a BRT (216) is higher compared to that of a LRT (142).

TABLE 17. INDICATOR VALUES OPERATORS PART 1

Public transport operators	Bus	Tram	Metro	

Criterion	Weight	Factor	Factor	Factor	Unit
Passenger forecast	0.213	337.5	1001	1500	Pass/hr.
Earnings	0.121	49	146	219	€/km
Polities	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.120	90	180	250	Passengers
Frequency	0.129	3.91	5.4	6.1	Dep./hr./dr.
Operational speed	0.108	12.5	17.6	37.1	Km/h.
TCO	0.158	1.78	8.23	73.16	€mln./yr.
Passenger safety	0.107	1276	3784	5670	€/day

TABLE 18. INDICATOR VALUES OPERATORS PART 2

Public transport operators		BRT	LRT	eBus	
Criterion	Weight	Factor	Factor	Factor	Unit
Passenger forecast	0.213	1080	1755	225	Passengers
Earnings	0.121	158	166	49	€/km
Polities	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.12	216	142	60	Passengers
Frequency	0.129	5	8	3.91	Dep./hr./dr.
Operational speed	0.108	30	24.11	12.5	Km/h.
TCO	0.158	3.22	31.57	1.83	€mln./yr.
Passenger safety	0.107	4082	4294	851	€/day

Now that the important criteria and their values are known and weights are determined for each group, the perceptions can be calculated. By first normalising each factor and multiplying the weights with the normalised value, the perceptions are determined. The table below,

Table 19, shows the result of the perception analysis. The analysis and all the corresponding tables (normalised tables for example) are presented in Appendix VIII. This Appendix shows tables where in detail can be seen which factors score high and low on the preference of the stakeholders.

Passenger's perspective

The bus is used as a benchmark to show how each system scores compared to the bus. The table shows that the Passengers are quite indifferent in their system choice. From the weights the conclusion was drawn that the system should be fast (operational speed) and frequent. The image does not influence their choice enormously. The same conclusion can be drawn from the perception analysis results, shown by the very low variation in preference for various systems.

Government's perspective

With regards to the Government, a whole different perception is obtained. The government's perception regarding light-rail systems is highest, closely followed by BRT systems. A metro, despite the fact that this system can transfer the most amount of people, together with the eBus, is preferred lowest.

The LRT scores high on preference for the government, mainly due to the low operational costs. For those low operational costs, the LRT system offers a high liveability, can handle a good amount of passengers, due to its system capacity.

The Metro scores low on the preference for the government due to high investment, maintenance and passengers safety costs. Also, the low flexibility contributes to this low preference.

Public Transport Operators perspective

The operators show a high preference, just like the government, for LRT also followed by BRT. However, seen from the operators' perspective, the preference for BRT and LRT are closely together. Whereas the distance in preference between LRT and BRT is higher, seen from the government's perspective. The Operators, show in general a high preference for rail-based systems.

The LRT system gets a high preference because of the high passenger forecast. It can transfer a huge amount of people, with a high frequency. This also contributes positively to the revenues (Earnings) of the Operators.

The BRT scores high due to its high revenues (Earnings), high system capacity and operational speed. Furthermore, the costs (TCO and passenger safety costs) for a BRT system are quite low.

The eBus scores low, as seen from the operators perspectives because of the low frequency, low capacity, low revenues and low operational speed.

TABLE 19. RESULTS PERCEPTION ANALYSIS

Stakeholders\Modality	Bus	Tram	Metro	BRT	LRT	eBus
Passengers	0%	-2%	0%	-1%	-1%	1%
Government	0%	2%	-17%	4%	5%	1%
PT operators	0%	32%	37%	45%	49%	-4%

4.6 THE BENEFITS OF PUBLIC TRANSPORT

This section describes which benefits occur with which system. As described by van Oort, van der Bijl & Maartens (2016), the benefits of public transport are highly underestimated. The descriptions below are meant to create awareness and trigger decision-makers also to take into account the aspects that one would not think of immediately. The benefits per modality are presented in Table 20. An explanation of each benefit per modality is given below.

4.6.1 BENEFITS BUS RAPID TRANSIT

The BRT system contributes to the accessibility of the region. By having a dedicated infrastructure, high frequency transport can be offered resulting in a high punctuality. This results in a high operational speed and the possibility to transfer a great amount of passengers. Furthermore, as described in Appendix VII, Section J, a BRT system results in higher property values nearby the stations, which contributes to economic development. The distance between stops is shorter compared to other systems resulting in a shorter walking distance to the system. Finally, transporting a high amount of people results in high revenues.

4.6.2 BENEFITS METRO

The dedicated infrastructure of a metro in combination with the fact that a metro does not experiences other traffic results in a high punctuality with high frequency. Combining the high capacity and the high frequency results in a high amount of people that can be transferred within a short period of time. The metro drives on electricity, making it a zero emission system. The fact that the metro can transfer a huge amount of passengers, in a short period of time over great distances highly contributes to the accessibility of the region. The combination of this high accessibility, together with low emissions contributes positively to the liveability of the region and its inhabitants. Finally, the highly positive effect of a metro on the property values contributes to the economic development of the region (Dewees, 1976), (Sun, Wang, & Li, 2016), (Agostini & Palmucci, 2008), (Dai, Bai, & Xu, 2016).

4.6.2 BENEFITS BUS AND EBUS

The bus (conventional and eBus) have the lowest capacity. To transfer a huge amount of people usually means implementing a higher frequency. This could results in more passengers, (due to the frequency bonus). Finally, from the 'OV-klantenbarometer', the conclusion can be drawn that in general, the bus has the highest travel comfort compared to other modes and that passenger feels safest in the bus. Also, the bus is characterized as a high flexibility system and low dependency on its infrastructure. This gives the bus the possibility to take a detour when necessary and still maintain (about) the same level of quality. Finally, the eBus operates on electricity making this system zero emission.

4.6.3 BENEFITS TRAM

A tram also contributes to the accessibility of the region and according to an article from Lloyds Bank (2017), also positively to the property values of houses in Manchester, Birmingham, Nottingham, London and Edinburgh. Such effects were also found in other studies (Gadzinski & Radzimski, 2016). Furthermore, the tram operators as a zero emission system. Combining the high accessibility and increase in property values results in a positive effect on the economical development. Furthermore, the dedicated infrastructure of the tram in combination with priority benefits also contributes to a punctual system.

4.6.4 BENEFITS LIGHT RAIL TRANSIT

Firstly, the highly positive contribution of a LRT system on the property values influences the economical development in certain regions (Wienberger, 2001). Furthermore, the dedicated infrastructure, in combination with a high frequency and a high operational speed results in a highly punctual system, which can transfer a huge amount of passengers. Transferring a huge amount of passengers results in a high revenues.

4.6.7 BENEFITS PER SYSTEM

Concluding the above mentioned benefits of the systems results in Table 20. This table visualises the benefits of each modality. The ++ indicates highly positive compared to the other modalities and a + indicates a positive contribution compared to the other modes.

TABLE 20. BENEFITS PER MODALITY

Benefits	Metro	Tram	Bus	eBus	LRT	BRT
Accessibility of the region	++	++			++	++
Emissions	++	++		++	++	
Flexibility			++	++		
High Earnings	+				+	+
High frequency	+	+			+	+
Economic development	++	+			++	+
Operational speed	++				++	+
Passenger safety			+	+		+
Property values	+				+	+
Punctuality	+	+			+	+
Travel comfort			+	+		
Walking distance to stop			++	++		+

4.7 CONCLUSIONS

This chapter served to provide an answer to the following sub-questions:

(2) Which criteria are important for comparison of public transport modalities and why?

(3) How do the comparison factors score on level of importance for different stakeholders?

The important criteria and their corresponding weights are categorized for each stakeholder and can be seen in Figure 14, Figure 15 and Figure 16 below. The orange coloured criteria indicate a duplicate in the criteria of other stakeholders. For example, the **system capacity**, occurs both in the important criteria from the Government as in the list of the Operators.

An interesting observation that can be made is about the difference in value for the **passenger safety** and **punctuality** criterion. Comparing the weights of the Passengers and Government show that the weights for the above-mentioned criteria are higher for the passengers group. From this, the conclusion can be drawn that passengers value these aspects higher compared to the government.

Finally, the most important criterion from a passenger's point of view is **Frequency**, and the least important is **Image.** From the governments perspective, **Investment costs** can be characterized as most important and both **Punctuality** and **Passenger Safety** as least important. The public transport operators' information show that **Passenger Forecast** is the most important criterion and **Ticket Price**, the least important one. Passenger forecast is also one of the most important (2nd) attributes for the government. The low weight for ticket price can be explained by the fact that this criterion is determined by law and the operators do not have any influence on this factor. Nonetheless, the ticket price contributes to (information regarding) passenger earnings and the to be obtained subsidy from the government.

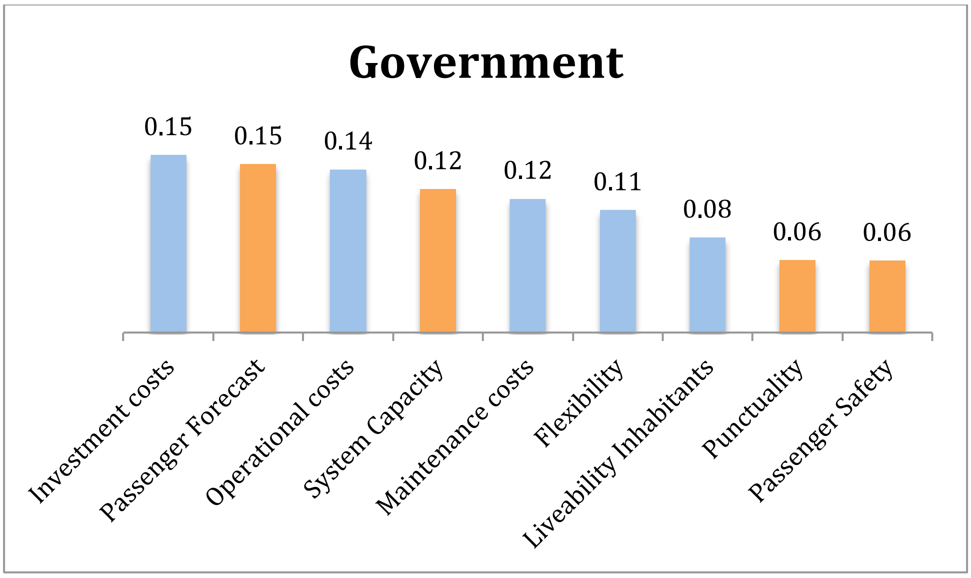


FIGURE 14. WEIGHTS GOVERNMENT

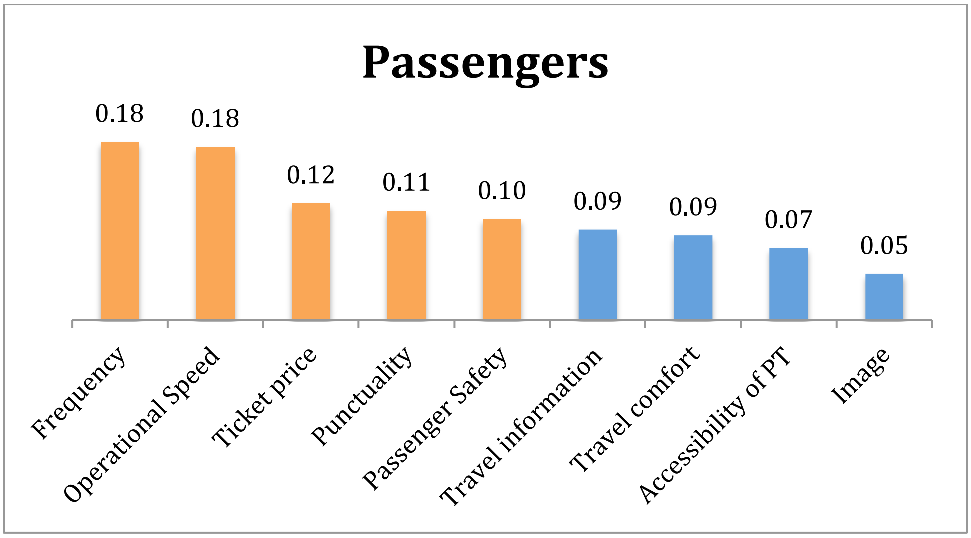


FIGURE 15. WEIGHTS PASSENGERS

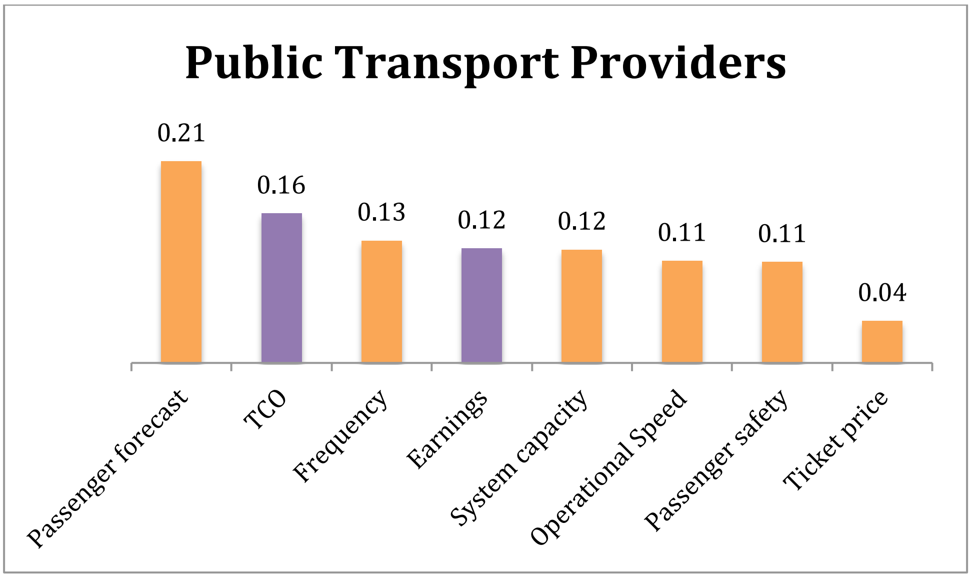


FIGURE 16. WEIGHTS PUBLIC TRANSPORT OPERATORS

The results of the perception analysis (Table 19) that the Government has a strong preference for a LRT system followed by BRT. The metro has high costs, which results in the lowest preference as seen from the government's perspective. The eBus has a very low capacity and higher costs compared to a bus and is also preferred low.

The Operators show a high preference for rail-based system. The LRT has the highest preference closely followed by the BRT system. Comparing this to the perception of the government, the LRT is preferred highest in both groups. The BRT scores high because of low costs and a relative high capacity.

The perception of the Passengers is highly interesting. There is not a high preference for a specific system or systems, as long as it is fast and has a high frequency. The preference for the eBus is highest and the metro and Bus score equally. The eBus mainly scores high because of the higher travel comfort and image.

Now that the general perceptions are known, the data can be applied on a case to obtain more information. A case study is used to apply the above-mentioned method on a real case to investigate whether the obtained information can be used in decision-making.

This chapter will investigate, by means of two case studies, which system suits better in specific cases, according to the stakeholders. Firstly, case study A, calculated the perceptions of the stakeholders where a tramline in The Hague is transformed to a bus line. The second case study, case study B, calculated the perceptions of the stakeholders, where a bus line is transformed to a tramline. Finally, the results will be discussed with the decision-makers and presented in chapter 5.3.

The goal of this chapter is to provide an answer to the following two sub-questions:

(4) Which public transport system suits best for implementation according to the perceptions of the stakeholders?

(5) To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

To perform this case study in a corrected manner, some of the values will be case specific. In the following three figures, Figure 17, Figure 18 and Figure 19, the nine most important criteria are shown for the three stakeholders. The criteria shown with a blue colour indicate an attribute change for this specific case compared to the general values, which are also described in Appendix VII. As can be seen, all the criteria with regards to the passengers' perception have a different value compared to the general indicators. For example, the travel comfort is case specific and therefore indicated with a blue colour.

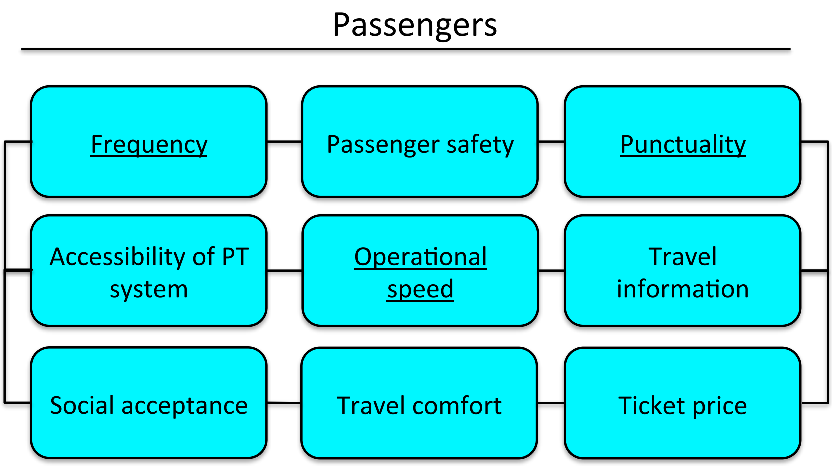


FIGURE 17. PASSENGER INDICATOR CHANGE CASE STUDIES

The underlined criteria represent criteria where general information is used. The information in the cases regarding the frequency for example, now the frequency of the system is used instead of the data from the 'OV-Klantenbarometer'. The operational speed that is used now is the general operational speed, as described in Appendix VII, Section C, instead of information from the surveys.

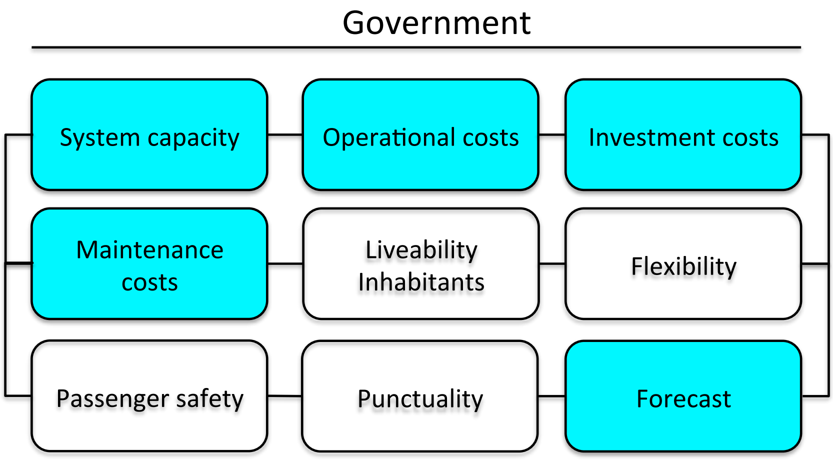


FIGURE 18. GOVERNMENT INDICATOR CHANGE CASE STUDIES

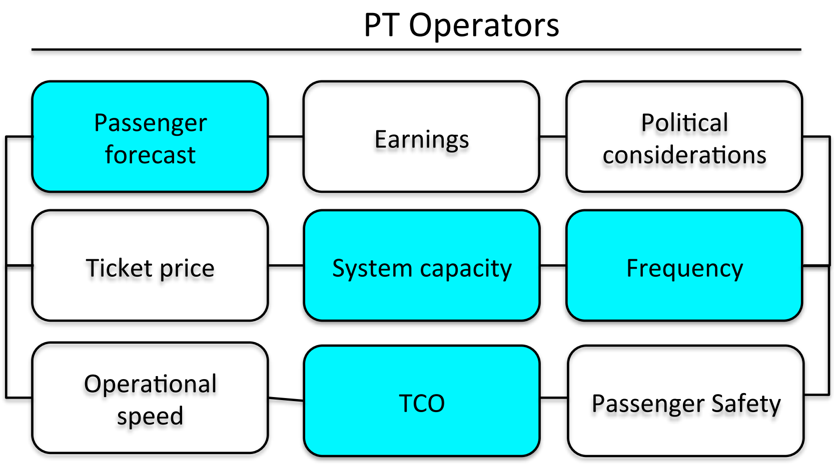


FIGURE 19. OPERATORS INDICATOR CHANGE CASE STUDIES

The data that is needed for both case studies is information from The Hague and Rotterdam for bus and trams. The 'OV-klantenbarometer' (Appendix V), specifies these results also for different regions. The information that is needed for both case studies is derived from the following regions:

- For the case of Tram line 12: data for bus is gathered from the region: 'Stadsvervoer Den Haag', which represents results from the city centre of The Hague, where the line is operational.
- For the case of Tram line 12: data for the tram is gathered from the region: 'Den Haag', representing data from The Hague, where the line is operational.
- For the case of Bus line 44: data regarding the tram is gathered from the region: 'Rotterdam', in which the line is operational.
- For the case of Bus line 44: data regarding the bus is gathered from the region: 'Rotterdam en omgeving', in which the line is operational.

Furthermore, in the case studies, the increase in percentage of extra ridership is used as explained by Bunschoten (2012). This takes into the account the rail-bonus: of 4.3% (on the long term) increase in travellers if rail mode is used compared to road transport system. However, Bunschoten describes that this increase only is applicable to the region of Utrecht because of the scope of the research. For this thesis, the assumption is made that the Utrecht region is comparable as the Rotterdam and The Hague region and therefore the rail-bonus of 4.3% is used in the case studies.

A frequency change leads to an increase or decrease in passengers, as described in 'De waaier van Brogt' (2013). A more detailed explanation is described in Appendix X. The increase in frequency can be seen as beneficial for the passengers because their average waiting time decreases. Also, when the frequency decreases, the average waiting time will increase, resulting in less passengers making use of the system. The tables, Table 21 and Table 22, show the passengers growth and loss as a result of a change in frequency. If the frequency of a system changes, for example, from 1 departure per hour (per direction) to 2 departures per hour (per direction), there is an increase in passengers of 60%.

TABLE 21. PASSENGER GROWTH AS A RESULT OF FREQUENCY CHANGE

Frequency change	Passengers growth	Time gains
0.5-->1	60%	60 min
1-->2	40%	30 min
2-->4	25%	15 min
4-->8	15%	7.5 min

TABLE 22. PASSENGER LOSS AS A RESULT OF FREQUENCY CHANGE

Frequency change	Passengers growth	Time loss
8-->4	-35%	7.5 min
4-->2	-45%	15 min
2-->1	-60%	30 min
1-->0.5	-80%	60 min

5.1 CASE STUDY A: TRAM 12 THE HAGUE

Tramline 12 from HTM has about 24 stops and a total length of 8 km. The trams' starting point is at Duindorp and ends about 40 minutes later at The Hague Hollandspoor station. This specific system, operates poorer compared to other system because it transfers, on average, less passengers. For this reason, a case study is executed to investigate whether the tramline can be transformed to a bus system.

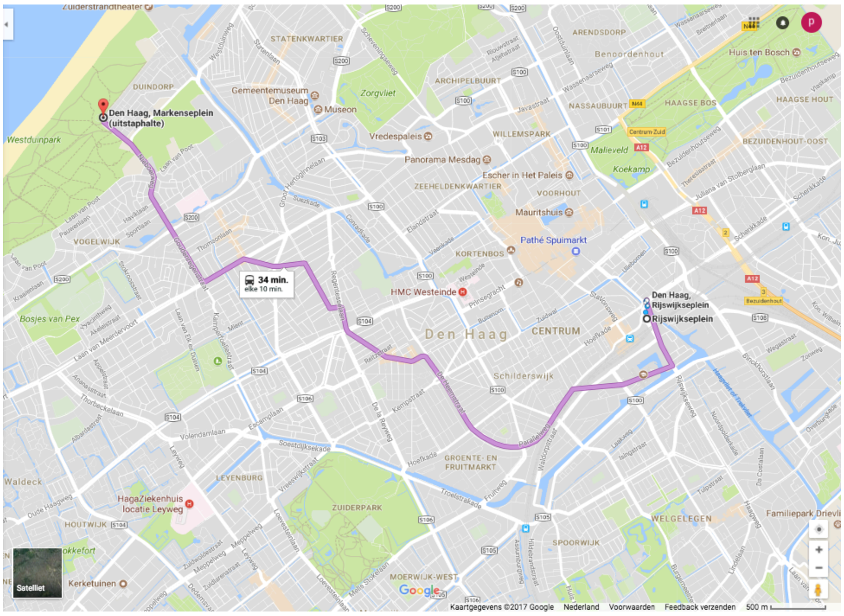


FIGURE 20. MAP TRAMLINE 12 HTM THE HAGUE

A tram is in general more expensive in maintenance and operational costs compared to a bus. Because public transport already needs to be subsidized by the government, the goal is to make the least amount of loss as possible. The (average) frequency and operational time of the line are shown in Table 23 below.

TABLE 23. FREQUENCY TRAM LINE 12

		Frequency				
Start	End	Morning	Afternoon	Evening	Night	Average
06:00	0:00	4.3	4	4.5	4	4.2

As can be derived from Table 23, the current average frequency (4.2) is lower compared to the average tram frequency (5.5). This shows that this specific line is underperforming compared to average, with regards to frequency. When taking a closer look at the passenger flow, more information will be gathered and a more suitable conclusion can be drawn regarding the performance of this system.

The amount of passengers using this line can be derived from the graph, Figure 21, shown below:

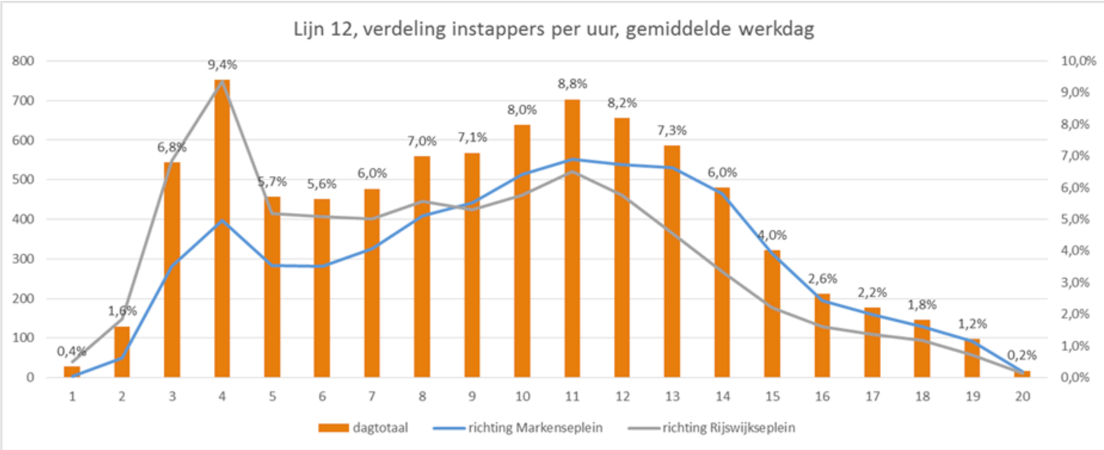


FIGURE 21. PASSENGERS TRAM LINE 12 HTM (PERSONAL COMMUNICATION, 13-09-2017)

The figure shows that approximately 8000 passengers per day per direction use this line. The maximum capacity of a tram, found in Appendix VII section A, is about 182 passengers. According to the Product Manager market exploration and Transport Development of HTM (appendix VI) an ''inzetnorm'' is used to calculate the needed capacity. This ''inzetnorm'' is a kind of standard or margin to keep the company from fully utilizing the occupancy rate of a vehicle. This standard is calculated by summing the amount of seats and 50% of the standing places of a vehicle. For an average tram, this standard is 138 passengers, which is about 75% of the maximum capacity.

The figure also shows that almost 9.5% of passengers throughout the day, travel in the 4th hour. This results in 760 passengers per hour that the system needs to handle. With an average capacity of 138 passengers, a frequency of 5.5 trams is able to handle that amount of passengers per hour. At least 6 trams are needed to cope with this demand.

A standard bus (12 meter) has a system capacity of 90 passengers (Appendix VII, section A and Appendix X). The average amount of passengers, one bus can transport, calculated with the standard, would be 75% of 90, which results in 68 passengers. To transfer 760 passengers per hour, this bus needs to have an average frequency of at least 11.18 departures per hour per direction. For this scenario, at least 12 buses are needed to cope with this kind of capacity. Another possible solution is to use longer buses, with higher capacity. Taking into account the 18-meter bus, with a maximum capacity of 149 passengers, the standard capacity of one of these buses, using the (75%) standard becomes, 112 passengers. To maintain the 760 passengers per hour, this bus needs to drive with an average frequency of 6.7 departures per hour per direction. For the second scenario, using an 18m bus, at least 7 buses are needed in peak hour. The eBus has a capacity of 60 passengers per hour (RET-Bus, 2017) and calculating with the (75%) standard norm, this gives an average capacity of 45 passengers. Transferring 760 passengers per hour, this eBus needs to have a frequency of 17 departures per hour per direction in peak hours. Furthermore, information, especially key numbers, regarding electric buses is hard to find. This in combination with the enormous frequency decided to take the eBus not into account in this case study.

Until now the following scenarios, presented in Table 24, are described and taken into consideration. The amount of vehicles for the current scenario is not applicable due to the fact that the vehicles are already purchased.

TABLE 24. SCENARIOS TRAM LINE 12 CASE A

Vehicle	Current situation Tram	Scenario 1: bus 12m	Scenario 2: bus 18m
Off peak freq.	4.2	6.5	4
Peak freq.	5.5	11.18	6.7
Nr. of vehicles	---	12	7

Table 25 below shows the values for the criteria for the passengers group. As can be seen, values used for the frequency are case specific. Values used for the punctuality and operational speed are system specific, meaning values are used that are applicable for the general system. These three criteria are shown in blue. For example, the average operational speed for a tram equals 17.6 km/h whereas the operational speed for an average bus equals 12.5 km/h (Appendix VII, section C). The data for the other values are derived from the 'OV-klantenbarometer' for the region of The Hague city centre, as that is the region, the line is operational. A detailed analysis can be found in Appendix X, for all three groups.

TABLE 25. PASSENGER INDICATOR AND CHANGES CASE A

Passengers	Weights	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Frequency	0.178	4.2	8.5	5.2	Dep./hr./dr.
Punctuality	0.119	91.3	85.82	85.82	%
Passenger Safety	0.116	7.8	7.5	7.5	[1-10]
Operational speed	0.152	17.6	12.5	12.5	Km/h
Accessibility of PT system	0.064	8.5	8.1	8.1	[1-10]
Travel information	0.092	6.7	6.8	6.8	[1-10]
Image	0.042	7.4	7.2	7.2	[1-10]
Travel comfort	0.090	7.5	7.4	7.4	[1-10]
Ticket price	0.147	5.5	4.9	4.9	[1-10]

After normalising the values and multiplying the weights with indicators, the results shown in Table 26, are obtained. The last row the perception of the new scenario compared to the current one. For example, the scenario with the 18m-bus is preferred 9% less compared to the current scenario. The blue coloured cells indicate an improvement compared to the current scenario. The frequency in the 12m-bus scenario is more than twice compared to the current tram scenario. Furthermore, it appears that passengers perceive the travel information as more positive in a bus compared to a tram.

TABLE 26. RESULTS PASSENGERS CASE STUDY A

Passengers	Tram	Bus	Bus
Criterion	Current	12m	18m
Frequency	0%	55%	-5%
Punctuality	0%	-6%	-6%
Passenger Safety	0%	-5%	-5%
Operational speed	0%	-29%	-29%
Accessibility of PT system	0%	-5%	-5%
Travel information	0%	1%	1%

Image	0%	-3%	-3%
Travel comfort	0%	-1%	-1%
Ticket price	0%	-11%	-11%
Results	0%	-2%	-9%

Using another system directly means that other costs are applicable. For the government and PT Operators, this means that for this specific case, new operational, maintenance and investment costs (and therefore TCO) are applicable. This information is presented in Table 27 and the calculations are executed for the two bus scenario's. The table shows that the investment costs for vehicles equals the amount of vehicles needed in peak hours. The frequency, for example, for an 18m bus equals 6.7 in peak hour. This means that at least 7x 18meter buses are needed, each with an investment cost of €450,000 (Appendix VII, Section C). Spreading this over a 50 years life span, the investment costs only for vehicles amount €63,000 per year.

The difference in peak and off-peak hours is calculated by assuming that 22% of the time the system is operating during peak hours (07:00-09:00 and 16:00-18:00). This results in a different frequency (peak frequency) during peak hours contributing to higher maintenance and operational costs. Furthermore, 78% of the time (14 out of 18 hrs), the system operates outside of peak hours, meaning less vehicles are needed and therefore another frequency is applicable.

The operational costs per year are calculated by multiplying the total operational costs by the amount of km's a vehicle drives on average on a yearly basis (Appendix VII, Section B). A more detailed calculation of the overall costs can be found Appendix X.

TABLE 27. TCO CALCULATION CASE STUDY A

Length line 12 = 8km	Tram	Bus 12m	Bus 18m	
Avg. frequency	4.2	6.5	4	Dep./hr./direction
peak frequency	5.5	11.2	6.7	Dep./hr./direction
System	Tram	Bus 12m	Bus 18m	
Investment total	**€4,200,000**	**€456,000**	**€447,000**	**Per year**
Investment infra	€3,840,000	€384,000	€384,000	Per year for 8 km
Investment vehicle	€360,000	€72,000	€63,000	Per year
Maintenance total	**€2,768,217**	**€761,600**	**€721,472**	**Per year**
Maintenance Peak	€113,342	€42,240	€29,568	Per year
Maintenance off peak	€334,875	€87,360	€59,904	Per year
Maintenance infra	€2,320,000	€632,000	€632,000	Per year
Operational total	**€11.22**	**€10.21**	**€6.34**	**Per year per km**
Operational Peak	€2.84	€3.33	€2.09	Per km
Operational off peak	€8.39	€6.88	€4.24	Per km
Operational costs per year	€621,721	€653,184	€405,606	Per year
TCO	**€7,589,938**	**€1,870,784**	**€1,574,078**	**Per year**

Table 28 below shows the weights and values for the criteria for the government. As can be seen, the operational cost, investment cost, maintenance cost, passenger forecast and system capacity are case specific. The passenger forecast is calculated using the rail-bonus of 4.3%, as described by Bunschoten (2012). This value indicates a change in the amount of passengers when a rail-based system is used compared to similar non-rail based system. Furthermore, due to a change in frequency, the amount of passengers differs and this is calculated using 'de waaier van Brogt' (Brogt, 2013), also explained in the introduction of this chapter. The blue criteria indicate the case specific ones and the weights shown in red indicate, the higher the value, the more negative this affects the perception.

TABLE 28. GOVERNMENT INDICATOR AND CHANGES CASE A

Government	Weight	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Operational costs	0.142	0.62	0.64	0.41	€ mln./year
Investments costs	0.155	4.20	0.46	0.45	€ mln./year
Maintenance costs	0.177	2.77	0.76	0.72	€ mln./year
Liveability inhabitants	0.083	7	6	6	[1-10]
Passenger Forecast	0.147	445	469	429	Pass/hr./dr.
Punctuality	0.063	91.3	85.82	85.82	%
Passenger safety	0.063	3784	1276	1276	€/day
Flexibility	0.107	1	8	8	[1-10]
System Capacity	0.125	138	68	112	Pass/vehicle

After normalising the values and multiplying them with the weights, the results shown in Table 29 obtained:

TABLE 29. GOVERNMENT GENERAL PERCEPTIONS

Government	Tram	Bus	Bus
Criterion	Current	12m	18m
Operational costs	0%	-2%	53%
Investments costs	0%	813%	840%
Maintenance costs	0%	265%	284%
Liveability inhabitants	0%	-14%	-14%
Passenger Forecast	0%	5%	-4%
Punctuality	0%	-6%	-6%
Passenger safety	0%	197%	197%
Flexibility	0%	700%	700%
System Capacity	0%	-51%	-19%
Result	0%	77%	96%

With regards to the Public Transport Operators, the values and the corresponding criteria are shown in Table 30. The Earnings are calculated by multiplying the passenger forecast with the ticket price. The TCO is calculated as seen as above in Table 27 and an explanation is given above the table. The passenger forecast changes from 445 passengers per hour to 469 due to the fact that the frequency changes from 4.2 to 6.5. The change in frequency is calculated by using the rail bonus (Bunschoten, 2012)and the frequency bonus (Brogt, 2013), also explained in the introduction of this chapter and Appendix X.

TABLE 30. OPERATORS INDICATORS AND CHANGES CASE A

Public transport operators	Weight	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Passenger forecast	0.213	445	469	426	Passengers/hr
Earnings	0.121	65.0	68.5	62.2	€/km
~~Politics~~	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.12	138	68	112	passengers
Frequency	0.129	4.2	6.5	4	Dep./hr/dir.
Operational speed	0.108	17.6	12.5	12.5	Km/h
TCO	0.158	7.59	1.87	1.57	€mln./year
Passenger safety	0.107	3784	1276	1276	€/day

After normalising the indicators and multiplying them with their weights, the results, shown in Table 31 are found. The table shows that the operators have a high preference for the 18m meter bus. The second scenario, where a 12m bus is used is also preferred above the current sitation. As can be seen, the 12m bus scenario scores better with regards to passenger forecast due to the fact more passengers will be using the system because of a higher frequency. Furthermore, the TCO and passenger safety costs score in both new scenario's higher.

TABLE 31. RESULT OPERATOR PERCEPTION CASE A

Public transport operators	Tram	Bus	Bus
Criterion	Current	12m	18m
Passenger forecast	0%	5%	-4%
Earnings	0%	5%	-4%
~~Politics~~	---	---	---
Ticket price	0%	0%	0%
System capacity	0%	-51%	-19%
Frequency	0%	55%	-5%
Operational speed	0%	-29%	-29%
TCO	0%	306%	382%
Passenger safety	0%	197%	197%
Results	0%	24%	19%

Summarizing the above results, the following table obtained, Table 32. The table also shows the results for the government and Operators when the investment costs of the current scenario are not taken into account. At the time this research is conducted, it is still unsure if their need to be new investments made in the current scenario. There may be a possibility that new infrastructure and/or new trams need to be purchased.

TABLE 32. RESULTS CASE A

Stakeholders	Tram Current	Bus 12m Scenario 1	Bus 18m Scenario 2
Passengers	0%	-2%	-9%
Government	0%	77%	96%
Government (- investment)	0%	6%	20%
Operators	0%	24%	19%
Operators (- investment)	0%	20%	16%

From the passengers' perspective, the conclusion can be drawn that they rank the tram in the current situation, the highest. Despite the higher frequency in the 12m bus scenario, the passengers perceive that a bus has a lower punctuality. Furthermore, they also feel less safe, experience lower travel times (operational speed), less travel comfort and a higher ticket price.

The operators, on the other hand, prefer both bus scenarios compared to the current scenario. The 18m-bus scenario gets preferred the most. The 12m bus scenario scores positive on the criteria: passenger forecast and earnings, frequency and costs (TCO and passenger safety costs). The 18m-bus scenario scores positive on the costs criteria.

From the government's perspective, the second scenario, 18m-bus, is highly preferred. This is because the bus is highly flexible and far less dependent on its infrastructure, making the system flexible. Also, the operational and passenger safety costs score higher in the bus scenarios.

So, both the government and operators prefer the bus scenarios compared to the current bus scenario. The passengers however, perceive the current tram scenario higher. The first option is to implement one of the bus scenarios and investigate how the criteria of the passengers need to be changed in order to positively influence their perception. The second option is to keep the current system operational, which will be (slightly) beneficial for the passengers.

5.2 CASE STUDY B: BUS 44 ROTTERDAM

For the second case study, RET Bus line 44 in Rotterdam is studied. The line is operated by RET, with a length of 9.5 km and 19 stops. The duration from the first stop, Zuidplein, until the last one, Rotterdam Central station, takes about 31 minutes. This bus line transfers more passengers compared to the average bus lines. A more detailed analysis can be found in Appendix X.

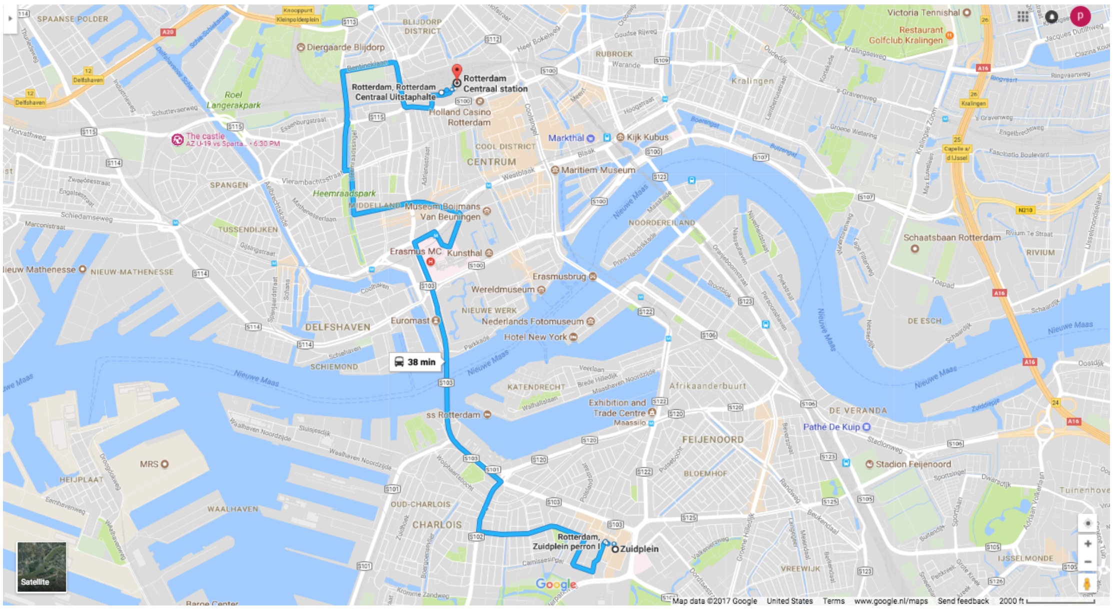


FIGURE 22. ROUTE BUS LINE 44 RET ROTTERDAM

This case study will determine if it is applicable to transform the bus line into a tram line. The operational time of the bus is from 05:54 – 00:01 on weekdays (RET-bus44, 2017) and the frequency of 6.5 can be derived from Appendix VII section F.

The average frequency of all bus operators amounts 3.91 and the average frequency of RET buses is 3.64. With a frequency of 6.5, bus line 44 operates more frequently compared to the average buses (of RET). The table below, Table 33, shows that the daily average of the bus amounts 5847 passengers. Assuming an average daily operational time of 18 hours, the passenger flow amounts: 325 passengers per hour.

TABLE 33. AVERAGE PASSENGERS PER MONTH BUS LINE 44 (EXCEL FILE MRDH).

Daily average	Passengers/month
2016-01	5852
2016-02	5797
2016-03	6238
2016-04	5908
2016-05	5433
2017-01	5525
2017-02	6417
2017-03	6375
2017-04	5154
2017-05	5766
Average	5847

Taking into account that 9.5% of passengers travel in peak hour (just like the first case study), a capacity of 556 passengers per hour need to be transported. The capacity of a tram, with the 'inzetnorm' amounts 138 passengers. In peak hours, the amount of trams that, at least are needed to transfer 556 passengers is equal to 4. The frequency, outside of peak hours (to transfer 325 passengers per hour) amounts 2.4 per hour per direction.

The indicator values used for the passengers, to calculate the perception, are shown in Table 34. As can be seen, the current average frequency of the bus is 6.5 buses per hour per direction. For the information regarding punctualities and operational speed, the average punctuality and operational speed of a system is used, explained in more detail in Appendix VII, respectively section E and section C. With regards to the values of the other criteria, data is used from the 'OV-klantenbarometer' (CROW-KpVV, 2016). This data is scoped for the Region of Rotterdam and only for the bus. A detailed analysis can be found in Appendix X, for all three groups.

TABLE 34. PASSENGERS INDICATOR VALUES CASE B

Passengers	Weights	Bus	Tram	Unit
Criterion		Current	Scenario 1	
Frequency	0.178	6.5	2.4	Dep./hr./dr.
Punctuality	0.119	85.82	91.3	%
Passenger Safety	0.116	7.7	7.8	[1-10]
Operational speed	0.152	12.5	17.6	Km/h
Accessibility of PT system	0.064	8.3	8.7	[1-10]
Travel information	0.092	7.0	7.3	[1-10]
Image	0.042	7.4	7.6	[1-10]
Travel comfort	0.090	7.4	7.6	[1-10]
Ticket price	0.147	5.7	5.7	[1-10]

After normalising the values and calculating the perceptions, the following table, Table 35, is obtained. The table shows how each indicator scores in the new tram scenario compared to the current scenario. The last row shows how the new tram scenario scores in general, according to the perceptions of the passengers, compared to the current bus scenario. As can be seen, the passengers perceive the new scenario as less attractive, compared to the current one. This is mainly because of the frequency change. The operational speed, however, shows a highly positive change in perception of the passengers. The last row shows the preference of the passengers of the new scenario (Tram) compared to the current, bus scenario. As can be seen, the passengers prefer the current scenario 5% more compared to the new scenario. This is mainly due to the high decrease in frequency.

TABLE 35. PASSENGERS RESULTS CASE B

Passengers	Bus	Tram
Criterion	Current	Scenario 1
Frequency	0%	-63%
Punctuality	0%	6%
Passenger Safety	0%	1%
Operational speed	0%	41%
Accessibility of PT system	0%	5%
Travel information	0%	4%
Image	0%	3%
Travel comfort	0%	3%
Ticket price	0%	0%
Result	0%	-5%

Using a new system also means new costs. The costs for the new scenario for the government and operators are shown in Table 36. As can be seen, the current average frequency amounts 6.5 and to cope with 556 passengers in peak hour, the frequency needs to be at least 8.5 departures per hour per direction. Assuming the frequency equals the amount of buses needed, there are 9 buses needed for the system. A detailed calculation can be found in Appendix X.

TABLE 36. TCO CALCULATION CASE B

Length line 44 = 9.5km			
Avg. frequency	6.5	2.4	Dep./hr./direction
peak frequency	8.5	4	Dep./hr./direction
System	Bus	Tram	
Investment total	**€510,000**	**€4,800,000**	**Per year**
Investment infra	€456,000	€4,560,000	Per year for 8 km
Investment vehicle	€54,000	€240,000	Per year
Maintenance total	**€869,540**	**€638,984**	**Per year**
Maintenance Peak	€31,680	€194,997	Per year
Maintenance off peak	€87,360	€388,887	Per year
Maintenance infra	€750,500	€55,100	Per year
Operational total	**€11.34**	**€6.45**	**Per year per km**
Operational Peak	€2.49	€1.42	Per km
Operational off peak	€8.85	€5.03	Per km
Operational costs per year	€725,760	€357,311	Per year
TCO	€2,105,300	€5,796,295	**Per year**

With regards to the government and its values, these are presented in Table 37. As can be seen, the operational costs of the bus scenario are higher compared to the tram scenario. This is due to the fact that in the new, tram scenario, 4 trams are needed in peak and only 3 outside of peak hours. For the bus, the current frequency is 6.5 and frequency needed in peak is 8.5 buses per hour per direction. The higher amount of vehicles needed contribute to a higher operational cost.

The passenger forecast for the new scenario is calculated using two incorporations: firstly the rail-bonus as described by Bunschoten (2012), secondly the change in passengers due to a frequency change as described by Brogt (2013). As mentioned above, the current bus scenario has on average, 325 passengers per hour. When transforming a line to rail, a 4.3% trambonus is applicable resulting a more people using the system 'just' because it now is a rail-based system. The frequency change, however, results in less people using the system because their waiting time increases, also mentioned in the introduction part of this chapter.

TABLE 37. GOVERNMENT INDICATOR VALUES CASE B

Government	Weight	Bus	Tram	Unit
Criterion		Current	Scenario1	
Operational costs	0.142	0.73	0.36	€mln./km
Investments costs	0.155	0.51	4.80	€mln./km

Maintenance costs	0.117	0.87	0.33	€mln./km
Liveability inhabitants	0.083	6	7	[1-10]
Passenger Forecast	0.147	325	187	Pass/hr.
Punctuality	0.063	85.82	91.3	%
Passenger safety	0.063	1276	3784	€/day
Flexibility	0.107	8	1	[1-10]
System Capacity	0.125	68	138	Pass/vehicle

After normalising the values and multiplying the weights with the normalised values, the following table, Table 38, is obtained. The table shows how the new scenario, as a perception of the government, scores compared to current scenario. The last row shows the perception of the new scenario compared to the current one. As can be seen, from the perception of the government, the current scenario is preferred more compared to the new scenario. This is mainly because of the high investment and passenger safety costs and the loss in flexibility of the system.

TABLE 38. GOVERNMENT RESULTS CASE B

Government	Bus	Tram
Criterion	Current	Scenario1
Operational costs	0%	-203%
Investments costs	0%	-941%
Maintenance costs	0%	-262%
Liveability inhabitants	0%	17%
Passenger Forecast	0%	-42%
Punctuality	0%	6%
Passenger safety	0%	-297%
Flexibility	0%	-88%
System Capacity	0%	103%
Result	0%	-18%

For the operators, the table shown below, Table 39, applies. The Earnings are dependent on the passenger forecast and ticket price (which is legally determined). As can be seen, the passenger forecast is almost twice as low in the new scenario, compared to the current one. This is due to the loss in frequency of the system. The blue criteria indicate the case specific changes. The red criteria indicate a negative impact on the overall perception, if the value increases.

TABLE 39. OPERATORS INDICATOR VALUES CASE B

Public transport operators	Weight	Bus	Tram	Unit
Criterion		Current	Scenario 1	
Passenger forecast	0.213	325	187	Pass/hr.
Earnings	0.121	47	27	€/km
Politics	---	---	---	---
Ticket price	0.044	0.146	0.146	€/km
System capacity	0.12	68	138	Pass/veh.
Frequency	0.129	6.5	2.4	Dep./hr./dr.
Operational speed	0.108	12.5	17.6	Km/h
TCO	0.158	2.11	5.49	€mln./yr.

Passenger safety	0.107	1276	3784	€/day

After normalising the values and multiplying them with the corresponding weights, Table 40 is obtained. The table shows that the operators also have a high preference for the current scenario. This is due to the costs, passenger safety and TCO, but also the lower frequency which results in a lower passenger forecast and less earnings.

TABLE 40. OPERATORS RESULTS CASE B

Public transport operators	**Bus**	**Tram**
Criterion	Current	Scenario 1
Passenger forecast	0%	-42%
Earnings	0%	-42%
~~Politics~~	~~---~~	~~---~~
Ticket price	0%	0%
System capacity	0%	103%
Frequency	0%	-63%
Operational speed	0%	41%
TCO	0%	-272%
Passenger safety	0%	-297%
Result	0%	-37%

The overall results of the three stakeholders, for this case study can be seen in Table 41. As can be seen, and as mentioned above, all the stakeholders have a high preference for the current scenario. For the government and operators, the costs are a big issue contributing to this negative perception. For the passengers, it is mainly the frequency, that contributes to this negative perception. Therefore, it is interesting to investigate the effect of various frequencies on the perceptions.

TABLE 41. RESULTS CASE B BUS LINE 44

Stakeholders	Bus – Current	Tram – Scenario 1
Passengers	0%	-5%
Government	0%	-18%
Operators	0%	-37%

The table also shows that leaving the investment costs out for the current situation would change the perceptions of this scenario more positively. Without the investment costs for the current scenario would only result in more negative perceptions regarding the tram scenario. Furthermore, because it is unsure what kind of new investments need to be made for the current scenario, for now, the investments costs are still taken into account in the current scenario.

As mentioned above, the frequency contributes highly to the perception of the passengers. Therefore, it is interesting to differ the frequencies and analyse the effect on the perceptions of the various stakeholders. Table 42 shows the results (calculated in Appendix X) for all stakeholders with various frequencies. As can be seen, the tram scenario is distinguished in 3 new scenarios where only the frequency differs. In the first tram scenario a frequency of 2.4 is used, the second scenario uses a frequency of 4 and the last scenario a frequency of 5.

The table shows that the perception of the passengers does not differ that much. The only scenario that is perceived as positive is the scenario where a tram is used with a frequency of 5.

With regards to the perception of the government, the most preferred scenario is the current one. The same applies to the Operators. For the government, this is due to the higher passenger forecast because of the high frequency, passenger safety costs and the high flexibility of the bus system.

The Operators prefer the current scenario also because of the passenger forecast and therefore, higher revenues (Earnings). The higher frequency of the bus system, lower costs (TCO and passenger safety costs) also contribute to this positive perception.

In conclusion, the frequency is a highly important criterion for the three groups. The passengers value this criterion as most important. For the operators and government, the frequency is an important criterion because it influences the total costs. When taking into account the new scenario with a variety of systems, the perceptions displayed in Table 42 are obtained.

TABLE 42. RESULTS OF USING A TRAM SYSTEM WITH A FREQUENCY OF 8.

	Bus	Tram 3.2	Tram 4	Tram 5	Tram 8
Passengers	0%	-3%	1%	3%	11%
Government	0%	-18%	-19%	-18%	-31%
Operators	0%	-33%	-24%	-12%	-5%

The table shows that with an increase in frequency, the perception of the passengers and operators becomes more positive. The perception of the government however becomes more negative, mainly due to the increase in costs. The increase of the perception seen from a passenger's point of view mainly results from the higher frequency and therefore lower waiting time.

The increase in perception as seen from the operator's point of view, when the frequency changes results from the higher passenger forecast and earnings. In can be concluded that for this group, the fact that more passengers can be transferred which result in higher earnings weigh more compared to the increase in TCO.

From a government's point of view, the increase in frequency each time shows a decrease in the perception value. This is because a higher frequency results in higher costs and therefore a decrease in perception. However, as shown in section 4.6, each public transport system has its own benefits and contributes on its own way to, for example, the economic development and/or accessibility of the region.

5.3 DISCUSSION WITH POLICY-MAKER

After determining the general perceptions of the three groups and the case studies, the results finally can be discussed with the policy decision-maker. A discussion is held with a

Senior Policy Developer and a Senior Concession Manager. They are one of the most important advisors to the policy decision-maker. This section will discuss the results and identify the added value of the perception analysis developed in this research. Finally, an answer will be given to the final sub-question formulated as follows:

(5) To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

To investigate whether information is useful, first the decision-making process needs to be known. This contributes to visualizing the overall process and their characteristics which makes it easier to determine in which phase of the process the information can be used. Currently, there is no standard procedure or standardized decision-making process. However, there are plans to implement one, which can be visualized using the 5 phases, shown in Figure 23. The blue dots show where in the process, the perception based analysis can be useful.

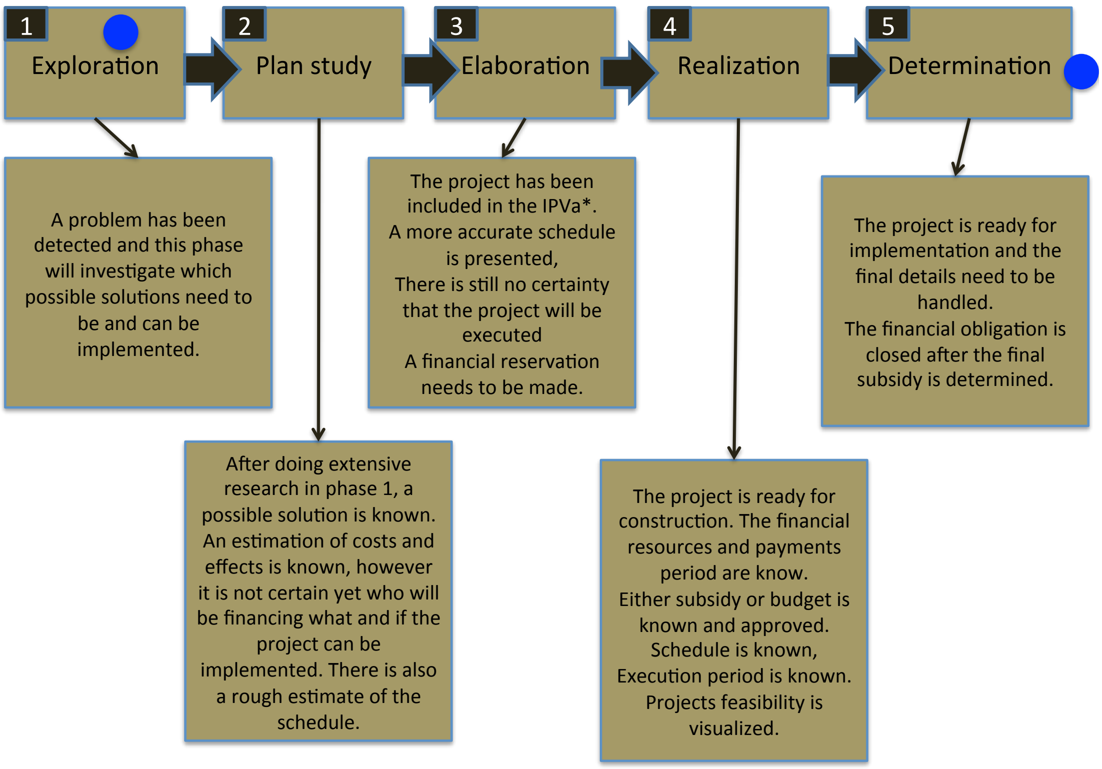


FIGURE 23. THE DECISION-MAKING PROCESS FOR PUBLIC TRANSPORT INVESTMENTS

* IPVa stands for InvesteringsProgramma Vervoersautoriteit and describes how the available financial resources are allocated to which projects and what kind of investments are needed (MRDH-begroting, 2017).

As indicated in the figure with the blue dots, the information regarding the perceptions of the stakeholders can be used both in the Exploration phase and after the Determination phase. In the Exploration phase a problem is identified and possible solutions are presented that could cope with this problem. In the second phase, the plan study, a possible solution is already known. This indicates that the information regarding the perceptions of the various groups can be used in the first phase of the process.

After the system is chosen, approved and implemented, the perception-based information can be used to increase the level of satisfaction for, for example, the passengers. If the government knows that Frequency, Travel information, Passenger safety and Punctuality are criteria that contribute to the perception of the passengers, measures can be taken in order to positively influence the perception of that group. This can be executed after the Determination phase when the system is ready for use.

According to the policy makers it is an interesting observation that the perceptions of the passengers regarding the different transport systems are close together. Also, the fact that the tram scores (2%) lower compared to bus also was not expected. Passengers feel safer; perceive better travel information and a lower price in a bus.

Even after implementation of the system, this information can be used to change the perception of passengers for example. The method calculates the perception of the passengers and therefore, information is known which criteria exactly determine and contribute to this perception. If these criteria are known, the governmental authorities (together with the operators) can take measures to change the values of the criteria in order to change the perception of the passengers. Therefore, the information regarding the perception of the passengers is of high importance.

Therefore, it is preferable to use this information in this method from the government's perspective instead of the users (passengers) perspective. The information can be used both in an early stage of the process or after the project is ready for implementation.

The opinion of the passengers does not decide which system is going to be implemented. However, their perception of the system is rather important due to the fact that they are the (future) users of the system. The system is chosen beforehand by the governmental organisation in collaboration with the operators.

This research studied the perception of three stakeholders and to what extend that information can be used in the decision-making process for public transport investments. After presenting the findings and discussing the results with the decision-maker, the following conclusion can be drawn: Knowing the perception of passengers regarding mode choice is extremely important in the sense that the system needs to satisfy the passengers needs. However, the perception of the passengers will not influence which system is going to be implemented, but this perception information can be used to change the perception of the passengers.

According to the advisors, this information could lead to other decisions because more insight is provided. Therefore, the decision-making process becomes more transparent. More importantly, the perception-based analysis can afterwards be used to change the perception of passengers.

5.4 CONCLUSION

The goal of this chapter is to provide an answer to the following two sub-questions

(4) Which public transport system suits best for implementation according to the perceptions of the stakeholders?

(5) To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

To answer the first sub-question, two case studies were conducted. The first case study is tram line 12 in The Hague which may be transformed to a bus system. The second case study is bus line 44 in Rotterdam where the possibility occurs that this system may be transformed into a tram.

The first case study (Table 43) shows that, from a passenger's point of view, the current scenario (tram) is preferred higher compared to the two bus alternatives. However, the general perception showed that passengers lightly prefer a bus system to a tram system. This is because the Passenger safety, Operational speed, accessibility of the system, Travel information, Image of the system, Travel comfort and Ticket price are perceived more positive in a bus system. In the case study however, the punctuality and operational speed are higher of a tram compared to a bus. Furthermore, the case study uses data from the MRDH region whereas for the general perception, national data is used. Therefore, the following criteria of the tram are perceived higher by the passengers: Punctuality, Passenger safety, Operational speed, Accessibility and Image of the system, Travel comfort and Ticket price.

With regards to the perception of the government and operators, the results from the first case study also tend to show a little contradictory information compared to the general perception. From the general perception, both stakeholders prefer the tram to the bus. In Case Study A however, both bus scenarios are preferred over the tram scenario.

The government prefers, in general, a tram to a bus because of lower operational costs, higher passenger forecast and a higher system capacity. In the first case study however, the government perceives a bus to a tram because of lower investment, maintenance and passenger safety costs. A higher forecast due to the frequency bonus and a higher flexibility of the system.

The Operators prefer, in general, a Tram to a Bus because of the higher passenger forecast and earnings, higher system capacity, frequency and operational speed. In the first case study however, the bus is perceived higher due to the higher frequency. The increase in frequency leads to a higher passenger forecast and higher earnings. Furthermore, the bus has lower costs (TCO and passenger safety costs).

TABLE 43. RESULTS CASE STUDY A: HTM TRAM LINE 12 TO BUS

Stakeholders	Tram Current	Bus 12m Scenario 1	Bus 18m Scenario 2
Passengers	0%	-2%	-9%
Government	0%	77%	96%
Government (- investment)	0%	6%	20%
Operators	0%	24%	19%
Operators (- investment)	0%	20%	16%

The second case study (Table 44) shows, for all three stakeholders, a higher preference for the current bus system compared to the tram systems. Only the tram scenario with a frequency of 5 trams is preferred slightly higher from a passenger's point of view. This is because of the frequency bonus. The passengers perceive the punctuality, Passenger safety, Operational speed, Accessibility and Image of the system, Travel information, and Travel comfort of the tram higher compared to bus. Still, with a lower frequency, the system is not attractive enough.

The government prefers the current bus scenario to all tram scenarios because of a higher passenger forecast, lower passenger safety costs and a higher flexibility. Furthermore, the (extra and high) investment costs of the tram also contribute to a lower perception of the tram. The general perception however, shows that the government prefers the tram to a bus system. This is due to lower operational costs, higher passenger forecast and a higher system capacity.

From the operator's perspective, the current bus scenario is preferred to all tram scenarios because of higher passenger forecast and earnings, higher frequency and lower costs (TCO and passenger safety). The general perception of the operators differs compared to that of the 2nd case study. In general, the tram is preferred to a bus because of the higher passenger forecast and earnings, higher system capacity, frequency and operational speed.

TABLE 44. RESULTS CASE STUDY B: RET BUS LINE 44 TO TRAM

Results	Bus	Tram 2.4	Tram 4	Tram 5
Passengers	0%	-5%	-1%	2%
Government	0%	-18%	-19%	-19%
PT Operators	0%	-36%	-26%	-14%

This research studied the perception of three stakeholders and to what extend that information can be used in the decision-making process for public transport investments. After presenting the findings and discussing the results with the decision-maker, the following conclusion can be drawn: Knowing the perception of passengers regarding mode choice is extremely important in the sense that the system needs to satisfy the passengers needs. However, the perception of the passengers will not influence which system is going to be implemented, but this perception information can be used to change the perception of the passengers.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This final chapter will present the conclusions of this research. Section 6.1 will start answering the main- and sub-research questions after which section 6.2 will describe some discussion points. This chapter will finalize in 6.3 with the recommendations.

6.1 CONCLUSIONS

The objective of this research was to investigate whether a perception-based method adds any valuable information in the decision making process for governmental organizations. The main research question that was formulated to reach the objective of this research is defined as follows:

What is the added value for governmental authorities, of a perception-based mode choice method for public transport investments?

The purpose of a new chosen public transport system is to maximize the level of satisfaction among the users. According to the policy advisors, who advise the policy decision-maker the results from this research could lead to other decisions. Providing more and other insights in the perceptions of the involved stakeholders results in a more transparent decision-making process. Furthermore, the government and operators (who decide one the system) are able to use this information to maximize the satisfaction of the chosen system. By knowing which criteria affect the perception of the passengers, these criteria can be changed with the goal to positively change the perception.

From the MCDM (Multi-criteria decision-making) methods compared in this research, MAMCA (Multi-actor multi-criteria analysis) is selected to conduct a perception-based analysis. This method is preferred because it takes into account stakeholders, which play an important part in the decision-making process of public transport investments. To obtain weights for the criteria, the Best-worst method (BWM) is chosen that will serve as input for the MAMCA. The BWM is chosen due to the following reasons:

- Less data is needed (compared to other methods)
- It leads to more consistent comparisons, which results in reliable results
- BWM can be combined with other MCDM methods
- BWM is a simple method to perform; comparisons are performed with integer numbers ranging from 1 to 9.

By identifying a best (most-preferred) criterion and a worst (least-preferred) criterion and comparing them the others, the weights of the criteria are obtained. This gives an accurate estimation of the perceptions of the weights and therefore, a clear image of the perceptions of the groups regarding public transport systems.

Applying the MAMCA, three important stakeholders can be identified, which are presented in Table 45, with their corresponding weights resulting from the BWM. These weights indicate the importance of a criterion compared to the other ones. The criteria indicated in blue show a duplicate within the other groups. For example, the **frequency** is an important criterion for both the passengers and the Operators. The criterion,

passenger safety, is the only criterion that occurs in all three groups. The difference however, with regards to the Government and Operators, is that this criterion is measured in passenger safety costs per day. Whereas, for the passengers group, it is measured as an indicator measuring how safe the passengers feel.

TABLE 45. CRITERIA AND WEIGHTS CORRESPONDING WITH THE STAKEHOLDERS

Passengers	Wp	Government	Wg	Operators	Wo
Frequency	0.18	Operational costs	0.14	Frequency	0.13
Punctuality	0.11	Punctuality	0.06	Subsidy	0.12
Passenger Safety	0.10	Passenger safety	0.06	Passenger safety	0.11
Operational speed	0.18	Liveability inhabitants	0.08	Operational speed	0.11
Accessibility PT system	0.07	System Capacity	0.13	System Capacity	0.12
Travel information	0.09	Passenger Forecast	0.15	Passenger forecast	0.21
Image	0.05	Maintenance costs	0.12	~~Political consideration~~	---
Travel comfort	0.09	Flexibility	0.11	TCO	0.16
Ticket price	0.12	Investment costs	0.16	Ticket price	0.04
Sum	1.00		1.00		1.00

The public transport system that suits best for implementation depends on the different stakeholders. Table 45 shows that the perception of the passengers does not differ across the various systems. Concluding from Table 45 and Table 46, the passengers highly value a system with a high frequency and a high operational speed.

From the perception of the government, Light-rail transit is the most preferred system followed closely by the Bus-Rapid Transit. The Metro and eBus are the systems that score lowest in the perception of the government. LRT scores high because it positively contributes to the liveability, has a high system capacity and (therefore) can transfer a great amount of people. The metro scores lowest in the perception of the government, mainly because of the high costs, higher investment, maintenance and operational costs bust also higher passenger safety costs. The eBus has a very low capacity and higher costs compared to a bus and is also preferred low.

The PT operators agree with the government and prefer the LRT also closely followed by the BRT. The BRT scores high because of low costs and a relative high capacity. The LRT is preferred due to the high passenger forecast, high revenues (earnings) and high frequency. Furthermore, with regards to the least preferred system, the operators share the same opinion as the government about the eBus. However, the metro scores higher compared to tram and conventional bus, whereas the perception of the metro for the government scores lowest.

The perception of the Passengers is highly interesting. There is not a high preference for a specific system or systems, as long as it is adequately fast and has a high frequency. From this the conclusion can be drawn that the passengers highly value a short travel time. The preference for the eBus is highest and the Metro and Bus score equally. The eBus mainly scores high because of the higher travel comfort and image.

TABLE 46. RESULTS PERCEPTION ANALYSIS

Stakeholders\Modality	Bus	Tram	Metro	BRT	LRT	eBus
Passengers	0%	-2%	0%	-1%	-1%	1%
Government	0%	2%	-15%	7%	9%	-15%
PT operators	0%	34%	41%	48%	54%	-5%

For the first case study, HTM tram line 12 in The Hague was studied and analyzed. The perceptions were calculated when converting the tram line to a bus line. For this case study, two new scenarios are considered. The first one is replacing the tram with a 12m bus and the second scenario uses an 18m bus. The results of the perception analysis are presented in Table 47. The table shows for both the government and operators group, the results with and without investment costs of the current system. For now, it is unsure if new investments need to be made to keep the tramline operational. There is a possibility that new trams and infrastructure need to be purchased.

TABLE 47. RESULTS PERCEPTION CASE A TRAM LINE 12

Stakeholders	Tram Current	Bus 12m Scenario 1	Bus 18m Scenario 2
Passengers	0%	-2%	-9%
Government	0%	77%	96%
Government (- investment)	0%	6%	20%
Operators	0%	24%	19%
Operators (- investment)	0%	20%	16%

The system that is most suited for implementation according to the government is the 18-meter bus. This can be attributed to the fact that the bus is a highly flexible and far less dependent on its infrastructure, making the system flexible. Also, the operational and passenger safety costs are lower in the bus scenarios.

According to the perception of the operators, the 12m-bus scenario is preferred. This can be explained due to the lower operational, maintenance and investment costs. Fewer buses are needed to transfer the same amount of passengers when 18m buses are used.

Both bus-scenario's score better compared to the current scenario for the government and for the operators. This can be explained due to higher revenues, higher frequency and more expected passengers due to the higher frequency.

With regards to the perception of the passengers, a preference is observed to the current scenario compared to both bus scenarios. This is because of the higher punctuality and operational speed of the tram. Furthermore, the passengers perceive the ticket price of a tram lower compared to bus. Finally, passengers in The Hague feel safer in a tram compared to a bus.

For the second case study, RET bus line 44 in Rotterdam is analyzed. The plan is to transform this bus line into a tram. The different scenarios and their results are presented in Table 48. For the three new tram scenarios, the frequency is varied ranging from 3.2, 4 and 5.

Similarly to the previous case, the results show that the perceptions of the passengers are very close together. The scenario where a tram is used with frequency 5 however, is the only positive one. Looking at the perception of the government and the public transport operators, the current scenario scores highest, compared to all the new scenarios. The current scenario scores best on the factors: passenger forecast, Earnings, frequency, TCO and passenger safety costs. The high frequency results in more passengers and a bus system has lower TCO compared to tram systems.

For the government the following criteria score high in the current scenario: Investment costs, passenger forecast, passenger safety costs and flexibility. The passenger forecast is highest due to the high frequency and the flexibility of the system can also be appointed as an important factor. The flexibility in this research is defined as the dependency on the infrastructure and the possibility to take de-routes if necessary, while maintaining around the same level of quality. A bus can take de-routes and maintain the (around) same level of quality, while a tram is 100% dependent on its infrastructure. Therefore it is for a tram much harder to take a detour.

Table 48 displays that the perception of the passengers and operators, positively changes when the frequency increases. The increase in frequency leads to a higher amount of passengers which results in higher revenues (earnings) for the operators. The benefits of a higher passenger forecast and higher revenues exceed the extra costs. The perception of the government however, changes more negatively with an increase in frequency. This is because of the higher costs. However, as shown in section 4.6, each public transport system has its own benefits and contributes on its own way to, for example, the economic development and/or accessibility of the region.

TABLE 48. RESULTS PERCEPTION CASE B BUS LINE 44

Results	Bus	Tram 3.2	Tram 4	Tram 5
Passengers	0%	-5%	-1%	2%
Government	0%	-23%	-19%	-20%
Government (-investments)	0%	-25%	-21%	-22%
PT Operators	0%	-37%	-26%	-16%

Table 49 shows for each system the corresponding benefits and the importance of the benefit. The "++" sign indicates highly positive compared to the other modalities while "+" sign indicates a positive contribution compared to the other modes. As can be seen, the economic development (of the surrounding region) of the metro and LRT is highest compared the other modalities.

TABLE 49. WIDER BENEFITS OF PUBLIC TRANSPORT

Benefits	**Metro**	**Tram**	**Bus**	**eBus**	**LRT**	**BRT**
Accessibility of the region	++	++			++	++
Emissions	++	++		++	++	
Flexibility			++	++		
High Earnings	+				+	+
High frequency	+	+			+	+
Economic development	++	+			++	+
Operational speed	++				++	+

Passenger safety			+	+		+
Property values	+				+	+
Punctuality	+	+			+	+
Travel comfort			+	+		
Walking distance to stop			++	++		+

1. To what extent do authorities consider MCDM-stakeholder analysis useful in the decision-making process for public transport investments?

According to the policy advisors, the information regarding perception-based analysis could lead to other decisions. Visualising the perceptions of the stakeholders results in a more transparent decision-making process. The method is able to calculate the perceptions of the involved stakeholders for the given modalities. This also provides insight in the criteria that influence the perception. The decision-maker, in this case the government, knows which criteria need to be changed to change the perception of, for example, the passengers.

The scientific contribution of this thesis is that it combines the MAMCA and BWM to calculate the perception of stakeholders involved in the decision-making process for public transport investments. It shows how MCDM can be used to calculate and analyse the perceptions and if and how perceptions can be used to improve the decision-making process. Furthermore, it shows if and how these perceptions add any value for governmental authorities in the decision-making process of public transport investments. Finally, this thesis contributed to visualising the costs and benefits of public transport by using the 5xE framework as presented in Table 49.

6.2 DISCUSSION

This thesis contains a great amount of data and key figures derived from several sources. In public transport, there are a huge amount of various projects who each have their own characteristics. This is one of the reasons, that for example, the investments costs of bus infrastructure ranges from €0.3 to €4 million per km. To make comparison possible between the public transport systems, these figures need to be comparable, which may result in less accurate estimates for the values of the criteria. One of the examples that were rough estimates was for the criteria **liveability** and **flexibility**.

Furthermore, data regarding bus, tram and metro was much easier to find compared to BRT, LRT and eBus. The data for eBus especially was hard to find. More data regarding the values of the criteria would give more certainty, not only for the result but also for the value of the criteria itself.

One of the downsides of visualising the perception of a decision-maker is that most organisations employ 1 or 2 final decision-makers. To obtain a more realistic perception, 5 people (who advise the decision-maker) were interviewed to represent the operators and (5 people who represent the) governments group. Therefore, the results obtained in the conducted research are based on the information derived from ''just'' 5 people and potentially could be appointed as somewhat biased.

Another point of discussion comprehends with the diversity of the passenger group and the conducted survey. The group currently exists of a high percentage of males, who are well educated, mainly Dutch and do have some correspondence with the Public transport sector. Also, because the survey was conducted in person with all the respondents, there may be chance of socially accepted behaviour which may skew the results.

The research conducted by Bunschoten (2012) concluded that a tram bonus exists and that for the long term, extra ridership of 4.3% is expected. This is not very high and can be used as an argument that is coherent with the results of this research. Namely, that passengers 'just' want a system that offers low travel time and the image matters far less.

The choice for the MCDM method, and the criteria to compare them is based on own analysis and literature research. This can be appointed as a weak point and possibly results could be more accurate if better substantiated.

The dependency of the criteria used for some of the stakeholders also may be a point of discussion. The factor **Earnings** for example, used for the Operators table is highly dependent on the **Passenger forecast** and the **Ticket price**.

The impacts of this study can be described as follows: one of the impacts is that the research that was conducted provided an additional tool for decision-making in public transport investments. Furthermore, it also contributes to a more transparent decision-making process. Thirdly, more insight is provided in what passengers value in their system choice and how this can be changed. Finally, the wider benefits of public transport are introduced per modality and their importance.

6.3 RECOMMENDATIONS

The following recommendations for <u>further research</u> can be distinguished:

The criterion, **political considerations**, is taken out of scope for this research, also explained in chapter 4. The results of this research however, show that both the Government and Operators want a system that has low costs and transfer a huge amount of passengers. Still, in practice, there are still decisions made regarding public transport investments that are not always coherent with the information derived from a CBA. This implies that other factors are affecting the decision-making process. The political considerations, therefore may be an important one for further research.

One of the downsides of visualising the perception of a decision-maker is that almost all organisations employee 1 or 2 final decision-makers. There is a high likelihood of obtaining biased information when gathering data, especially in such a short, 6 months, time frame. Furthermore, information regarding the eBus, especially key figures, are harder to find compared to bus, tram and metro. Also, the developed method to calculate the perceptions is tested and gives valuable results. However, more data regarding the values of the criteria would give more certainty, not only for the result but also for the value of the criteria itself. Finally, the values for the criterion liveability are rough estimates which possibly can be more accurate if more data is gathered. Therefore, one of the recommendations is to gather more data which contributes to more reliable results.

Another recommendation comprehends with the diversity of the passenger group and the conducted survey. The group currently exists of a high percentage of males, who are well educated, mainly Dutch and do have some correspondence with the Public transport sector. One of the recommendations regarding the diversity of the group is to further analyse what if and how the results (of the weights) would change if a more diverse group is used.

The following recommendations are suggested to investigate if and how the results will differ: Firstly, instead of applying the MAMCA in combination with the BWM, it would be interesting to apply the other MCDM methods (or a combination of them). Secondly, 9 criteria got assigned to each stakeholder. One recommendation is to extent these criteria and/or to use different criteria. Finally, using other stakeholders or extending the stakeholders, for example distinguishing the passengers into different age or groups.

As described in the discussion, to obtain weights of the passengers, only 15 passengers and 5 decision-makers of each group were interviewed. It would be interesting for further research to interview more people and check if and how the results would differ

This research only took into account regional transport services that operators currently offer. Nowadays, travellers have various options for transportation. Taking into account other means of transportation like Mobility as a Service (MaaS), autonomous vehicles or services like Uber would be an interesting topic for further research.

The final recommendation regards applying the method in other sectors. This thesis only explains how the method is executed for regional public transport.

<u>Practical</u> recommendations:

Since there currently is not a specific uniform decision-making process for public transport investments, the first recommendation is to design, implement and use a standardized procedure for decision-making.

One of the recommendations for MRDH is give the same definition to the KPI's of the different operators. Currently, some definitions of the KPI's or even the KPI's itself differ between the operators. One example is that the punctuality of RET is defined differently compared to the definition that is used for HTM. This makes comparison difficult, which could result in unrealistic performance measurement.

Another practical recommendation with regards to applying this method comprehends with the data that is needed to calculate the perceptions. For example, the infrastructure investment costs of a metro has a very broad range (€30mln. - €150mln per km). However, for each case, this data can be made highly specific, especially with regards to costs. Therefore one of the practical recommendations when applying this method is to use as much case specific details as possible.

BIBLIOGRAPHY

Aber, J. (2016). *Electric Bus Analysis for New York City Transit.* Columbia University, New York city Transit. Columbia University.

Aboo, S., & Robertson, E. (2016, 08 03). A quality Public Transport System, elements for consideration. (Automotive, Ed.) Pretoria, South Africa.

Agostini, C. A., & Palmucci, G. (2008). The Anticipated Capitalisation Effect of a New Metro Line on Housing Prices. *Fiscal Studies Journal of Applied Public Economics , 29* (2), 233-256.

Andersson, M., Brundell-Freij, K., & Eliasson, J. (2017). Validation of aggregate reference forecasts for passenger transport. *Transportation Research Part A: Policy and Practice , 96*, 101-118.

Annema, J., Koopmans, C., & van Wee, B. (2007). Evaluating Transport Infrastructure Investments: The Dutch Experience with a Standardized Approach. *Transport Reviews: A Transnational Transdisciplinary Journal , 2*, 125-150.

Annema, J., Kroesen, M., Koopmans, C., & Frenken, K. (2016). Relating cost-benefit analysis results with transport project decisions in the Netherlands. *Letters in Spatial and Resource Sciences , 10*, 109-127.

Annema, J., Mouter, N., & Razaei, J. (2015). Cost-benefit Analysis (CBA), or Multi-criteria Decision-making (MCDM) or Both: Politicians' Perspective in Transport Policy Appraisel. *Transportation Research Procedia , 10*, 788-797.

APTA. (2014). *Economic Impact of Public Transportation Investment.* American Public Transportation Association. Economic Development Research Group.

APTA. (2016). *Public Transportation Benefits & Fact Book.* From American Public Transport Association: http://www.apta.com/mediacenter/ptbenefits/Pages/default.aspx

Balbontin, C., Hensher, D. A., Ho, C. Q., & Mulley, C. (2017). Cross-cultural contrasts of preference for Bus Rapid Transit and Light Rail Transit. *International Conference Series on Competition and Ownership in Land Passenger Transport .* Stockholm, Sweden: Thredbo15.

Battes, P. (2015, 04 15). *Amsterdam steekt tientallen miljoenen in elektrische bussen*. Retrieved 09 04, 2017 from Financieel Dagblad: https://fd.nl/economie-politiek/1100424/amsterdam-steekt-tientallen-miljoenen-in-elektrische-bussen

Benayoun, R., Roy, B., & Sussman, N. (1966). *Manual de reference du programme electre. Note De Synthese et Formaton* (Vol. no. 25). Paris, France: Direction Scientifique SEMA.

Best, M. v. (2015, 07 28). *RET verwacht capaciteitsproblemen RandstadRail*. Retrieved 05 06, 2017 from OVpro.nl: https://www.ovpro.nl/metro/2015/07/28/populariteit-randstadrail-maakt-uitbreiding-noodzakelijk/

Bestuursforum. (2013, 10 28). Aanbieding Voorstellen Metropoolregio Rotterdam Den Haag.

Bian, T., Hu, J., & Deng, Y. (2017). Identifying influential nodes in complex networks based on AHP. *Physica A: Statistical Mechanics and its Applications , 479*, 422-436.

Boarnet, M. G. (2011, 06 21). A Broader Context for Land Use and Travel Behavior, and a Research Agenda. *Journal of the American Planning Association* .

Bollinger, C., & Ihlanfeldt, K. (1997). The impact of rapid rail transit on economic development: The case of Atlanta's MARTA. *Journal of Urban Economics , 42* (2), 179-204.

Boujelbene, Y., & Derbel, A. (2015). The performance Analysis of Public Transport Operators in Tunisia Using AHP Method. *Procedia Computer Science , 73*, 498-508.

Brans, J., & Vincke, P. (1985). A preference ranking organization method. *Management Science , 31* (6), 647-656.

Brans, J., Vincke, P., & Marescha, B. (1986). How to select and how to rank projects: the PROMETHEE method. *Operations Research , 24*, 228-238.

Bridgman, P. (1922). *Dimensional Analysis.* Yale: Yale University Press.

Bristow, A., & Nellthorp, J. (2000). Transport project appraisal in the European Union. *Transport Policy , 7*, 51-60.

Brogt, P. (2013, 01 16). *De waaier van Brogt.* Retrieved 09 23, 2017 from Issu.com: https://issuu.com/gcoffeng/docs/waaier-van-brogt

BRT Data freq. (2017). *Peak Frequency buses per hour*. Retrieved 08 23, 2017 from BRTdata: http://brtdata.org/indicators/systems/peak_frequency_buses_per_hour

BRT Data speed. (2017). *Operating Speed*. Retrieved 09 01, 2017 from BRTdata: http://brtdata.org/indicators/systems/operating_speed

BRTData infra. (2017). *Infrastructure costs per km*. Retrieved 09 2, 2017 from brtdata: http://brtdata.org/indicators/systems/infrastructure_cost_per_kilometer_us_million_per_km

Buchner, S., Klausner, S., & Engel, M. (2015). Conception and implementation of a charging station for electric buses in public transport. *15. Internationales Stuttgarter Symposium . 15*, pp. 585-594. Springer.

Buchter, H., & Naumann, S. (2018). Charging electrically driven buses considering load balancing in the power grid. *Advances in Intelligent Systems and Computing , 631*, 124-132.

Bunschoten, T. (2012). *To tram or not to tram: Exploring the existenece of the tram bonus.* TU Delft & Goudappel Coffeng, Civil Engineering. TU Delft.

Calgary Transit Planning. (2002). *A Review of Bus Rapd Transit.*

Cambridge Dictionary. (n.d.). *perception*. Retrieved 08 21, 2017 from dictionary.cambridge.org: http://dictionary.cambridge.org/dictionary/english/perception

Cao, H., Liu, F., Liu, C., & Li, C. (2006). An integrated method for product material selection considering environmental factors and a case study. *Materials Science Forum* , 1032-1035.

Carmen, C., & Lidestam, H. (2016). Dominating factors contributing to the high(er) costs for public bus transports in Sweden. *Research in Transportation Economics , 59*, 292-296.

Cats, O., Koppenol, G., & Warnier, M. (2017). Robustness assessment of link capacity reduction for complex networks: Application for public transport systems. *Reliability Engineering & System Safety , 167*, 544-553.

Chicago Transit Authority. (n.d). *Electric Bus*. Retrieved 09 02, 2017 from Transit Chicago: http://www.transitchicago.com/electricbus/

Chica-Olmo, J., Gachs-Sanchez, H., & Lizarraga, C. (2017). Route effect on the perception of public transport services quality. *Transport Policy , In Press Corrected Proof*.

Civitas. (2011). *Implementation status report on security improvements in PT.* Civitas, ELAN. Zagreb: Civitas.

Clean fleets. (2015). *Case Studies.* Retrieved 09 04, 2017 from Clean Fleets: http://www.clean-fleets.eu/case-studies/

Clifton, G., & Mulley, C. (2017). Barriers and facilitators of integration between buses with a higher level of service and rail: An Australian Case Study. *International Conference Series on Competition and Ownership in Land Passenger Transport* (pp. 1-22). Thredbo, AUS: THREDBO.

Cobuloglu, H., & Büyüktahtakın, I. (2015). stochastic multi-criteria decision analysis for sustainable biomass crop selection. *Expert Systems with Application , 42* (15-16), 6065–6074.

Conexxion. (2016, 10 25). *Beleidsverklaring Kwaliteit, Veiligheid, Gezondheid en Milieu .* Retrieved 09 18, 2017 from Conexxion.nl: https://www.connexxion.nl/data/upload/Cxx%20OV%20Beleidsverklaring%20KVGM%20V2%2025%20okt%202016.pdf

Conexxion. (2017, 03 2017). *Honderd e-bussen en achttien dubbeldekkers*. Retrieved 09 11, 2017 from Conexxion: https://www.connexxion.nl/reizen/1190/honderd-e-bussen-en-achttien-dubbeldekkers/4741

Conexxion-vervoerplan 2018. (2016). *Vervoerplan 2018 Concessie Haaglanden Regio.* Conexxion.

connekt. (2016). *Mobility as a service.* Retrieved 04 08, 2017 from connekt: https://www.connekt.nl/initiatief/mobility-as-a-service/

CROW-KpVV factors. (2016). *Kengetallen regionaal openbaar vervoer 2015.* Kennisplatform Verkeer en Vervoer, Collectief Vervoer. CROW.

CROW-KpVV. (2016). *OV-klantenbarometer.* Retrieved 06 18, 2017 from ovklantenbarometer: http://www.ovklantenbarometer.nl/Resultaten.aspx

Currie, G., Flugel, S., Gregersen, F. A., Killi, M., Toner, J., & Wardman, M. (2017). Competition and substitution between public transport modes. *International Conference Series on Competition and Ownership in Land Passenger Transport .* Stockholm,Sweden: Thredbo15.

CVOV. (2005). *Kostenketgetallen openbaar veroer.* Ministerie van Verkeer en Waterstaat, Rijkswaterstaat. Rotterdam: Centrum Vernieuwing Openbaar Vervoer.

Dai, X., Bai, X., & Xu, M. (2016). The influence of Beijing rail transfer stations on surrounding housing prices. *Habitat International , 55*, 79-88.

De Gelderlander. (2008, 01 31). *Superbus rijdt proef* . Retrieved 09 12, 2017 from Weezenhof Centraal: http://www.weezenhofcentraal.nl/index.php?option=com_content&view=article&id=478%3Asuperbus-rijdt-proef&Itemid=46

de Jong, E. (2014, 06 19). *Nieuwe Haagse tram komt deze maand* . Retrieved 08 25, 2017 from OV Magazine: https://www.ovmagazine.nl/2014/06/nieuwe-tram-voor-den-haag-komt-deze-maand-1740/

Deng, T., & Nelson, J. D. (2013). Bus Rapid Transit implementation in Beijing: An evaluation of performance and impacts. *Research in Transportation Economics , 29* (1), 108-113.

Des Rosiers, F., Theriault, M., Voisin, M., & Dube, J. (2010). Does an Improved Urban Bus Service Affect House Values? *International Journal of Sustainable Transportation , 4* (6), 321-346.

Dewees, D. (1976). The effect of a subway on residential property values in Toront. *Journal of Urban Economics , 3* (4), 357-369.

Duduta, N., Adriazola-Steil, C., Hidalgo, D., Lindau, L. A., & dos Santos, P. M. (2013). *THE RELATIONSHIP BETWEEN SAFETY, CAPACITY, AND OPERATING SPEED ON BUS RAPID TRANSIT.* the WRI Center for Sustainable Transport,, Rio de Janeiro, Brazil.

Eenink, R., & Vlakveld, W. (2013). *Toekomstbeelden en Europese trends op het gebied van verkeer en vervoer met gevolgen voor de verkeersveiligheid.* Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV. Den Haag: SWOV.

eindhoven.raadsinformatie. (n.d.). Commissie Notitie Rapport: Tram in Eindhoven?

Eisenkopf, A., Burgdorf, C., & Knorr, A. (2017). User acceptance of long distance bus services in Germany. *International Conference Series on Competition and Ownership in Land Passenger Transport . 15.* Thredbo, AUS: Thredbo.

Eisenkopf, A., Christian Burgdorf, & Andreas Knorr. (2017). User acceptance of long distance bus services in Germany. *International Conference Series on Competition and Ownership in Land Passenger Transport.* Stockholm, Sweden: Thredbo15.

European Union. (2007). Regulation No. 1370/2007 of the European Parliament and of the council.

Fietsersbond. (n.d.). *Landscheidingsfietspad*. Retrieved 09 04, 2017 from Lansingerland fietsersbond: https://lansingerland.fietsersbond.nl/oude-zaken/landscheidingsfietspad/

Fishburn, P. (1967). Additive Utilities with Incomplete Product Set: Applications to Priorities and Assignments. *Naval Research Logistics , 14* (1), 1-13.

Fishman, T. (2012). Digital Age Transportation: The Future of Urban Mobility. *Deloitte University Press* .

Foreman, E., & Sally, M.-A. (2001). *Decision by Objective: How to Convince Others that You are Right.* Washington: World Scientifi.

Fountain, H. (2016, 11 04). A Slow Ride Toward the Future of Public Transportation . *New York Times* .

Fouracre, P., & Dunkerley, C. (2002). Mass rapid transit systems for cities in the developing world. *Transport Reviews , 23* (3), 299-310.

Freeman, R. E. (2010). *Strategic Management: A Stakholder Approach* (Vol. 1). Cambridge: Cambridge University Press.

FTA. (2001). *BUS RAPID TRANSIT VEHICLE CHARACTERISTICS.* Federal Transit Administration, U.S. Department of Transportation. Washington: FTA.

FTA-BRT. (2009). *Bus Rapid Transit and development: Policies and practices that affect development around transit.* Federal Transit Administration.

Gadzinski, J., & Radzimski, A. (2016). The first rapid tram line in Poland: How has it affected travel behaviours, housing choices and satisfaction, and apartment prices? *Journal of Transport Geography , 54*, 451-463.

Geldermann, J., & Rentz, O. (2001). Integrated technique assessment with imprecise information as a support for the identification of best available techniques. *OR Spektrum , 23*, 137-157.

Gemeente Den Haag. (n.d.). *Beleid en regelgeving*. Retrieved 08 11, 2017 from denhaag.nl: https://www.denhaag.nl/nl/bestuur-en-organisatie/beleid-en-regelgeving.htm

Gemeente Rotterdam. (2017). *Stadsvisie*. Retrieved 08 11, 2017 from Rotterdam.nl: https://www.rotterdam.nl/wonen-leven/stadsvisie/

Gilbert, A. (2008). Bus Rapid Transit: Is Transmilenio a Miracle Cure? . *Transport Reviews , 28* (4).

Glassman, R. B., Garvey, K. J., Elkins, K. M., Kasal, K. L., & Couillard, N. L. (1994). Spatial working memory score of humans in a large radial maze, similar to published score of rats, implies capacity close to the magical number 7 ± 2. *Brain Research Bulletin , 34* (2), 151-159.

Government.nl . (n.d.). *Ministry of Infrastructure and the Environment*. Retrieved 05 19, 2017 from government.nl: https://www.government.nl/ministries/ministry-of-infrastructure-and-the-environment

Gray, G. E. (1979). Perceptions of public transportation . *Public transportation : planning, operations, and management* .

GVB. (n.d.). *Bus*. Retrieved 09 12, 2017 from Over GVB: https://over.gvb.nl/vervoer/bus

Haagsetrams. (n.d.). *Materieel*. Retrieved 08 28, 2017 from Haagsetrams: http://www.haagsetrams.com/randstadrail/materieel.html

Hensher, D. (2017). Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change? *Transportation Research Part A: Policy and Practice , 98*, 86-96.

Hensher, D., Mulley, C., & Weisbrod, G. (2016). Recognising the complementary contributions of cost benefit analysis and economic impact analysis to an understanding of the worth of public transport investment: A case study of bus rapid transit in Sydney, Australia. *Research in Transport Economics , 59*.

Het Parool. (2016, 07 08). *Noord/Zuidlijn gaat pas rijden in 2018*. Retrieved 09 02, 2017 from Parool: https://www.parool.nl/amsterdam/noord-zuidlijn-gaat-pas-rijden-in-2018~a4336085/

Hietanen, S. (2014). 'Mobility as a Service' – the new transport model? *Eurotransport , 12* (2), pp. 2-4.

Hoomans, D. (2015, 03 20). *35,000 Decisions: The Great Choices of Strategic Leaders.* Retrieved 08 25, 2017 from Robert Weslyan College: https://go.roberts.edu/leadingedge/the-great-choices-of-strategic-leaders

HSLHRT. (2013, 08 29). *Public transport increasing in popularity faster than motoring in the Helsinki region*. Retrieved 05 02, 2017 from HSL.fi: https://www.hsl.fi/en/news/2013/public-transport-increasing-popularity-faster-motoring-helsinki-region-2515

HTM jaarverslag. (2012). *HTM Jaarverslagd 2011.* HTM, OV. HTM Corporate Communicatie.

HTM. (n.d.). *Missie en Visie HTM*. Retrieved 05 19, 2017 from overhtm.nl: https://www.overhtm.nl/nl/over-ons/onze-missie-visie/

HTM. (n.d.). *onze missie visie*. Retrieved 08 07, 2017 from overHTM.nl: https://www.overhtm.nl/nl/over-ons/onze-missie-visie/

HTM timetable. (n.d.). *Tram 12*. Retrieved 09 12, 2017 from HTM: https://www.htm.nl/reisinformatie/tram-12/

HTM2016. (2017). *Jaarverslag 2016.* HTM. HTM.

HTM-b. (n.d.). *Onze trams en bussen*. Retrieved 07 20, 2017 from htm.nl: https://www.htm.nl/onze-trams-en-bussen/

HTM-RR. (2017). *RandstadRail*. (HTM, Producer, & HTM) Retrieved 09 07, 2017 from overhtm: https://www.overhtm.nl/nl/over-ons/ons-vervoer/randstadRail/

HTM-vervoerplan 2018. (2016). *HTMbuzz Vervoerplan 2018.* Den Haag: HTM.

HTM-vervoerplan rail 2018. (2016). *Vervoerplan Rail 2018.* HTM Reizigers. Den Haag: HTM.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making : methods and applications.* Berlin ; New York: Springer-Verlag.

Infrasite. (2015). *Project*. Retrieved 05 17, 2017 from infrasite.nl: http://www.infrasite.nl/projects/project.php?ID_projecten=145

Jacobs, I. (2016, 01 04). *RET: Metro's en trams kunnen in 2017 zonder subsidie rijden*. Retrieved 09 13, 2017 from OV Pro: https://www.ovpro.nl/metro/2016/01/04/metros-en-trams-van-ret-rijden-in-2017-zonder-subsidie/

Jain, D., & Tiwari, G. (2016). How the present would have looked like? Impact of non-motorized transport and public transport infrastructure on travel behavior, energy consumption and CO2 emissions – Delhi, Pune and Patna. *Sustainable cities and society , 22*, 1-10.

Karapetrovice, S., & Rosenbloom, E. (1999). A quality control approach to consistency paradoxes in AHP. *Europan Journal of Operations Research , 119* (3), 704-718.

Kay, M., Clark, M., Duffy, C., Laube, M., & Lian , S. *Bus Lifecycle Cost Model for Federal Land Management Agencies.* John A. Volpe National Transportation Systems Center , US Department of Transportation. Research and Innovative Technology Administration.

Kelman, S. (1981). Cost–benefit analysis: an ethical critique. *AEI Journal on Government and Society Regulation , 18* (7), 74-82.

Kenniscentrum InfoMil. (n.d.). *Vervoerplan - waaraan moet een vervoerplan voldoen?* Retrieved 09 23, 2017 from Kenniscentrum Infomil: https://www.infomil.nl/onderwerpen/duurzaamheid-energie/vervoermanagement/vragen-en-antwoorden/@89888/vervoerplan_-_0/

Kennisplatform CROW. (2017). *Rapporten.* Retrieved 08 12, 2017 from Ovklantenbarometer: http://www.ovklantenbarometer.nl/Rapporten.aspx

Kennisplatform Crow. (2017, 03 22). *Terugblik presentatie OV-Klantenbarometer 2016*. Retrieved 08 21, 2017 from crow.nl: https://www.crow.nl/kennis/bibliotheek-verkeer-en-vervoer/kennisdocumenten/terugblik-presentatie-ov-klantenbarometer-2016

Keyvan-Ekbatani, M., & Cats, O. (2015). Multi-Criteria Appraisel of Multi-Modal Urban Public Transport Systems. *Transportation Research procedia* , 000-000.

Kolios, A., Mytilinou, V., Lozano-Minguez, E., & Salonitis, K. (2016). A Comparative Study of Multiple-Criteria Decision-Making Methods under Stochastic Inputs. *Energies , 9*, 566.

Kopp, R., Krupnick, A., & Toman, M. (1997). *Cost–Benefit Analysis and Regulatory Reform: An Assessment of the Science and the Art.* Discussion Paper, Resources for the Future, Washington DC.

Krawiec, K. (2016). Location of Electric Buses Recharging Stations Using Point Method Procedure. *Intelligent Transport Systems and Travel Behaviour . 505*, pp. 187-194. Springer.

Krawiec, K., & Kłos, M. J. (2017). Parameters of Bus Lines Influencing the Allocation of Electric Buses to the Transport Tasks. In L. N. Systems (Ed.), *Scientific And Technical Conference Transport Systems Theory And Practice. 21*, pp. 129-138. Springer.

Kunith, A., Mendelvitch, R., & Goehlich, D. (2017). Electrification of a city bus network—An optimization model for cost-effective placing of charging infrastructure and battery sizing of fast-charging electric bus systems. *International Journal of Sustainable Transportation , 11* (10), 707-720.

Lahdelma, R., Salkminen, P., & Hokkanen, J. (2000). Using multicriteria methods in environmental planning and management. *Environmental Management , 26* (6), 595.

Leendertse, W., Langbroek, M., Arts, J., & Nijhuis, A. (2016). Generating Spatial Quality through Co-creation: Experiences from the Blankenburgverbinding (The Netherlands). *Transportation Research Procedia , 14*, 402-411.

Lei, Z., Chun, H., & Haoming, Y. (2014). Study of Charging Station Short-Term Load Forecast Based on Wavelet Neural Networks for Electric Buses. *Chinese Conference on Pattern Recognition. 484*, pp. 555-564. Springer.

Li, X., & Tang, B. (2017). Incorporating the transport sector into carbon emission trading scheme: an overview and outlook. *Natural Hazards , 88* (2), 683-698.

Lindau, L. A., Hidalgo, D., & de Almeida Lobo, A. (2014). Barriers to planning and implementing Bus Rapid Transit systems. *Research in Transportation Economics , 48*, 9-15.

Lindau, L. A., Petzhold, G., Tavares, V. B., & Facchini, D. (2016, 07 2016). Mega events and the transformation of Rio de Janeiro into a mass-transit city. *Research in Transport Economics* .

Lloyds Bank. (2017, 05 12). *House prices boosted after opening tram routes in five leading cities*. Retrieved 08 22, 2017 from Lloyds Banking Group: http://www.lloydsbankinggroup.com/Media/Press-Releases/press-releases-2017/lloyds-bank/House_prices_boosted_after_opening_tram_routes/

Lootsma, F. (1990). The French and The American School in Multi-Criteria Decision Analysis. *Operations Research - Recherche Opérationnelle , 24* (3), 263-285.

Lui, Z., & Song, Z. (2017). Robust planning of dynamic wireless charging infrastructure for battery electric buses. *Transportation Research Part C: Emerging Technologies , 83*, 77-103.

Mälkki, H. (2010). Life Cycle Cost (LCC). *Training toolkit Nordplus, GreenIconproject 2010 - 2012* .

Macharis, C. (2005). The importance of stakeholder analysis in freight transport. *European Transport , 25* (26), 114-126.

Macharis, C., de Witte, A., & Turcksin, L. (2010). The Multi-Actor Multi-Criteria Analysis (MAMCA) application in the Flemish long-term decision making process on mobility and logistics. *Transport Policy , 17* (5), 303-311.

Macharis, Turcksin, & Lebau. (2012). Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. *Decision Support System , 53*, 610-620.

MacKechnie, C. (2016, 06 29). *Bus and light rail costs.* Retrieved 05 17, 2017 from Thoughtco: https://www.thoughtco.com/bus-and-light-rail-costs-2798852

MacKechnie, C. (2017, 07 10). *How Long Do Buses (and Other Transit Vehicles) Last?* Retrieved 08 28, 2017 from Thoughtco: https://www.thoughtco.com/buses-and-other-transit-lifetime-2798844

Mahmoud, M., Garnett, R., Ferguson, M., & Kanaroglou, P. (2016). Electric buses: A review of alternative powertrains. *Renewable and Sustainable Energy Reviews , 62*, 673-684.

Martinez-Lao, J., Montoya, F. G., Manzano-Agugliaro, F., & Montoya, M. G. (2017). Electric vehicles in Spain: An overview of charging systems. *Renewable and Sustainable Energy Reviews , 77*, 970-983.

McDermott, S. (2017, 04 29). *News*. Retrieved 05 17, 2017 from Cnet: https://www.cnet.com/roadshow/news/self-driving-cars-automated-public-transport-bus/

Mensonides, F. (2012, 08 14). *Zoro aanleg*. Retrieved 09 04, 2017 from Frans Mensonides: http://www.fransmensonides.nl/zoro_aanleg.html

Metrocov. (2015). *Over Metrovoc*. (Metrocov) Retrieved 09 25, 2017 from Metrocov: http://www.metrocov.nl/metropool/homme/over-metrocov

Millard-Ball, A., & Schipper, L. (2010, 11 18). Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries. *Transport Reviews: A Transnational Transdisciplinary Journal* .

Miller, D., & Starr, M. (1969). *Executive Decisions and Operations Research.* Englewood Cliffs, New Jersey, USA: Prentice-Hall.

Miller, G. A. (1955). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review , 101* (2), 343-352.

Mohammad, S., Graham, D., Melo, P., & Anderson, R. (2013). A meta-analysis of the impact of rail projects on land and property values. *Transportation Research Part A: Policy and Practice , 50*, 158-170.

Mott MacDonald. (2017). *Audi BOV-kosten lokaalspoor vervoerregio's.* Metropool Regio Rotterdam Den Haag.

Mouter, N., & Annema, J. A. (2013). Improving the problem analysis in cost-benefit analysis for transport projects: An explorative study . *Proceedings of the BIVEC-GIBET Transport Research Days, Walferdange, Luxemburg, 30-31 May 2013* . BIVEC-GIBET.

MRDH. (2017). *Begroting 2018 en meerjarenbeeld 2019-2021.* Metropoolregio Rotterdam Den Haag, OV, The Hague.

MRDH. (2017). *Over MRDH - Missie*. From Metropolitan Region Rotterdam The Hague: http://mrdh.nl/over-mrdh

MRDH OV-monitor. (n.d.). OV-Monitor opzet database. Metropoolregio Rotterdam-Den Haa.

MRDH-agendapunt10. (2016, 12 07). Subsidieverlening concessies Openbaar Vervoer 2017. *Bestuurscommissie Vervoersautoriteit* . The Hague: MRDH.

MRDH-begroting. (2017). *Ontwerp begroting en meerjarenbeeld 2019-2021.* Metropoolregio Rotterdam Den Haag. Den Haag: MRDH.

MRDH-concessie. (2017). *Concessiemonitor MRDH 2017.* MRDH, Verkeersontwikkeling. The Hague: MRDH.

MRDH-kmBus. (2017). Dieselverbruik bussen Definitief. RET.

MRDH-metro. (2016, 01 06). Beschikking tot subsidieverlening aanschaf 6 Bombardier railvoertuigen. *Bestuurscommissie vervoersautoriteit* . Den Haag, Zuid-Holland, Nederland.

MRDH-OV. (2017). *Openbaar Vervoer*. Retrieved 08 25, 2017 from MRDH: https://mrdh.nl/project/openbaar-vervoer

MRDH-OV. (2013). *Strategische bereikbaarheidsagenda Vervoersautoriteit Metropoolregion Rotterdam Den Haag.* Metropoolregion Rotterdam Den Haag, Openbaar Vervoer. Den Haag: MRDH.

MRDH-PvE Bus. (2016). *Programma van Eisen Busconcessies.* Metropoolregio Rotterdam Den Haag, Openbaar Vervoer. Den Haag: MRDH.

MRDH-PvE HTM. (2016). *Concessiedocument 2: Programma van Eisen Rail Haaglanden 2016-2026.* MetropoolRegio Rotterdam Den Haag, Openbaar Vervoer. Den Haag: MRDH.

MRDH-PvE RET. (2016). *Concessiedocument 3: Programma van Eisen Rail Rotterdam 2016-2026.* Metropoolregio Rotterdam Den Haag, Openbaar Vervoer. Den Haag: MRDH.

MRDH-RailHTM. (2017, 07 05). Subsidiebeschikking HTM Personenvervoer 2017.

MRDH-RailRET. (2017, 07 05). Subsidiebeschikking RET 2017.

MRDH-tram. (2016, 05 25). HTM Rail bevoorschotting 2016 i.v.m. instroom Avenio railvoertuigen. *Bestuurscommissie Vervoersautoriteit* . The Hague, NL: MRDH.

Mulley, C., & Weisbrod, G. (2016). Workshop 8 report: The wider economic, social and environmental impacts of public transport investment. *Research in Transport Economics , 59*.

Mulliner, E., Malys, N., & Maliene, V. (2015). Comparitive analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega , 59*, 146-156.

Mullins, J., Washington, E., & Stokes, R. (1987). *Land Use Impacts of the Houston Transitway System: Third Year Update .* Texas A&M Transportation Institute, Department of Transport. TTI.

NCEA. (n.d.). *Wat is MER*. (Netherlands commission for environmental assessment) Retrieved 08 13, 2017 from commissiemer.nl: http://www.commissiemer.nl/regelgeving/wat-is-mer

Noel, L., & McCormack, R. (2014). *A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus.* University of Delaware ISE Lab, Newark, DE 19716, Center for Carbon-Free Power Integration. University of Delaware.

NRC. (2012, 12 01). *Boorwerk Noord-Zuidlijn afgerond - 'eerste metro rijdt in 2017'*. Retrieved 09 04, 2017 from NRC: https://www.nrc.nl/nieuws/2012/12/01/boorwerk-noord-zuidlijn-amsterdam-afgerond-eerste-metro-in-2017-a1439485

NSG. (2004). *Geluid is te meten maar geluidshinder niet*. Retrieved 07 25, 2017 from Nederlandse Stichting Geluidshinder: http://nsg.nl/nl/geluids_is_te_meten_maar_geluidshinder_niet.html

Nurhadi, L., Boren, S., & Ny , H. (2014). A sensitivity analysis of total cost of ownership for electric public bus transport systems in Swedish medium sized cities. *Transportation Research Procedia 3 , 3*, 818 – 827.

NZTA. (n.d.). *Public transport information.* From New Zealand Transport Agency: https://www.nzta.govt.nz/assets/resources/public-transport-information-pack/docs/public-transport-information-pack-no-5.pdf

OV Pro-21m Bus. (2016, 12 04). *Connexxion zet lange Mercedes-Benz CapaCity L in rondom Schiphol*. Retrieved 09 12, 2017 from OV Pro: https://www.ovpro.nl/bus/2016/02/04/connexxion-zet-lange-mercedez-benz-capacity-l-in-rondom-schiphol/

OV-magazine eBus. (2017, 01 12). *16 elektrische stadsbussen voor Haarlem* . Retrieved 9 11, 2017 from OV Magazine: https://www.ovmagazine.nl/2017/01/16-elektrische-bussen-voor-haarlem-ijmond-1557/

Oxford dictionary. (n.d.). *perception*. Retrieved 08 24, 2017 from xforddictionaries.com: https://en.oxforddictionaries.com/definition/perception

Oxford Economics. (2015). *Economic Impact Analysis*. Retrieved 05 01, 2017 from Economic Impact: http://www.oxfordeconomics.com/economic-impact/economic-impact-analysis

Peek, G., & van Hagen, M. (2002). Creating synergy in and around stations: three strategies in an around stations. *Transportation Research Record , 1793*, 1-6.

Pereira, B. M., Sennaa , L. , & Lindaub, L. A. (2017). Stakeholder Value Network: modelling key relationships for advancing towards high quality bus transit systems . *International Conference Series on Competition and Ownership in Land Passenger Transport* . Stockholm, Sweden: Thredbo15.

Perk, V. A., Catala, M., & Reader, S. (2012). *Land Use Impacts of Bus Rapid Transit: Phase II—Effects of BRT Station Proximity on Property Values along the Boston Silver Line Washington Street Corridor.* Federal Transit Administration , TRID and ITRD database. Tampa, Florida: Transportation Research Board.

Peypoch, N., & Botti, L. (2013). Multi-criteria ELECTRE method and destination competitiveness. *Tourism Management Perspective , 6*, 106-113.

Pineda, P. G., Liou, J. J., Hsu, C.-C., & Chuang, Y.-C. (2017). An integrated MCDM model for improving airline operational financial performance. *Journal of Air Transport Management , corrected proof*.

Priest, R. (2016, 09 13). *Deze elektrische bus heeft een actieradius van 560 km*. Retrieved 09 04, 2017 from groen7.nl: https://www.groen7.nl/deze-elektrische-bus-heeft-een-actieradius-van-560-km/

Provincie Gelderland. (2016, 03 15). *mobiliteit.gelderland.nl*. Retrieved 05 02, 2017 from Toekomstige mobiliteit: https://mobiliteit.gelderland.nl/trends/default.aspx

PTV. (2013). *Benefits of Public Transport*. Retrieved 05 02, 2017 from Public Transport Victoria: https://www.ptv.vic.gov.au/about-ptv/media-centre/student-media-enquiries/benefits-of-public-transport/

Public Transportation.org. (n.d.). *Need for Investments*. Retrieved 04 26, 2017 from publictransportation.org: http://www.publictransportation.org/benefits/needforinvestment/Pages/default.aspx

Puchalsky, C. M. (2005). Comparison of Emissions from Light Rail Transit and Bus Rapid Transit.

Putra, K., & Sitanggang, J. (2016). The Effect of Public Transport Services on Quality of Life in Medan City. *Procedia - Social and Behavioral Sciences , 234*, 383-389.

Qin, N., Gusrialdi, A., Brooker, R., & T-Raissi, A. (2016). Numerical analysis of electric bus fast charging strategies for demand charge reduction. *Transportation Research A: Policy and Practice , 94*, 386-296.

RET- corporate. (2017). *Organisatie RET*. Retrieved 05 19, 2017 from Corporate ret: http://corporate.ret.nl/over-ret/organisatie.html

RET. (2017). *Jaarverslag 2016.* Retrieved 08 07, 2017 from retjaarverslag.nl: http://retjaarverslag.nl

RET. (2017). *Materieel*. Retrieved 05 15, 2017 from corporate.ret.nl: http://corporate.ret.nl/over-ret/materieel.html

RET. (2017). *Missie*. Retrieved 08 02, 2017 from RET Corporate: http://corporate.ret.nl/over-ret/missie.html

RET-b. (n.d.). *Materieel*. Retrieved 07 20, 2017 from corporate.ret.nl: http://corporate.ret.nl/over-ret/materieel.html

RET-Bus. (2017). *Busmaterieel*. Retrieved 08 29, 2017 from corporate.ret.nl: http://corporate.ret.nl/over-ret/materieel/busmaterieel.html

RET-bus44. (2017). *Dienstregeling Bus 44*. (RET) Retrieved 09 27, 2017 from ret.nl: https://www.ret.nl/home/reizen/dienstregeling/bus-44.html

RET-ferry. (n.d.). *De Fast Ferry: zó op je werk*. (RET) Retrieved 09 22, 2017 from ret.nl: https://www.ret.nl/home/reizen/dienstregeling/informatie-fast-ferry/fast-ferry-page.html

RET-fiets. (n.d.). *Mag mijn fiets mee in de bus, tram of metro?* . Retrieved 09 20, 2017 from RET.nl: https://www.ret.nl/vraag-antwoord/de-reis/reisinformatie/algemeen-reisinformatie/mag-mijn-fiets-mee-in-de-bus-tram-of-metro.html

RET-Infra. (2017). *corporate ret*. Retrieved 09 04, 2017 from Infra: http://corporate.ret.nl/over-ret/infra.html

RET-Metro. (2017). *Metromaterieel*. Retrieved 08 29, 2017 from corporate.ret.nl: http://corporate.ret.nl/over-ret/materieel/metromaterieel.html

RET-Tram. (2017). *Trammaterieel*. Retrieved 08 29, 2017 from corporate.ret.nl: http://corporate.ret.nl/over-ret/materieel/trammaterieel.html

RET-vervoerplan 2018. (2016). *Vervoerplan RET.* Rotterdam: RET.

RET-wifi. (2015, 01 29). *RET start met gratis wifi in trams en metro's*. Retrieved 05 17, 2017 from RET: http://corporate.ret.nl/nieuws/nieuwsbericht/ret-start-met-gratis-wifi-in-trams-en-metros.html

Rezaei, J. (2014). Best-worst multi-critera decision-making method. *Omega , 53*, 49-57.

Rieck, F. (2014, 12 12). *NEMS: Electric Busses at Ro3erdam.* Retrieved 09 04, 2017 from Clean Fleets: http://www.clean-fleets.eu/fileadmin/files/e-Busz_Rotterdam_final_Ecomobiel-Bremen_-_Rieck_small_.pdf

Rijkswaterstaat. (2017). *Akoestisch rapport wegverkeerslawaai Wgh*. Retrieved 05 15, 2017 from Kenniscentrum InfoMil: http://www.infomil.nl/onderwerpen/hinder-gezondheid/geluid/inhoudelijk-dossier/regelgeving/wet-geluidhinder/wegverkeerslawaai/akoestisch-rapport/

Rosenberg, H. (2016, 05 24). *Tram 19, een tram naar nergens* . Retrieved 07 12, 2017 from Algemeen Dagblad: http://www.ad.nl/delft/tram-19-een-tram-naar-nergens~a193e479/

Roy, B. (1991). The outranking approach and the foundations of electre methods. *Theory and Decision , 31* (1), 49-73.

Rudnicki, A. . (1997). Measures of Regularity and Punctuality in Public Transport Operation. *IFAC Proceedings volumes , 30* (8), 661-666.

Saaty, T. L. (1994). *Fundamentals of Decision Making and Priority Theory with the AHP.* Pittsburgh, Pennsylvania, USA: RWS Publications.

Saaty, T. L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation .* NY, NY, USA: McGraw-Hill.

Saaty, T. L., & Vargas, L. G. (2012). *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process* (Springer Science+Business Media New York ed., Vol. 2nd). (I. S. Science, Ed.) Springer US .

Schacter, D. L., Gilbert, D. T., & Wegner , D. M. (2011). *Psychology* (Vol. 2nd). Cambridge, USA: Worth Publishers.

Schafer, A., & Victor, D. G. (1998). The future mobility of the world population. *Transportation Research Part A , 34*.

Schiavone, J. J. (2010). *Preventive Maintenance Intervals for Transit Buses.* Transportation Research Board. Washington, D.C. : e Federal Transit Administration in Cooperation with the Transit Development Corporation.

Scholten, L., Maurer, M., & Lienert, J. (2017). Comparing multi-criteria decision analysis and integrated assessment to support long-term water supply planning. *PLOS One , 12* (5), e0176663.

Schroten, A., & Kortmann, R. (2006). *Schone bussen voor Brabant .* CE Delft. Delft: CE Delft.

Serrai, W., Abdelli, A., Mokdad, L., & Hammal, Y. (2017). Towards an efficient and a more accurate web service selection using MCDM methods. *Journal of Computation Science , xxx*, xxx-xxx.

Sightline. (n.d.). *CO2 by Mode*. Retrieved 09 08, 2017 from Sightline: http://www.sightline.org/maps-and-graphics/climate-co2bymode/

Simons, T., Pelled, L., & Smith, K. (1999). Making use of difference: diversity, debate, and decision comprehensiveness in top management teams. *Academy of Management Journal , 42*, 662-673.

Singal, B. (2015). LIFE CYCLE COST ANALYSIS OF ALTERNATIVE PUBLIC TRANSPORT MODES. *Urban Mobility Conference and Expo* . India: Institute of Urban Transport.

Snauwaert, D. (2017, 09 01). *Van Hool builds 8 hydrogen-powered tram-buses for Pau (France*. (Van Hool) Retrieved 09 15, 2017 from van Hool: http://www.vanhool.be/ENG/actua/exquicitypau.html

Snelder, M. (2010). *Designing Robust Road Networks A general design method applied to the Netherlands.* Doctoral dissertation, Delft University of Technology, TRAIL, Delft, The Netherlands.

Stadsgewest Haaglanden. (n.d.). *Doelstelling en Taken*. From Stadsgewest Haaglanden: http://stadsgewesthaaglanden.nl/doelstelling-en-taken

Stadsgewest Haaglanden-RR. (2009). *Lijnnet Nota Netwerk RandstadRail.* Lijnnet Nota, Uitwerking visie Randstadrail.

Stiles Machinery. (2012, 06 25). *Corrective versus Preventive Maintenance: What is the difference and where is the value?* Retrieved 05 17, 2017 from Stiles machinery: https://www.stilesmachinery.com/articles/corrective-versus-preventive-maintenance-what-is-the-difference-and-where-is-the-value

Stokenberga, A. (2014). Does Bus Rapid Transit Influence Urban Land Development and Property Values. *Transport Reviews: A Transnational Transdisciplinary Journal , 34* (3).

Sturm, E. (2008, 04 19). *Spoorbus kan regiolijn redden*. Retrieved 08 11, 2017 from Trouw: https://www.trouw.nl/home/spoorbus-kan-regiolijn-redden~ac12ceeb/

Sun, H., Wang, Y., & Li, Q. (2016). The impact of subway lines on residential property values in Tianjin: An empirical study based on hedonic pricing model. *Discrete Dynamics in Nature and Society , 2016*, 10.

Swanson, J. D. (2004). Light Rail Without Wires A Dream Come True? *Transportation Research Circular E-C058: 9th National Light Rail Transit Conference* (pp. 729-744). Chicago, IL, USA, USA: Parsons Brinckerhoff Quade & Douglas, Inc.

Tamaki, T., Nakamkura, H., Fujii, H., & Managi, S. (2016, 09 13). Efficiency and emissions from urban transport: Application to world city-level public transportation. *Economic Analysis and Policy* .

The Free Dictionary. (n.d.). *perception*. Retrieved 08 24, 2017 from The Free Dictionary: http://www.thefreedictionary.com/perception

The International Association of Public Transport . (2013). *Financing Public Transport.* From UITP: http://www.uitp.org/sites/default/files/Financing%20public%20transport.pdf

Thomopoulos, N., Grant-Muller, S., & Tight, M. (2009). Incorporating equity considerations in transport infrastructure evaluation: current practice and a proposed methodology. *Evaluation and Program Planning , 32* (4), 351-359.

Thredbo. (2017). *Thredbo15*. (Stockholm, Producer, & International Conference Series on Competition and Ownership in Land Passenger Transport) Retrieved 08-09 2017 from Thredbo Conference: http://www.thredbo-conference-series.org/papers/thredbo15/

Transit Bangkok. (n.d.). *BRT*. Retrieved 09 1, 2017 from transitbangkok: http://www.transitbangkok.com/brt.html

Transit Technologies. (n.d.). *Light Rail Transit (LRT): A Technology Brief.* Retrieved 09 04, 2017 from Our Transit Future: http://ourtransitfuture.com/wp-content/uploads/2013/07/transit_technoloiges_FS.pdf

Transport System Catapult. (2016). *MOBILITY AS A SERVICE EXPLORING THE OPPORTUNITY FOR MOBILITY AS A SERVICE IN THE UK.* Transport System Catapult. London: Transport System Catapult.

Transportation Economics Committee . (n.d). *Transportation Benefit-Cost Analysis*. From Transportation Economics: http://bca.transportationeconomics.org/system/app/pages/sitemap/hierarchy

Transportationeconomics.org. (n.d.). *BCA vs. Economic Impact Analysis .* Retrieved 05 01, 2017 from Transportation Benefit-Cost Analysis: http://bca.transportationeconomics.org/home/bca-vs-economic-impact-analysis

Triantaphyllou, E. (2000). *Multi-Criteria Decision Making Methods: A Comparative Study* (Vol. 44). (P. M. Pardalos, & D. Hearn, Eds.) Baton Rouge, Louisiana, USA: SPRINGER-SCIENCE+BUSINESS MEDIA B.V.

Tuzkaya, G., Gulsun, B., Kahraman, C., & Ozgen, D. (2010). An integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem and an application. *Expert Systems with Applications , 37*, 2853-2863.

UITP. (2012). *Metro, Light rail and tram systems in Europe.* European Rail Research Advisory Council, International Association of Public Transport. Bruxelles: UITP - ERRAC Roadmaps.

United States Department of Transportation. (2016). *2015 operating expenses.* Retrieved 05 17, 2017 from Federal Transit Administration: https://www.transit.dot.gov/ntd/data-product/2015-operating-expenses

Vahdani, B., Haji, A., Jabbari, K., Roshanaei, V., & Zandieh, M. (2010). Extension of the ELECTRE method for decision-making problems with interval weights and data. *The International Journal of Advanced Manufacturing Technology , 50* (5-8), 793-800.

Valley Metro. (2013, 10 01). *LIGHT RAIL VEHICLE.* Retrieved 09 03, 2017 from Valley Metro: http://www.valleymetro.org/images/uploads/lightrail_publications/LR_Vehicle_Fact_Sheet_-_October_2013.pdf

van Oort, N. (2011). *Service Reliability and Urban Public Transport Design.* TU Delft, Civil Engineering. the Netherlands TRAIL Research School.

van Oort, N., & van der Bijl, R. (2014). *Light Rail Explained.* European Metropolitan Transport Authorities. EMTA.

van Oort, N., Bukman, B., & van der Bijl, R. (2015). *Investeren in de stad. Lessen uit 47 light rail projecten.* Milete Media.

van Oort, N., van der Bijl, R., & Maartens, M. (2016, 06 16). Waarde ov sterk onderschat. *OV-Magazine* .

van Oort, N., van der Bijl, R., & Verhoof, F. (2017). The wider benefits of high quality public transport for cities. *in progress* .

van Oort, N., van der Bijl, R., & Verhoof, F. (2017). The wider benefits of high quality public transport for cities. *European Transport Conference 2017* (p. 17 pages). Barcelona, Spain: Association for European Transport.

Vecino-Ortiz, A. I., & Hyder, A. A. (2015). Road Safety Effects of Bus Rapid Transit (BRT) Systems: a Call for Evidence. *J Urban Health , 92* (5), 940-946.

Veeneman, W., & Mulley, C. (2017). Multi-level governance in public transport: governmental layering and its influence on public transport service solutions. *International Conference Series on Competition and Ownership in Land Passenger Transport. H11, R42.* Stockholm, Sweden: Thredbo15.

Vejchodská, E. (2015). Cost-Benefit Analysis: Too often biased. *Economics and Management , 8*.

Ventura Systems. (n.d.). *Buses that think they are trams*. Retrieved 09 09, 2017 from Ventura systems: http://www.venturasystems.com/en-3-152/buses-that-think-they%E2%80%99re-trams-.html

Verkeersnet. (2012, 12 06). *Zoetermeer haakt aan op metro Rotterdam* . Retrieved 09 04, 2017 from Verkeersnet: https://www.verkeersnet.nl/8508/zoetermeer-haakt-aan-op-metro-rotterdam/

VTPI. (2017). *Evaluating Public Transit Benefits and Costs.* Victoria Transport Policy Institute.

Vulević, T. , & Dragović, N. (2017). Multi-criteria decision analysis for sub-watersheds ranking via the PROMETHEE method. *International Soil and Water Conservation Research , 5* (1), 50-55.

Wagner, G. A., Komarek, T., & Martin, J. (2017). Is the light rail “Tide” lifting property values? Evidence from Hampton Roads, VA. *Regional Science and Urban Economics , 65*, 25-37.

Walker, J. (2010, 11 05). *Basics: The Spacing of Stops and Stations*. Retrieved 06 10, 2017 from Human Transit: http://humantransit.org/2010/11/san-francisco-a-rational-stop-spacing-plan.html

Wang, Y., Huang, Y., Xu, J., & Barclay, N. (2017). Optimal recharging scheduling for urban electric buses: A case study in Davis. *Transportation Research Part E: Logistics and Transportation , 100*, 115-132.

Wee, B. v. (2011). How suitable is CBA for the ex-ante evaluation of transport projects and policies? A discussion from the perspective of ethics. *Transport Policy , 19* (1), 1-7.

Weijdt, J., & Brussen, M. (2016). *Beleidslijn Sociale Veiligheid in het Openbaar Vervoer.* Metropoolregio Rotterdam Den Haag, Openbaar Vervoer. MRDH.

Weisbach, D. A. (2014). Distributionally Weighted Cost–Benefit Analysis: Welfare Economics Meets Organizational Design . *Journal of Legal Analysis , 7* (1), 151-182.

Weisbrod, G., Mulley, C., & Hensher, D. (2016). Recognising the complementary contributions of cost benefit analysis and economic impact analysis to an understanding of the worth of public transport investment: A case study of bus rapid transit in Sydney, Australia. *Research in Transportation Economics , 59*, 450-461.

Whitehead, J. (2009, 10 12). *Benefit-cost analysis vs economic impact analysis .* Retrieved 05 01, 2017 from Environmental Economics: http://www.env-econ.net/2009/10/benefitcost-analysis-vs-economic-impact-analysis.html

Wienberger, R. (2001). Light rail proximity: benefit or detriment in the case of Santa Clara County, California? *Transportation Research Record , 1747*, 104-113.

Wijk C. (2012). *Onderzoek naar snelheden bussen binnenstad Utrecht.* Utrecht.

Wijmenga, N., Veeneman, W., & Hirschhorn, F. (2017). Benchmarking the costs of urban public transport in the Netherlands. *International Conference Series on Competition and Ownership in Land Passenger Transport* . Thredbo, Australia: Thredbo 15.

Wu, I., & Pojani, D. (2016, 05 18). Obstacles to the creation of succesful bus rapid transit systems: The case of Bangkok. *Transport Economics* .

Xylia, M., & Silveira, S. (2017). On the road to fossil-free public transport: The case of Swedish bus fleets. *Energy Policy , 100*, 397-412.

Xylia, M., Leduc, S., Patrizio, P., Kraxner, F., & Silveira, S. (2017). Locating charging infrastructure for electric buses in Stockholm. *Transportation Research Part C: Emerging Technologies , 78*, 183-200.

Yang, J., Quan, J., Yan, B., & He, C. (2016). Urban rail investment and transit-oriented development in Beijning: Can it reach a higher potential. *Transportation Research Part A: Policy and Practice , 89*.

Yap, M. (2014). *Robust public transport from a passenger perspective:.* Master thesis, TU Delft, Transport & Planning, Delft, The Netherlands.

Zak, J. (2010). The methodology of multiple criteria decision making/aiding in public transportation. *Journal of Advanced Transportation , 45* (1), 1-20.

Zhang, Y., & Han, Q. (2017). Development of electric vehicles for China's power generation portfolio: A regional economic and environmental analysis. *Journal of Cleaner Production , 162*, 71-85.

APPENDIX I. STAKEHOLDER ANALYSIS

The goal of a stakeholder analysis is to identify the important stakeholders involved in the process. When the important stakeholders are identified, it is more convenient to determine which stakeholders can influence the process and how they should be kept up to date. A stakeholder can be defined as an individual or a group of individuals who have an interest or are influenced, either positively or negatively, by the project or the process (Macharis C. , The importance of stakeholder analysis in freight transport, 2005). A stakeholder analysis can be executed to visualise stakeholder alignment and show which have common interests and which have opposite interests.

This will contribute to minimizing threats and obstruction of the project and maximize cooperation. An example that shows the importance of stakeholders, as shown by Lindau, Hidalgo & Almeida Lobo (2014), is the BRT (Bus Rapid Transit) system in Bangkok (Wu & Pojani, 2016). Not all stakeholders were sufficiently taken account in the process. No negotiations took place with bus operators and there was hardly any cooperation with traffic police. This led to lack of control of the overall process and had a negative effect on the BRT implementation and operation.

Looking at public transport investments, the quality triangle shown in Figure 24, characterizes the involved and most important stakeholders.

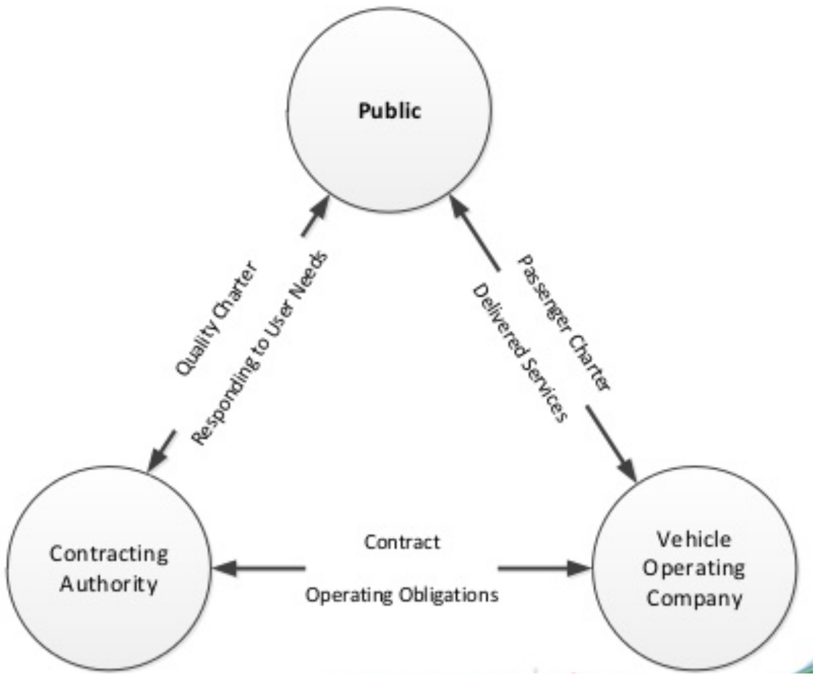


FIGURE 24. QUALITY TRIANGLE

The figure shows the three most important groups:

1. Contracting Authorities can be characterized as different governmental authorities making decisions regarding selecting and making agreements with the service provider(s). The role of the governmental agencies and institutions is to improve the quality of life, access and mobility in a clean, safe and sustainable environment (Government.nl , n.d.), (Gemeente Rotterdam, 2017), (Gemeente Den Haag). The following governmental agencies and institutions play an important role regarding public transport investments:

    - Province of South-Holland
    - Ministry of Infrastructure and the Environment
        - Rijkswaterstaat (as executive organ for the Ministry)
    - MRDH
    - 23 Municipalities (represented by MRDH)

2. Vehicle Operating Companies, also public transport operators are the stakeholders that, despite they are competitors, share the following (same) goal (HTM, n.d.), (RET, Missie, 2017):

    To transport their passengers in the fastest, safest, cheapest way possible.

    They work together with the governmental institutions to provide these transport services for the public and receive subsidy to operate and maintain the systems. The following public transport organizations already are operating in the metropolitan region and therefore have an interest in the decision making process regarding public transport investments:
    - RET
    - HTM
    - Veolia
    - Conexxion
    - Arriva

3. The Public is the final group in the triangle and are the users of the system. The public transport operators are assessed on service they deliver and by conducting surveys, the passengers are able to provide feedback on the quality of service of these companies. The government makes agreements with public transport companies and uses, among other things, the survey data to check if the agreements they made are still met (CROW-KpVV, 2016).

The public transport operators are assessed on the service they deliver and by conducting surveys, the Public, represented by the passengers are able to provide feedback on the quality of service of these companies. The government makes agreements with public transport companies (Carmen & Lidestam, 2016) and uses, among other things, the survey data to check if the agreements they made are still met (CROW-KpVV, 2016). Finally, according to Hakan Zor, Fleet Manager of the RET, the amount of passengers play an important role in the operational costs of the public transport operators

(Appendix VI & personal communication RET, 24-08-2017). The subsidies, the government provides the public transport operators, will decrease the upcoming years meaning that the amount of passengers must increase. The increase in volume, while maintaining at least the same service quality, will lead to more passengers per trip, which leads to more earnings per trip. Therefore, fewer subsidies are required which result in more financial resources available for investments.

Due to the fact that this research focuses on public transport investments, the Public, as a stakeholder, can be divided into two categories. The first one is the passengers, who (actively) are using public transport and the second group is the inhabitants which may experience a more negative impact of the system. The latter group also consists of people who never use public transport but still can be impacted by a (new) system.

With regards to the decision-making process, the perception of the inhabitants does not add any extra value in the decision-making process, especially compared to the information gathered from the passengers. Furthermore, the assumption is made that

The government already made a decision regarding the implementation of a new public transport system. What kind of public transport system is not yet known, however, all complaints and objections of the inhabitants regarding a new public transport system are assumed to be handled by the governmental institutions. For these reason, the inhabitants, as a group, is not taken into account and therefore fall out of the scope in this research.

Due to the fact that this research focuses on public transport investments, the Public, as a stakeholder, can be divided into two categories. The first one is the passengers, who (actively) are using public transport and the second group is the inhabitants which may experience a more negative impact of the system. The latter group also exists of people who never use public transport but still can be impacted by a (new) system.

Based on the Quality triangle (Figure 24) and the description mentioned above, the following list of stakeholders can be characterized, Table 50:

TABLE 50. STAKEHOLDERS

Public transport operators
RET
HTM
Conexxion
Veolia
Arriva
Governmental agencies and institutions
23 municipalities (represented by MRDH)
Province of South-Holland
Ministry of Infrastructure and the Environment
Rijkswaterstaat (as executive organ for the Ministry)
Public
Inhabitants
Passengers

Public transport operators

The RET and HTM are the local public transport operators operating respectively in the region of Rotterdam and The Hague. Connexxion, Arriva and Veolia are public transport operators operating in (areas in) the Netherlands.

The main Goal of the RET is to offer perfectly organized highly qualitative public transport facilities (RET- corporate, 2017). The Goal of HTM is to bring people in a safe, comfortable and efficient manner to their destination (HTM, n.d.). Both organizations try to achieve their goals by closely working together with each other, their municipalities and MRDH. In the case of public transport investment decision-making, the public transport operators all want to transport their passengers in the fastest, safest, cheapest way possible. This is the main reason that the four aforementioned parties can be categorized under the same stakeholder: the Public transport operators.

The involvement of the public transport operators and their effect on decisions in the overall decision-making process categorizes them as a high power and high interest stakeholder.

Government

With regards to governmental agencies and institutions, in general, the municipalities, province of South-Holland, Ministry of Infrastructure and Environment and Rijkswaterstaat all have the same goal: Improving quality of life, access and mobility in a clean, safe and sustainable environment (Government.nl , n.d.). The main differences between the institutions mainly exist in terms of execution. For example, the municipalities mainly focus on their regions, whereas the Ministry's main focus lays on leading and collaborating with the underlying institutions, both parties still keeping in mind to the main goal. The fact that the main goal is about the same for the 5 abovementioned stakeholders gives reason to categorize them under the same stakeholder: the Government. The government is also highly involved in the decision-making process making it also a high interest stakeholder. The government is the most important stakeholder with regards to its influence on the process to decide upon major decisions. This makes the government an important stakeholder.

Passengers

The Passengers can also be categorized as an important stakeholder with regards to public transport. After all, this group consists of all the users of these systems and therefore, it is important to know what kind of facilities are important when designing such a system. This high interest makes the travellers an interesting group to take into account in the decision-making process. Their goal is to reach their destination in the most efficient way, which can have different meanings. Efficiency in this case, can be either be characterized as cheap, fast or a comfortable journey. Furthermore, due to their important involvement in the end project, this group can be characterized as a group with medium power. This means that their influence in the process is not that high in terms of affecting any major differences in the process.

Inhabitants

The goal of inhabitants is to experience a livable environment. A new public transport system in the backyard usually does not contribute to a more positive environment for the majortity of the inhabitants (no taking into account the inhabitants who also can be characterized as travellers). Inhabitants may experience both positive and negative effects of public transport projects. When looking at the indirect (wider) benefits of public transport, the accessibility of the region as well as the house prices shows an increase when implementing a new system. However, when an area becomes more attractive, it is likely that this area will attract more people making it more dynamic, hectic and noisy. The perception of inhabitants does not adds any value in the decision-making process for the policy decision-maker, this group is not taken into account in the process. The perception of the passengers however, may have an important role due to the fact that this group actually are (going to be) the users of the system.

Formal Relations Diagram

Figure 25 below shows the formal relations diagram of all the stakeholders involved with regards to public transport investments. As can be derived from the figure, the governmental institutions can be grouped under one stakeholder, the government. This also goes for the public transport operators. Taking into account the relations between the stakeholders is an essential part of the analysis. Stakeholders who have a large influence on the process or stakeholders who have an important formal relation with such a stakeholder can be of great value in the process.

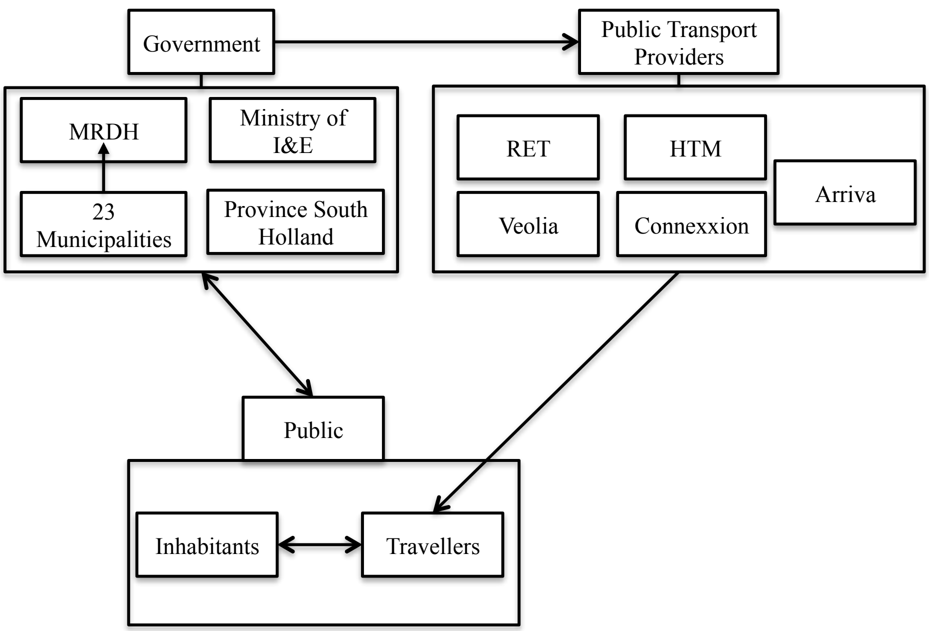


FIGURE 25. FORMAL RELATIONSHIP DIAGRAM

The public transport companies agree with the government to deliver a minimal service in exchange for a concession to operate in the contracted areas. The government decides and provides subsidy, where and what kind of system may be implemented.

The Public serves a quality charter for the government to check whether the public transport operators are delivering the services that were agreed upon. This information is gathered through surveys (CROW-KpVV, 2016) and used as a benchmark for performance of the various transport systems.

Summarizing the above-mentioned stakeholders together with the three important groups from the quality triangle, the following conclusion can be drawn:

The stakeholders mentioned below in Table 51. Stakeholders after grouping have an important role in the decision-making process regarding public transport investments. These three groups are further taken into account when conducting a perception analysis.

TABLE 51. STAKEHOLDERS AFTER GROUPING

Stakeholders
Public transport operators
Government
Passengers

APPENDIX II. MCDM METHODS

In Appendix II, the Multi-criteria decision making methods are explained. The steps of these methods are presented below. The following methods are described:

A. Best-Worst Method
B. Weighted Sum Model
C. Weighted Product Model
D. Multi-Actor Multi-Criteria Analysis
E. TOPSIS
F. AHP
G. PROMETHEE
H. ELECTRE

A. Best-Worst Method

The Best-worst method is a vector based multi-criteria decision-making method developed by Dr. Jafar Razaei (Rezaei, 2014). This method can be characterized as a pairwise comparison between a set of criteria. From this set of criteria, the participant chooses one criterion which in his or her opinion is most important (best) and one that is least important (worst). The best-criterion is then compared with the remaining criteria and the same is done for the worst-criterion. The benefits of the Best-worst method, compared to other Multi-criteria decision-making methods are:

- BWM requires less comparison data
- It leads to more consistent comparisons, which results in reliable results
- BWM can be combined with other MCDM methods
- BWM is a simple method to perform; comparisons are performed with integer numbers ranging from 1 to 9.

The BWM is used in this research because of these benefits and serves as proof that this method is useful for conducting an analysis regarding perception of public transport systems. It seems that BWM may be one of the best methods to use when deciding on weights for parameters (Serrai, Abdelli, Mokdad, & Hammal, 2017). This is because not only the best and worst criteria are predefined by the users, but also the comparison of the other elements to them.

To conduct a Best-worst analysis, the following five steps are necessary (Rezaei, 2014):

Step 1 - Firstly, a set of decision criteria $\{c1, c2, \dots, cn\}$ needs to be determined. These are the criteria which can be compared with each other to determine the best outcome.

Step 2 - Determine the Best and the Worst criteria. In this step the decision-maker determines, out of all the criteria, the best criterion and worst criterion. There is no comparison made yet, however, in the next step, the best (worst) criterion can be compared with the remaining criteria.

Step 3 - Determine preference of Best criterion over other criteria. In this step the criterion that is chosen as best, will be compared to the other criteria using a scale between 1 and 9. These numbers indicate the amount of preference, where a 1 = equal preference and a 9 = 9x times more important. The following, best-to-other comparison vector shows what the result of this step will look like:

$$AB = (aB1 , aB2 , \dots , aBn)$$

Step 4 - Determine preference of other criteria over Worst criterion. In this step all the criteria are compared to the criterion that is chosen as worst, using a scale between 1 and 9. These numbers indicate the amount of preference, where a 1 = equal preference and a 9 = 9x times more important. The following, others-to-worst comparison vector shows what the result of this step will look like:

$$AW = (aW1 , aW2 , \dots , aWn)$$

Step 5 - Find the optimal weights.

The final step is to calculate the optimal weights for the criteria (w*1, w*2, … ,w*n) such that the maximum absolute differences $\left|\frac{wb}{wj} - \mathbf{aBj}\right|$ and $\left|\frac{wj}{ww} - \mathbf{ajW}\right|$ are minimized. This results in the following problem:

$$\text{Min max j} \left\{ \left|\frac{wb}{wj} - \mathbf{aBj}\right| , \left|\frac{wj}{ww} - \mathbf{ajW}\right| \right\}$$

$$\textstyle\sum_j \boldsymbol{wj} = 1$$

$$wj \geq 0, \text{ for all j}$$

Solving the problem will result in finding the optimal weights (w*1, w*2, … ,w*n) and the consistency ratio **ξ***. A higher **ξ*** means a higher consistency ratio and a higher ratio results in less reliable comparisons.

B. Weighted Sum Model

One of the most common MCDM methods is the Weighted Sum Model, WSM (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). This method is easily applicable and easy to use in combination with other methods. The WSM method compares alternatives, based on a given set of criteria, with each other. Each criterion is given a certain weight and by multiplying the weight of the criteria with the score of the alternatives, an optimal solution is given.

TABLE 52. WSM EXAMPLE

	C1	C2	C3
Weights/ Alternatives	0.35	0.25	0.4
A1	30	20	55
A2	40	35	15
A3	25	10	20

The WSM problem results in finding an optimal solution for the following equation (Fishburn, 1967):

$$A^*_{WSM} = \max \sum_i^m aij\ wj$$

where i = 1 , … , m
A^*_{WSM} represents the weighted sum score which results from multiplying the weights with the scores of the Alternative
aij represents the score of alternative i with respect to criterion j, shown in the 3rd, 4th and 5th row in Table 52.
wj is the weight of criterion j, shown in the second row in Table 52.
One of the disadvantages of the WSM is that the problem becomes difficult to conduct when both qualitative and quantitative comparison factors are used. Furthermore, a change in range of the attributes could result in another optimal solution, making this method very sensitive to units change. This change in optimal solution could also happen when some scores are a bit exaggerated.

C. Weighted Product Model

The Weighted Product Model method is a MCDM method that has many similarities compared to the WSM (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). The biggest difference however, with the WSM is that a WPM used a product to calculate the optimal solution instead of a sum (Triantaphyllou, 2000). The equation below shows a comparison between the alternatives A_K and A_L. If R exceeds 1, this means that alternative A_K, is preferred compared to alternative A_L.

The optimal solution is found by making use of the following equation [(Miller & Starr, 1969) & (Bridgman, 1922)]:

$$R\left(\frac{Ak}{Al}\right) = \prod_{j=1}^{n}\left(\frac{a_{kj}}{a_{lj}}\right)^{wj}$$

with n representing the number of criteria
aij represents the score of alternative i with respect to criterion j
wj is the weight of criterion j.

D. Multi-Actor Multi-Criteria Analysis

MAMCA is a Multi-Actor Multi-Criteria Analysis developed by Prof. Dr. Cathy Macharis (Macharis C. , 2005). This method can be characterized as a multi-criteria decision analysis that enables decision-makers a simultaneous evaluation of various projects (Macharis, de Witte, & Turcksin, The Multi-Actor Multi-Criteria Analysis (MAMCA) application in the Flemish long-term decision making process on mobility and logistics, 2010). One of the most important benefits of MAMCA compared to other MCDM methods is that MAMCA explicitly takes into account the opinion of different stakeholders. This is of high importance deciding which public transport investment will be most efficient. Involving stakeholders early in the process will give policy decision-makers not only and understanding and insight in their own problem but will also allow them to gain an understanding in the perspective of other stakeholders. Figure 3 below shows the seven required steps for performing a MAMCA, as defined by Macharis et al (2010).

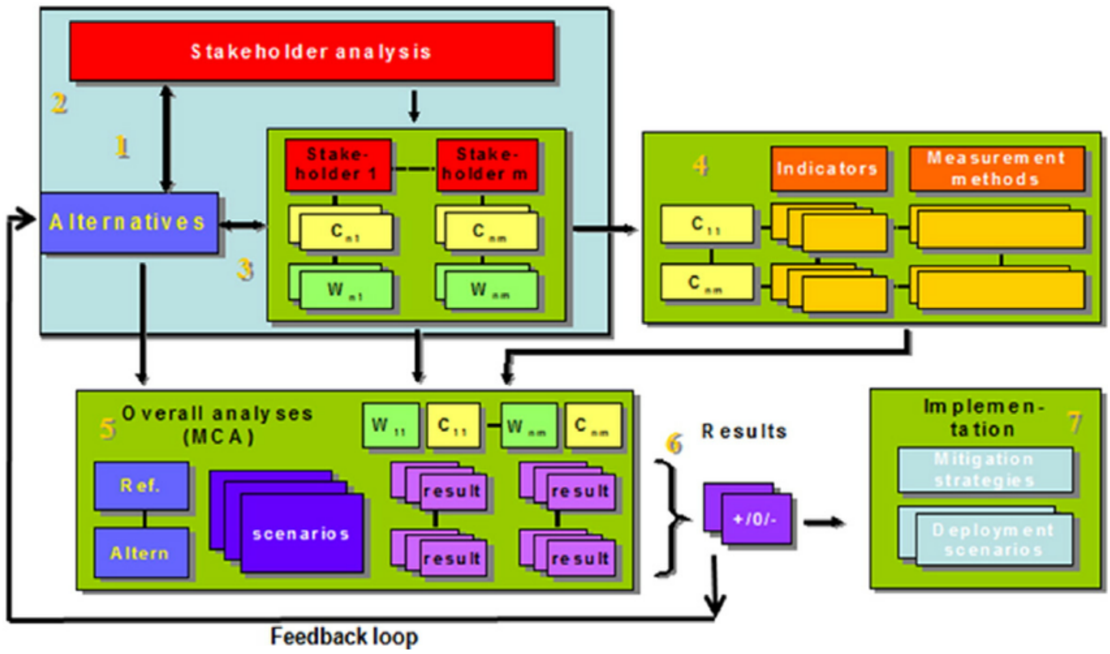


FIGURE 26. STEPS MAMCA

The steps shown in Figure 26 regarding the MAMCA method can be explained as follows (Macharis, Turcksin, & Lebau, 2012):

Step 1 – Firstly, the problem needs to be defined and several possible alternatives need to be classified. These alternatives can later be evaluated.

Step 2 – Stakeholder analysis. This step is characterized as the stakeholder analysis where all the important stakeholders are identified. Taking into account the involved important stakeholder early in the process will benefit the final result. By performing a stakeholder analysis, certain aspects like, priorities, problems, interests and conflicts will be revealed in an early stage in the decision-making process. This can be taken into account further in the overall process, leading to an enhancement of the final result. Furthermore, this analysis also gives insight in the policy level of the project which clarifies the impact of the project and which governmental level (municipality, province, national, European) needs to be taken into account.

Step 3 – Define criteria and weights.

The third step is to define the criteria for the stakeholders and assign weights to them to show their importance. The criteria are chosen based on the following two properties:

- Objectives of the involved stakeholders
- Purpose of the considered alternatives

This also means that for each stakeholder group, a different set of criteria could be important, which would be based on their specific objectives. To show the involved stakeholders together with their goals and objectives, there is a possibility to present a hierarchical criteria tree (in this step).

Together with the stakeholder, weights can be determined to their set of criteria, based on the amount of value the stakeholder assigns to his objectives. These weights then, represent the importance of the criteria. Finally, if necessary, there is also a possibility to assign weights to the stakeholders. These are able to represent the importance of the stakeholder in the decision-making process.

Step 4 – Criteria, indicators and measurement methods.

In this step, indicators are determined for the criteria constructed in step 3. These indicators are used to measure how an alternative contributes to the criteria. The indicator provides a certain weight that enables measurement of the contribution of the alternative to the criteria.

Step 5 – Overall analysis and ranking.

This step evaluated each alternative, comparing them by use of the aforementioned criteria and indicators. This makes it possible to elaborate more on the alternatives in such a way that they are translated into scenarios. A scenario can be characterized as a more detailed alternative where also the effects on and from the environment are taken into account. After these scenarios are clearly identified, an evaluation table can be presented for each stakeholder.

Step 6 – Results

After the overall analysis and ranking a classification of the proposed alternatives can be presented. This step helps the decision-maker in its decision-making process by pointing out for each stakeholder which elements have a positive or negative influence on the alternatives. It clearly shows which stakeholder prefers which alternative and the level of importance.

Step 7 – Implementation

The final step, the gathered information and data can be used to formulate a policy recommendation for the decision-maker. Macharis (2012) explains two approaches for implementation from the decision-makers point of view, taking into account that decision-makers most of the time are governmental organisations. The first approach is to implement the alternative that will give the highest benefit to society. This approach is derived from the fact that the government represents the needs of society. The second approach is to implement the alternative that tries to take into account all interests of all involved stakeholders, where some kind of compromise situation is achieved.

E. TOPSIS

The TOPSIS (Technique for Order Preference by Similarities to Ideal Solution) method is used broadly in various research fields (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016) and developed by Hwang and Yoon (1981). This method uses the Euclidean distance to find the best solution as close as (shortest distance) possible to the ideal alternative and at the same time as far away (longest distance) from the most negative solution. Both the best and the most negative solution result from this method and each criterion can lead to a change in utility (Triantaphyllou, 2000). The change in utility for every criterion eventually can lead to an ideal solution and a non-ideal solution and an optimal alternative within this range. However, by making use of the Euclidean distance, any correlation that may occur between criteria is not taken into account and could have difficulty to weight Qualitative parameters (Serrai, Abdelli, Mokdad, & Hammal, 2017).

Figure 27 shows the necessary steps of the methodology, starting with defining the criteria and alternatives. A decision matrix can be constructed from the criteria and alternatives.

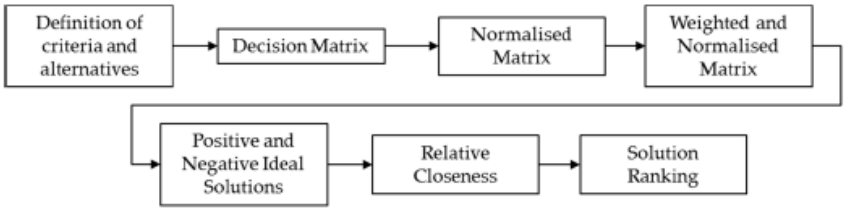


FIGURE 27. TOPSIS METHODOLOGY (KOLIOS ET AL. 2016)

Step 1 – Normalized Decision Matrix

The first step is to construct a Normalized Decision Matrix where a normalised value (r_{ij}) can be calculated, as follows:

$$\boldsymbol{r_{ij}} = \left(\frac{\boldsymbol{x_{ij}}}{\sqrt{\sum_{k=1}^{m} \boldsymbol{x_{kj}^2}}} \right)$$

where x_{ij} is the value for criterion i for alternative Aj

Step 2 – Weighted and Normalised Matrix

Now that the Normalised Decision Matrix is constructed and the normalised values have been calculated, the Weighted Normalised Decision Matrix can be constructed. Each normalised value, r_{ij} is multiplied with a weight, $W = (w_1, w_2, \dots, w_n)$ with $\sum \boldsymbol{w_i} = 1$, to determine these normalised decision values, v_{ij}.

$$\boldsymbol{v_{ij} = w_i r_{ij}}$$

Step 3 – Positive and Negative Ideal Solutions

The third step is to determine the best, indicated as A^{+}, and also the most negative, indicated as A^{-}, solution. These solutions are defined as follows:

$$A+ = \{v1+, \dots, vn+\} = \{(MAX_j v_{ij} \mid i \in I), (MIN_j v_{ij} \mid i \in I')\}$$

$$A- = \{v1-, \dots, vn-\} = \{(MIN_j v_{ij} \mid i \in I), (MAX_j v_{ij} \mid i \in I')\}$$

Where i is associated with the benefit criteria and i' associated with costs criteria.

Step 4 – Relative Closeness

Consequently, to calculate the distances from the alternatives to A+ and A-, the n-dimensional Euclidean distance is applied. Si^{+} calculates the distance for every alternative to A+ and Si^- calculates the distance for each alternative from the most non-ideal solution.

$$Si^+ = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_i^+)^2}$$

$$Si^- = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_i^-)^2}$$

The Relative Closeness C_j, of each alternative compared to the ideal situation can be calculated using the following equation:

$$C_j = \left(\frac{S_i^-}{S_i^+ + S_i^-}\right)$$

with $1 \geq C_j \geq 0$, where Cj = 1, if $A_i = A^+$ and Cj = 0, if $A_i = A^-$

Step 5 – Solution Ranking

The final step is to determine the best solution by ranking Cj in a preference order. The best alternative should be the alternative which has the shortest distance from A+ and the longest distance from the non-ideal solution. According to step 4, this should be the alternative which has the highest Cj value.

F. Analytic Hierarchy Process

The Analytic Hierarchy Process, AHP method (Triantaphyllou, 2000) is developed by Saaty almost 40 years ago (1980). This method is mostly applied in problems with conflicting criteria and in the energy planning sector (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). There even is a case where an AHP based method is developed which can cope with problems where uncertain data is available (Cobuloglu & Büyüktahtakın, 2015). The AHP method used a hierarchy structure and pairwise comparison to decide upon complex decision-making problems.

The following 4 steps are necessary when executing the AHP method (Bian, Hu, & Deng, 2017), (Saaty, 1994):

Step 1 – Hierarchical structure

The first step consists of constructing the decision problem into a hierarchical structure. At the top of the structure, the goal of the decision problem is located. Furthermore, the criteria and sub-criteria, which affect the decision, are placed on the lower levels. Finally, the alternatives are positioned at the bottom level of the structure.

Step 2 – Criteria Weights

The second step is to determine the weights of the criteria into a vector. This can be done by conducting a pairwise comparison using a matrix, for example matrix A. Every aspect in the matrix, a_{ij}, can be defined as the level of importance of the criterion i compared to criterion j, taking into account the alternative. This results in vector

$$W_i = (w_1, w_2, \dots, w_n)^T$$

representing the weights of the criteria. Furthermore, to check the consistency of the pairwise comparisons, the following two equations are used:

$$\boldsymbol{\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{i^{th}\ entry\ in\ AW^T}{i^{th}\ entry\ in\ W^T}}$$

where $\boldsymbol{\lambda_{max}}$ represents the largest Eigenvalue of the Matrix A.

Step 3 – Performance Alternatives for criteria

This step calculates for each criterion, the score of the alternative. After the score of each criterion is calculated the overall score can be determined in the last step.

Step 4 – Alternative Ranking

The final step calculates the score of the alternatives, Ai.

The following equation is used:

$$\boldsymbol{A_i = \sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{k} a_{ij}} * w_j}$$

A_i represents the score of alternative i
k is the number of alternatives
n is the number of criteria
wj is the weight of criterion j
aij is the value of criterion i compared to criterion j

G. PROMOTHEE

The Preference Ranking Organization Method for Enrichment Evaluation method is created by Brans in 1985 (Brans & Vincke, 1985), (Brans, Vincke, & Marescha, 1986) and is widely used for problems in the energy sector (Kolios, Mytilinou, Lozano-Minguez, & Salonitis, 2016). By using pairwise comparison, the method provides an overall ranking of the alternatives based on positive and negative outranking flows. PROMETHEE is an easy to use method, especially compared to other MCDM methods (Tuzkaya, Gulsun, Kahraman, & Ozgen, 2010). One of the advantages of PROMETHEE is that it can deal with qualitative and quantitative factors simultaneously (Serrai, Abdelli, Mokdad, & Hammal, 2017).

Two main categories of information PROMETHEE needs are:

3. Weights of the criteria
4. Preference of the decision-makers if applicable

This means that a specific method to determine the weights is not provided, which can be seen as a disadvantage. When dealing with a higher number of criteria (eight or higher), this can make things quite difficult for the decision-maker (Serrai, Abdelli, Mokdad, & Hammal, 2017).

Figure 28 shows the steps of the PROMETHEE method and below the figure a description is given of the method and its 5 steps (Cao, Liu, Liu, & Li, 2006), (Brans, Vincke, & Marescha, 1986), (Tuzkaya, Gulsun, Kahraman, & Ozgen, 2010), (Vulević & Dragović, 2017) and (Geldermann & Rentz, 2001).

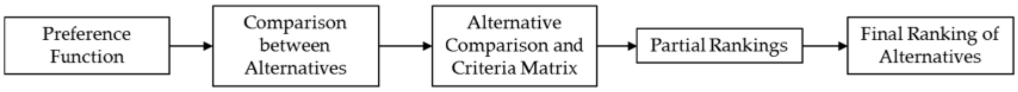


FIGURE 28. PROMETHEES METHOD

Step 1- Preference function

The first step is to determine the preference function for each criterion and its weight. Each criterion will be assigned a certain weight to show the importance. If the decision-maker assumes that all criteria are equally important, then all criteria get the same weight, meaning they do not need to be normalized.

Step 2 – Comparison between Alternatives

In this step, the global preference index is calculated to determine the amount preference of alternative Ai over Ak. This global preference index is calculated using the following equation:

$$\boldsymbol{P_j(a,b) = F_j[d_j(a,b)]}$$

where Pj represents the preference of a over b
Fj is a function of the observed deviations between a and b.
Step 3 – Alternative Comparison and Criteria Matrix

To calculate the amount of preference between a and b the following equation is used:

$$\pi(a,b) = \sum_{j=1}^{n} P_j(a,b)w_j$$

where Pj(a,b) represents the preference function
wj represents the weight of the criteria j
Step 4 – Partial Rankings

In this step, the outranking flows are calculated. The positive outranking flow can be calculated using the following equation:

$$\phi^+(a) = \frac{1}{n-1}\sum_{x\in A} \pi(a,x)$$

To calculated the negative outranking flow (incoming flow), the following equation is used:

$$\phi^{-}(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x, a)$$

Step 5 – Final Rankings of Alternatives

After the outranking flows are calculated, the final step determines the net outranking flow:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a)$$

The higher the positive outranking flow $\phi^{+}(a)$ and lower the negative outranking flow $\phi^{-}(a)$, means a more positive alternative. For the net outranking flow $\phi(a)$, this means a higher flow results in a better alternative.

H. ELECTRE

The Elimination and Choice Translating Reality method was first introduced around 1966 by Bernard Roy can also be characterized as a pairwise comparison method (Benayoun, Roy, & Sussman, 1966). ELECTRE is executed by comparing two alternatives on each criterion. This makes ELECTRE not always able to classify the most interesting alternative, which can be a great disadvantage depending on the goal of the problem (Triantaphyllou, 2000). However, when a situation occurs with few criteria and a huge amount of alternatives (Lootsma, 1990), ELECTRE may be a great choice to use to compare the different solutions. This method can also deal with both qualitative and quantitative factors simultaneously. However, because ELECTRE can be characterized as a complex decision making method, a great amount of data is required to perform a worthy analysis.

This method can be applied in many various fields to determine which alternatives are preferred considering a set of criteria (Vahdani, Haji, Jabbari, Roshanaei, & Zandieh, 2010).

For conducting an ELECTRE analysis, two indices are taken into account: the concordance and disconcordance index (Roy, 1991). When comparing alternative Aj with alternative Ak, the concordance index shows the when the criteria of one alternative dominates the other one ($a_{ji} > a_{ki}$). The disconcordance index, shows exactly the opposite, when criteria of Ak dominates alternative Aj ($a_{ji} < a_{ki}$). The concordance index can be calculated using the following equation (Peypoch & Botti, 2013):

$$C(hsk) = \frac{\sum_{j \in l'} w_j}{\sum_{j \in l} w_j}$$

where l represents all the criteria and l' represents the concordance criteria.

The disconcordance index can be measured according to the following equation:

$$D(hsk) = \max_{\{j\,:\; r_{hj} < r_{hk}\}} \{r_{kj} - r_{hj}\} / d_{max}$$

with r_{hj} represents the performance of alternative i with criterion j
d_{max} represents the maximum difference in performance of the alternatives.

Summarizing these methods, there advantages, disadvantages and there characteristics, the following table, table 53, can be constructed:

TABLE 53. MCDM EVALUATION TABLE

MCDM	Stakeholders	Transparency	Year	Data needed	Quality (weights)	Combine with other methods
1. BWM	--	+/-	2014	++	++	++
2. WSM	--	++	1967	++	--	++
3. WPM	--	++	1969	++	--	++
4. MAMCA	++	+/-	2005	--	--	+
5. TOPSIS	--	-	1981	+/-	--	--
6. AHP	--	+/-	1980	+/-	+	+/-
7. PROMETHEE	--	--	1985	+/-	+	-
8. ELECTRE	--	--	1966	+/-	+	+

Passengers

1. Please specify your gender

0 Male
0 Female

2. Please specify your Age

0 12-18
0 19-26
0 27-55
0 55-65
0 65+

3. Please specify your Nationality

……………………………

What is your highest or current level of degree?

0 High School (MAVO/HAVO/VWO)
0 MBO
0 HBO
0 WO
0 PhD
0 Other; ………….

Do you have any correspondence with public transport sector?

0 Yes, I currently work with/in the public transport sector
0 Yes, I have worked in/for the public transport sector
0 Yes, I am currently studying/doing a research regarding public transport
0 No, I only make use of the public transport system
0 No....
0 Other ……………………….

1/2

I. Choose Best (most preferred) criterion
II. Choose Worst (least preferred) criterion
III. Compare Best to other criteria
Use a scale between 1-9
IV. Compare other criteria to Worst,
Use a scale between 1-9

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9

Equally important < -----------------------> 9x important

	Best criterion	: ………………………….
1.	Frequency	
2.	Punctuality	
3.	Safety	
4.	Travel time	
5.	Accessibility PT system	
6.	Travel information	
7.	Image	
8.	Travel comfort	
9.	Ticket price	

	Worst criterion	: ………………………….
1.	Frequency	
2.	Punctuality	
3.	Safety	
4.	Travel time	
5.	Accessibility PT system	
6.	Travel information	
7.	Image	
8.	Travel comfort	
9.	Ticket price	

2/2

Government

I. Choose Best (most preferred) criterion
II. Choose Worst (least preferred) criterion
III. Compare Best to other criteria
Use a scale between 1-9
IV. Compare other criteria to Worst,
Use a scale between 1-9

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9

Equally important < -----------------------> 9x important

	Best criterion :	
1.	Operational costs	
2.	Investments costs	
3.	Maintenance costs	
4.	Liveability Inhabitants	
5.	Passenger forecast	
6.	Punctuality	
7.	Passenger Safety	
8.	Flexibility	
9.	System Capacity	

	Worst criterion :	
1.	Operational costs	
2.	Investments costs	
3.	Maintenance costs	
4.	Liveability Inhabitants	
5.	Passenger forecast	
6.	Punctuality	
7.	Passenger Safety	
8.	Flexibility	
9.	System Capacity	

Public Transport Operators

I. Choose Best (most preferred) criterion
II. Choose Worst (least preferred) criterion
III. Compare Best to other criteria
Use a scale between 1-9
IV. Compare other criteria to Worst,
Use a scale between 1-9

1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9

Equally important < ------------------------> 9x important

	Best criterion :	
1.	Passenger forecast	
2.	Subsidy	
3.	Political consideration	
4.	Ticket price	
5.	System capacity	
6.	Frequency	
7.	Operational speed	
8.	TCO	
9.	Passenger safety	

	Worst criterion :	
1.	Passenger forecast	
2.	Subsidy	
3.	Political consideration	
4.	Ticket price	
5.	System capacity	
6.	Frequency	
7.	Operational speed	
8.	TCO	
9.	Passenger safety	

Public Transport Operators

APPENDIX IV. DETAILED BWM RESULTS

This appendix presents the results of the Best-Worst method. The tables below show the weights calculated for each stakeholder and their average weight. These weights represent the perception of the stakeholders.

Ksi is the consistency index, the closer to 0 the more consistent the weights. Consistency index indicates and verifies the reliability of the weights (Rezaei, 2014)

TABLE 54. RESULTS BWM PUBLIC TRANSPORT OPERATORS WEIGHTS

Weights Public transport Operators						
Respondent No.	1	2	3	4	5	Average
Passenger forecast	0.208333333	0.15018315	0.181818182	0.275394133	0.25	0.21314576
Subsidy	0.166666667	0.15018315	0.054545455	0.067052485	0.166666667	0.121022885
Politics	---	---	---	---	---	---
Ticket price	0.125	0.014652015	0.036363636	0.02694073	0.018518519	0.04429498
System capacity	0.125	0.15018315	0.109090909	0.047894632	0.166666667	0.119767072
Frequency	0.083333333	0.15018315	0.218181818	0.083815606	0.111111111	0.129325004
Travel time	0.041666667	0.084249084	0.218181818	0.111754141	0.083333333	0.107837009
Total cost of ownerhsip	0.125	0.15018315	0.072727273	0.275394133	0.166666667	0.157994244
Passenger safety	0.125	0.15018315	0.109090909	0.111754141	0.037037037	0.106613047
Sum	1.00	1.00	1.00	1.00	1.00	---
Ksi	0.041666667	0.018315018	0.036363636	0.05986829	0.083333333	---

TABLE 55A. RESULTS BWM PASSENGERS WEIGHTS

Weight Passengers						
Respondent No.	1	2	3	4	5	6
Frequency	0,268843015	0,103092784	0,141221374	0,184194369	0,095238095	0,236065574
Punctuality	0,168026884	0,103092784	0,141221374	0,073677748	0,028571429	0,137704918
Passenger Safety	0,067210754	0,06185567	0,08778626	0,283659328	0,19047619	0,091803279
Travel time	0,112017923	0,257731959	0,141221374	0,092097184	0,152380952	0,091803279
Accessibility of PT system	0,035845735	0,077319588	0,08778626	0,046048592	0,123809524	0,068852459
Travel information	0,048007681	0,154639175	0,08778626	0,122796246	0,095238095	0,068852459
Image	0,048007681	0,025773196	0,015267176	0,022103324	0,095238095	0,032786885
Travel comfort	0,084013442	0,154639175	0,141221374	0,052626963	0,095238095	0,068852459
Ticket price	0,168026884	0,06185567	0,15648855	0,122796246	0,123809524	0,203278689
Sum	1,00	1,00	1,00	1,00	1,00	1,00
Ksi	0,067210754	0,051546392	0,034351145	0,08472941	0,066666667	0,039344262

TABLE 24B. RESULTS BWM PASSENGERS WEIGHTS

Respondent No.	7	8	9	10	11
Frequency	0,266159696	0,15625	0,155015198	0,102243681	0,178453345

Punctuality	0,159695817	0,15625	0,103343465	0,061346208	0,119064935
Passenger Safety	0,106463878	0,078125	0,077507599	0,03834138	0,116098662
Travel time	0,106463878	0,260416667	0,155015198	0,224936098	0,152127602
Accessibility of PT system	0,030418251	0,026041667	0,077507599	0,224936098	0,06373663
Travel information	0,045627376	0,104166667	0,103343465	0,102243681	0,092273047
Image	0,045627376	0,0625	0,027355623	0,015904573	0,041628817
Travel comfort	0,079847909	0,052083333	0,077507599	0,076682761	0,089558928
Ticket price	0,159695817	0,104166667	0,223404255	0,153365521	0,147058034
Sum	1,00	1,00	1,00	1,00	1,00
Ksi	0,053231939	0,052083333	0,08662614	0,081794945	0,050632911

TABLE 24C. RESULTS BWM PASSENGERS WEIGHTS

Respondent No.	12	13	14	15	Average
Frequency	0,237918216	0,233314816	0,089320388	0,331785739	0,183504112
Punctuality	0,037174721	0,149988096	0,133980583	0,133878456	0,112614554
Passenger Safety	0,096654275	0,099992064	0,133980583	0,044626152	0,103983216
Travel time	0,144981413	0,26109039	0,221359223	0,200817684	0,178366519
Accessibility of PT system	0,096654275	0,042853742	0,089320388	0,044626152	0,073999667
Travel information	0,096654275	0,074994048	0,089320388	0,100408842	0,093022965
Image	0,096654275	0,049996032	0,089320388	0,057376481	0,047281837
Travel comfort	0,096654275	0,059995238	0,133980583	0,057376481	0,08711127
Ticket price	0,096654275	0,027775573	0,019417476	0,029104012	0,12011586
Sum	1,00	1,00	1,00	1,00	---
Ksi	0,05204461	0,038885803	0,046601942	0,069849629	---

TABLE 56. RESULTS BWM GOVERNMENT WEIGHTS

Weights Government						
Respondent No.	1	2	3	4	5	Average
Operational costs	0,101626016	0,247058824	0,185157972	0,114441417	0,062434358	0,142143717
Investment costs	0,076219512	0,247058824	0,290962528	0,114441417	0,04459597	0,15465565
Maintenance costs	0,101626016	0,077840451	0,185157972	0,114441417	0,104057264	0,116624624
Liveability Inhabitants	0,018292683	0,077840451	0,023512123	0,058855586	0,235259901	0,082752149
Passenger Forecast	0,234756098	0,077840451	0,061719324	0,202724796	0,156085896	0,146625313
Punctuality	0,152439024	0,020306205	0,046289493	0,057220708	0,039021474	0,063055381
Passenger Safety	0,06097561	0,103787268	0,092578986	0,032697548	0,022621144	0,062532111
Flexibility	0,101626016	0,044480258	0,052902278	0,076294278	0,257881045	0,106636775
System Capacity	0,152439024	0,103787268	0,061719324	0,228882834	0,078042948	0,12497428
Sum	1,00	1,00	1,00	1,00	1,00	---
Ksi	0,070121951	0,064302981	0,079353417	0,026158038	0,054290746	---

As can be seen from the tables above, all the consistency ratios show a consistency below 0.08.

Combining the information in the above mentioned tables, the weights of each criteria coherent with their stakeholder are shown in table 57 below.

TABLE 57. WEIGHTS STAKEHOLDERS AND CRITERIA

Passengers	**Wp**	**Government**	**Wg**	**Operators**	**Wo**
Frequency	0.18	Operational costs	0.14	Frequency	0.13
Punctuality	0.11	Punctuality	0.06	Subsidy	0.12
Passenger Safety	0.10	Passenger safety	0.06	Passenger safety	0.11
Operational speed	0.18	Liveability inhabitants	0.08	Operational speed	0.11
Accessibility PT system	0.07	System Capacity	0.13	System Capacity	0.12
Travel information	0.09	Passenger Forecast	0.15	Passenger forecast	0.21
Image	0.05	Maintenance costs	0.12	~~Political consideration~~	---
Travel comfort	0.09	Flexibility	0.11	TCO	0.16
Ticket price	0.12	Investment costs	0.16	Ticket price	0.04
Sum	1.00		1.00		1.00

TABLE 58. DIVERSITY PASSENGERS GROUP

Gender	Male	73%	11	Degree	High School	0%	0
	Female	27%	4		MBO	0%	0
					HBO	13%	2
Age	12--18	0%	0		WO	87%	13
	19--26	27%	4		PhD	0%	0
	27--55	60%	9				
	56--65	13%	2	Correspondence with PT sector	Currently work in PT Sector	50%	7
	65+	0%	0		Have worked in PT	0%	0
					Study/research in PT	21%	3
Nationality	Dutch	80%	12		No, I only use PT	21%	3
	Indonesian	13%	2		No	7%	1
	Greek	7%	1		Other	0%	0

APPENDIX V. FINDINGS KLANTENBAROMETER

Each year, CROW-KpVV presents the results of the OV-Klantenbarometer, (Public Transport Customer barometer) (CROW-KpVV, 2016). This is a survey where passengers are able to give their opinion and rate certain aspects regarding their travel experience. Aspects such as travel time, travel comfort, safety and travel information are tested, shown in Table 59. The following aspects were taken into account in the survey of 2016:

TABLE 59. CRITERIA OV-BAROMETER

Criteria OV-Barometer	English translation
Geluid	Noise
Stiptheid	Punctuality
Info halte	Information PT stop
Algemeen sociale veiligheid	General passenger safety
Zitplaats	Seating availability
Klantvriendelijkheid	Customer service
Snelheid	Speed (travel time)
Info vertraging	Information delays
Rit- sociale veiligheid	Trip safety
Netheid	Cleanliness
Rijstijl	Driving style
frequentie	Frequency
Aankoop kaartje	Purchasing of ticket
In-en uitstappen	Accessibility PT System
prijs	Ticket price
halte- sociale veiligheid	PT Stop safety
Totaal	Total (Average)
Enquetes	Amount of surveys

Table 60 shows the criteria that were tested in the Netherlands in 2016 together with their ratings. The total number of surveys conducted for bus, tram and metro around the metropolitan area, are respectively 42,559, 6907 and 7530, which should be a sufficient amount to get a realistic image of the passengers perspective. The surveys were held throughout the Netherlands by asking the passengers how they experience certain aspects (Table 11) in public transport.

Figure 29. Example OV-klatenbarometer shows how the results are presented on the website of KpVV.

FIGURE 29. EXAMPLE OV-KLATENBAROMETER

As can be seen colours indicate the degree of positiveness.

TABLE 60. PASSENGERS RATING PER MODE (CROW-KPVV, 2016)

2016 - Criterion	Bus	Tram	Metro
Geluid	6.6	6.3	6.6
Stiptheid	7.2	7.2	7.5
Info halte	7.7	7.4	7.9
Algemeen sociale veiligheid	7.9	7.6	7.4
Zitplaats	8.5	8.2	7.7
Klantvriendelijkheid	7.8	7.4	7.1
Snelheid	7.6	7.5	7.8
Info vertraging	5.8	5.4	6.2
Rit- sociale veiligheid	8.1	7.9	7.7
Netheid	7.3	7.1	6.7
Rijstijl	7.4	7.2	7.2
Frequentie	7.2	7.3	7.5
Aankoop kaartje	7.9	7.6	7.6
In-en uitstappen	8.6	8.3	8.8
Prijs	5.6	5.1	5.1
Halte- sociale veiligheid	8.0	7.7	7.5
Totaal	7.6	7.5	7.5
Enquetes	42,559	6,907	7,530

It should be noted that the OV-klantenbarometer asks questions in such a way that they measure the concessions provided by the public transport operators. Before using this information, the following two assumptions are made: 1. The public transport operators are doing their best to provide an optimal concession and 2. By taking into account data from all of the Netherlands, more than 70 regions and around 82,000 surveys (Kennisplatform Crow, 2017), the conclusion can be drawn that the data can be characterized as reliable. Taking into account a maximum of a handful of regions where passengers are not satisfied with the public transport, does not influence the data in such a way that it is not reliable anymore. Therefore, the data gives a clear and realistic perception of how passengers experience public transport in the Netherlands.

Looking at the criteria selected for the passengers for the perception analysis (section 3.3), immediately can be seen that almost all factors from the survey are coherent with the criteria:

TABLE 61. CRITERIA PASSENGERS AND OV-BAROMETER

Passengers	**Criteria OV-Barometer**
Criterion	Can be calculated/represented by
Frequency	Frequency
Punctuality	Punctuality
Passenger Safety	General safety + Trip safety + PT stop safety
Travel time	Speed
Accessibility of PT system	Accessibility PT system
Travel information	Information delays + information PT stop
Image	Total
Travel comfort	Noise + Seating availability + Cleanliness + driving style
Ticket price	Ticket price

This gives a clear, representable image regarding the perception of passengers and their public transport experience.

Combining the previous tables leads to Table 62, below.

TABLE 62. PASSENGERS PERCEPTION

Passengers	Bus	Tram	Metro
Criterion	Factor	Factor	Factor
Frequency	7.2	7.3	7.5
Punctuality	7.2	7.2	7.5
Passenger Safety	8.0	7.7	7.5
Travel time	7.6	7.5	7.8
Accessibility of PT system	8.6	8.3	8.8
Travel information	6.8	6.4	7.1
Image	7.6	7.5	7.5
Travel comfort	7.5	7.2	7.1
Ticket price	5.6	5.1	5.1

Because Light rail can be seen as a hybrid between tram and metro, the average of these systems is used for the LRT factors. eBus same as bus except for image and Travel comfort (noise). BRT hybrid between tram and bus.

Passengers	BRT	LRT	eBus
Criterion	Factor	Factor	Factor
Frequency	7.25	7.40	7.2
Punctuality	7.2	7.35	7.2
Passenger Safety	7.85	7.6	8.0
Travel time	7.55	7.65	7.6
Accessibility of PT system	8.45	8.55	8.6
Travel information	6.60	6.75	6.8
Image	7.55	7.55	7.8
Travel comfort	7.35	7.15	7.9
Ticket price	5.35	5.10	5.6

According to the Head of Strategy of Conexxion, to calculate the Image and Travel Comfort:

eBus Image = 2,5% higher compared to bus (sustainable and new)

eBus travel comfort = 5% better compared to bus due to no noise and more comfortable acceleration.

Information for case studies:

TABLE 63. INFORMATION FOR CASE A: TRAM LINE 12

Passengers	'Stadsvervoer Den Haag'	
Criterion	Bus	Tram
Frequency	---	---
Punctuality	---	---
Passenger Safety	7.8	7.5
Operational speed	---	---
Accessibility of PT system	8.5	8.1
Travel information	6.7	6.8
Image	7.4	7.2
Travel comfort	7.5	7.4
Ticket price	5.5	4.9
Surveys	735	1745

TABLE 64. INFORMATION FOR CASE B: BUS LINE 44

Passengers	'Rotterdam en omgeving'	
Criterion	Bus	Tram
Frequency	---	---
Punctuality	---	---
Passenger Safety	7.7	7.8
Operational speed	---	---
Accessibility of PT system	8.3	8.7
Travel information	7.0	7.3
Image	7.4	7.6

Travel comfort	7.4	7.6
Ticket price	5.7	5.7
Surveys	621	2160

APPENDIX VI. INTERVIEWS

Table 65 shows the interviewed employees.

TABLE 65. INTERVIEWED EMPLOYEES

Government(al agencies)	Public transport Operators
Strategic Advisor Assets	1. RET- Manager Asset department
Asset Manager	2. RET - Head of Strategy
Strategic Advisor Public Transport	3. HTM – Concession Manager Assets
Senior Policy Developer	4. Conexxion Head of Strategy
Senior Concession Manager	5. Product Manager Market exploration en Transport development

SECTION A. INTERVIEW TEMPLATE CRITERIA SELECTION

Questions asked to the Operators and Government:

1. Describe short your role for/at [the company]
2. Presented before you is a list of costs and benefits that represent all criteria which enables comparison of public transport systems. What is your opinion of this list? Are there criteria missing or unclear? Do you have something to add?
3. From these, criteria, the following 9 were selected as most important? Do you agree with this? (If no, why not?). Do you have anything to add?
4. Any last comments…?

Interviewers Public Transport Operators

1. RET Manager of Asset Management department – Hakan Zor

Manager of several Asset Managers for Rolling Stock, Reliability Engineers, System Engineers, Projectleaders(Capital), Asset Configuration controllers and QA/QC

Tram = € 2,000,000 – € 2,500,000

Metro price = € 5,000,000

Forecast high of importance

2. RET Head of Strategy – Youp Hamburger

Heading RET's department responsible for strategy, businessplan, concessions, innovation and legal ('regie & ontwikkeling'). Member of RET's executive board ('directieteam')

Forecast high of importance

3. HTM Concession Manager Assets– Hans van Rooden

Beheer en onderhoud van infrastructuur, voertuigen (lightrail, tram en bus) en facilitaire voorzieningen, gericht op optimale beschikbaarheid voor het openbaar vervoer in Haaglanden.

4. Conexxion Head of Strategy – Peter Krumm

Image eBus

Travel comfort eBus; no noise eBus and smoother acceleration;

From these facts, if I had to make an estimate, eBus 10% more travel comfort and therefore better 2.5% better image, = guess/estimation of Peter Krumm…

5. HTM Hans van der Stok - Product Manager Market exploration en Transport development

Takes into account travellers interest, thinks about long-term developments and how to effectively make use of busses and trams and the design, construction and implementation of Park+Ride facilities.

Inzetnorm voor voertuigen = seats + 50% standing places

The most important criteria, 9 for the Operators are:

1. Passenger forecast
2. Earnings
3. Political considerations
4. Ticket price
5. System capacity
6. Frequency
7. Operational Speed
8. Total Cost of Ownership
9. Passenger Safety

Interviewers Government

1. Senior Policy Advisor Lodewijk Lacroix→ legt verantwoording af aan de bestuurscommissie die 10x per jaar vergaderd.

2. Senior concession manager – Peter Dubbeling

Bus vehicle = € 300,000

Tram vehicle = € 3,000,000

Bus concession = € 27,000,000/ year

3. Asset Manager – Vesna Stevovic

4. Strategic Advisor Assets - Pim Uijtdewilligen

Infrastructure costs Tram = 15 mln/km

Infrastructure metro = 1,000 mln/ km underground and 50 mln/km above

Infrastructure LRT = about the same metro = 50 mln/km

Tram aanschaf = 3,5 - 4,0 mln

The government mainly operates stuurt on investment costs and the public transport operators highly on operational costs…

5. Strategic Advisor Public Transport – Maarten Strooper

Why light rail differs from tram and metro:

Light rail differs from metro (and tram) due to the difference in characteristics, which are described below. One of the great benefits of LRT is the sharing of infrastructure with other modes (van Oort & van der Bijl, 2014). These arguments are derived from literature, personal communication by means of interviews and discussions with the public transport operators and experts from the rail infrastructure department at MRDH.

- A metro operates most of the time, if not always, underground while a LRT system operates above ground.
- Operating underground means that for a metro system different safety measures, protocols and systems are needed.
- A light rail makes use of an overhead line to receive its energy, while a metro uses a third-rail line (Swanson, 2004).
- LRT encounters other traffic users, while a metro is much less dependable on other traffic.
- The light rail system uses signals to operate, where a tram 'only' uses sight.
- The quality of LRT seems higher compared to a tram. This can be achieved due to the increase in frequencies, upgraded stops and the newer vehicles which lead to higher comfort (van Oort, Bukman, & van der Bijl, 2015).
- Light rail typically is characterized by more stops (2-3 stops) compared to the amount of stops a metro would have (1 stop) in the same (hypothetical) situation (van Oort & van der Bijl, 2014).

The most important criteria when deciding upon public transport systems for the government are:

1. System capacity
2. Operational costs
3. Investment costs
4. Maintenance costs
5. Liveability inhabitants
6. Flexibility

7. Passenger Safety
8. Punctuality
9. Passenger forecast

SECTION B. INTERVIEW WITH POLICY DECISION-MAKERS

- How does the current Decision-making process look like?

Currently, there is not a standard decision-making process. However we plan to work towards the following process (Figure 27):

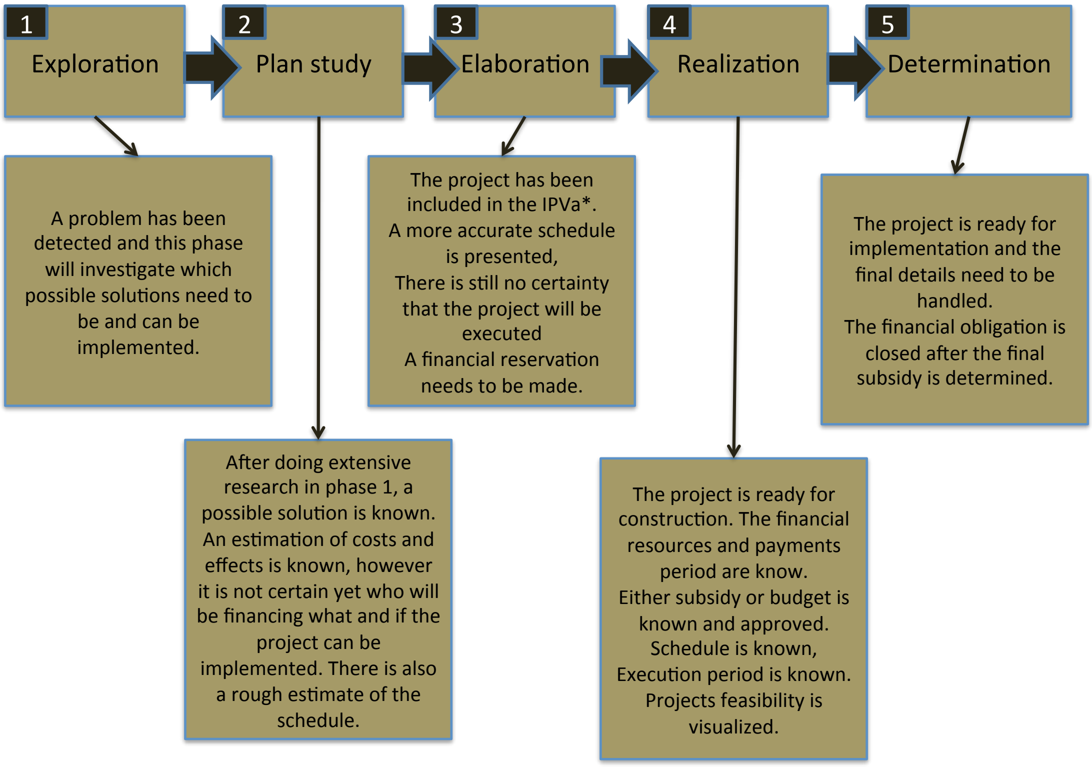


FIGURE 30. DECISION-MAKING PROCESS OF PUBLIC TRANSPORT INVESTMENTS

- Where in the process can this information be used?

The information regarding the perceptions of the stakeholders can be used in the exploration phase. In this phase a problem is identified and possible solutions are presented that could cope with this problem. In the second phase, the plan study, a possible solution is already known. This indicates that the information regarding the perceptions of the various groups can be used in the first phase of the process.

Interesting observation that the perceptions of the passengers are close together. Furthermore, the perception of tram scores lower compared to the perception of a bus in the passengers group. Even after implementation of the system, this information can be used to change the perception of passengers. The method calculates the perception of the passengers and therefore, information is known which criteria exactly determine and contribute to this perception. If these criteria are known, the governmental authorities (together with the operators) can take measures to change the values of the criteria in order to change the perception of the passengers. Therefore, the information regarding the perception of the passengers is of high importance.

- How important is the perception of passengers in the decision-making process?

The passengers are eventually the users of the passengers. The perception of the passengers therefore is of high importance. However, in the decision-making process the passengers do not have any influence. This is because of the following three reasons:

1. Passengers do not have any financial resources
2. Passengers do not have any (administrative) powers
3. Passengers do not experience the downsides of a bad public transport decision. Assume that a new residential area is going to be constructed and a choice needs to be made between a bus and tram. Despite making the 'wrong' choice, seen from a governments or operators perspective, the passengers are still provided with and able to use a transport system.

- Is this information useful in the DM process and why (not)?

The perceptions of the passengers sure can be useful in the decision-making process. Keep in mind that a tool like this, just as a CBA will not be used as a decisive tool but to improve the overall decision-making process. The decision-making process should be as transparent as possible and by using tools like this, the process becomes more transparent.

- Will this information lead to other decisions…?

This information makes the decision-making process more transparent. By providing more insight in the criteria that influences the perception of the different groups, extra information will be available where the final decision will be based on. Also, the goal of the system is to satisfy the users. This does not mean that their transport system of preference will be chosen for implementation, it only means that we need to work on increasing the level of satisfaction. Now that we have information regarding the perception of the passengers and which criteria changes their perception, we can investigate if and how these criteria can be changed to improve the perception.

APPENDIX VII. CRITERIA INFORMATION

The following appendix will present all the criteria values and information. The following sections will be discussed:

Section A. System capacity
Section B. Investments, Maintenance and Operational costs
Section C. Operational Speed
Section D. Ticket price
Section E. Punctuality
Section F. Frequencies
Section G. Passenger forecast
Section H. Subsidy
Section I. Total Cost of Ownership
Section J. Livability Inhabitants
Section K. Flexibility of the system
Section L. Earnings
Section M. Passenger Safety (costs)

SECTION A. SYSTEM CAPACITY

TABLE 66. CHARACTERISTICS BUS (RET-BUS, 2017)

RET- BUS	City A78	Alliance B96	Citaro O530	Citaro G	eBusz
Seats	43	44	34	45	33
Standing places	45	37	67	81	27
Total	88	81	101	136	60
Length (m)	11,86	12	11,95	18	12

For the calculation of the average system capacity of a conventional bus, only the first three types are taken into account. Concluding from the table, the average maximum capacity of the bus is 90 passengers, for an eBus this is 60.

TABLE 67. CHARACTERISTICS TRAM (RET-TRAM, 2017)

RET- Tram	Citadis 1	Citadis II
Seats	59	56
Standing places	118	124
Total	177	180
Lengte (m)	31,30	30,85

TABLE 68. CHARACTERISTICS LR & TRAM HTM (HAAGSETRAMS, N.D.)

HTM Tram	GTL8-I	GTL8-II	Avenio
Seats	71	76	69
Standing places	118	112	168
Total	189	188	237
Length (m)	28.6	29	35

Concluding from the table, the average maximum capacity of the trams is 182 passengers.

TABLE 69. CHARACTERISTICS RR HTM

HTM RandstadRail	RegioCitadis I	RegioCitadis II
Seats	86	86
Standing places	130	130
Total	216	216
Length (m)	36.8	36.8

The average capacity of a LRT system = 216.

TABLE 70. CHARACTERISTICS METRO (RET-METRO, 2017)

RET- Metro	MG2/1	SG2/1	RSG3	SG3	HSG3
Seats	72	64	104	104	104
Standing places	153	153	166	166	166
Total	225	217	270	270	270
Length (m)	30,5	30,5	42,71	42,71	42,71

Concluding from the table, the average maximum capacity of a metro is 250 passengers.

TABLE 71. BRT SYSTEM CAPACITY CHARACTERISTICS.

BRT	Capacity	Source
	120-200	(Calgary Transit Planning, 2002)
	135	(FTA, 2001)
	149	(GVB, n.d.)

The average of the below two capacities gives a BRT capacity of 142 passengers, which is exactly in the range of the first source of table 41. For these reasons, the average system capacity of a BRT that is used is 142 passengers.

TABLE 72. DIFFERENT BUS LENGTH WITH CAPACITY

Bus length	Capacity	Source
12 m	90	(RET-Bus, 2017)
18 m	149	(GVB, n.d.)
21 m	191	(OV Pro-21m Bus, 2016)
24 m	200	(De Gelderlander, 2008)

SECTION B. INVESTMENTS, MAINTENANCE AND OPERATIONAL COSTS

The tables below show the data that is used to calculate the investment, maintenance and operational costs shown below the table.

TABLE 73. CHARACTERISTICS BUS

BUS	
Investment vehicle	$300.000 (Kay, Clark, Duffy, Laube, & Lian)
Investment vehicle	$300.000- $400.00 (Calgary Transit Planning, 2002)
Investment vehicle	$354.000 (Transit Technologies, n.d.)
Investment vehicle	€250k euro (CROW-KpVV factors, 2016)
Operational cost	1,33 euro per km (Rieck, 2014)
Maintenance bus	8000 euro per year (Clean fleets, 2015)
Investment infra 2-way	0.3-4 mln euro per km (CROW-KpVV factors, 2016)
Investment infra 2-way	0.6-3.7 mln euro per km (CVOV, 2005)
Investment bus stop (2 stops)	50k-400k euro (CROW-KpVV factors, 2016)
Making stops accessible	20k-35k euro (CROW-KpVV factors, 2016)
Infra maintenance	1-2% of the infrastructure investment (CROW-KpVV factors, 2016)
Infra maintenance	68k-90k euro per km per year (CVOV, 2005)
Maintenance vehicle	0.25 euro per km (CROW-KpVV factors, 2016)
Energy costs	0.40 euro per km (CROW-KpVV factors, 2016)
Driver (900-1250 DRU)	50k-55k euro a year (CROW-KpVV factors, 2016)
DRU costs	108euro per hour (CROW-KpVV factors, 2016)
DRU costs	77 euro per hour (CVOV, 2005)
Operational costs	30.000 euro per year (CVOV, 2005) + 53.000 euro driver (CROW-KpVV factors, 2016) = 83.000 euro per jaar / 64.000 km per jaar average bus drives (Excel Joost Dieselkm's)= €1.28 per km.
Costs per km	0.50 euro per km (CVOV, 2005)
eBus investment vehicle	$850.000 (Calgary Transit Planning, 2002)
eBus investment vehicle	$799.000 (Priest, 2016)
eBus investment vehicle	785,275.63 euro

	(Rieck, 2014)
eBus investment vehicle	400k euro (Clean fleets, 2015)
eBus investment vehicle	340k euro (Battes, 2015)
Operational eBus	1,19 euro per km (Rieck, 2014) 0.99 euro = 70% bus
Maintenance eBus	2700 euro a year (30% of normal bus) (Clean fleets, 2015)
Ebus investment infra	90k euro station charging point 320k euro charging point at depot (Clean fleets, 2015)
Energy costs	70% of 0.40euro per km (CROW-KpVV factors, 2016)
Maintenance eBus	\$0.20 per mile = \$0.124 per km = €0.11 per km. (Noel & McCormack, 2014)

TABLE 74. CHARACTERISTICS TRAM

TRAM	
Investment vehicle	\$ 3.0 mln. (Calgary Transit Planning, 2002)
Investment vehicle	3.5 mln. euro (MRDH-tram, 2016)
Investment vehicle	2.7 mln. euro (CROW-KpVV factors, 2016)
Investment costs Tramlijn 19 Delft Centraal - TU-wijk	53.521 mln. Euro (MRDH, 2017)
Infra tram investment 2-way	12-35 mln. euro per km (CROW-KpVV factors, 2016)
Infra tram investment 2-way	3.3-28.5 mln euro per km (CVOV, 2005)
PT Stop	400k-600k euro (CROW-KpVV factors, 2016)
Infra regular maintenance	50k-60k euro per km per year 1-way (CROW-KpVV factors, 2016)
Infra regular maintenance	450k-550k euro per km 2-way (CVOV, 2005)
Vervangingsonderhoud	65k-115k euro per km per year 1-way (CROW-KpVV factors, 2016)
Maintenance vehicle	1.20 euro per km (CROW-KpVV factors, 2016) 1.69 euro per km GTL 1.87 euro per km Avenio (Excel OV Monitor average = 1.59 euro per km)
Energy costs	0.30-0.40 euro per km (CROW-KpVV factors, 2016)
Driver	50k-55k euro a year

	(CROW-KpVV factors, 2016)
DRU costs	207 euro per hour (CROW-KpVV factors, 2016)
DRU costs	150-200 euro per hour (CVOV, 2005)
Operational costs	145k-238k per year (CVOV, 2005)
Costs per km	1.50 euro per km (CVOV, 2005)

Investment vehicle costs: €210 mln. For 60 trams = €3.5 mln. per tram (MRDH-tram, 2016)

TABLE 75. PRICE PER TRAM AND LRT (CROW-KPVV FACTORS, 2016)

Modus	City	Amount	Price (€)	Average (€)
Tram	Basel	19	4.1	
Tram	Freiburg	12	2.8	
Tram	Munchen	8	3.6	
Tram	Den Haag	60	2.6	
Tram	Avignon	24	1.9	
Tram	Dallas	2	3.6	
Tram	Bratislava (1)	15	2.5	
Tram	Bratislava (2)	15	2.6	
Tram	Konya	60	1.8	
Tram	Sao Paolo	22	4.1	
Tram	Sydney	6	2.7	
Tram	Waterloo	14	4.8	
Tram	Cincinnati	5	4.1	3.2
Light rail	Calgary	60	2.3	
Light rail	Hannover	50	2.4	
Light rail	Los Angeles	97	2.7	2.5

TABLE 76. CHARACTERISTICS METRO

METRO	
Investment vehicle	5 mln. Euro
Investment Infra	29.7-146.5 mln euro per km (CVOV, 2005)
PT Stop	1.2-10 mln. Euro (CROW-KpVV factors, 2016)
Elektrification 1-way rail	1.2 mln. euro per km (CROW-KpVV factors, 2016)
Maintenance infra regular	130k-200k per km per yr enkelspoor (CROW-KpVV factors, 2016)
Maintenance infra regular	815k euro per year (CVOV, 2005)
Replacement infra maintenance	185k-250k per km per year enkelsp (CROW-KpVV factors, 2016)
Maintenance vehicle	1.05 euro per km (CROW-KpVV factors, 2016)

Energy	0.15euro per km (CROW-KpVV factors, 2016)
Driver	50k-55k euro a year (CROW-KpVV factors, 2016)
DRU costs	450 euro per hour (CROW-KpVV factors, 2016)
Operational costs	130k-640k per year (CVOV, 2005)

Metro Investment costs – purchase: 31 mln. euro for 6 vehicles = 5 mln. euro per vehicle (MRDH-metro, 2016).

TABLE 77. CHARACTERISTICS BRT

BRT	
Investment vehicle	+25% normal bus (CROW-KpVV factors, 2016)
Investment vehicle	Articulated bus = BRT $700.000 (Calgary Transit Planning, 2002)
Investment Infra	$10.2 mln. per km (BRTData infra, 2017) = 8.575.000 euro per km 4.7-12 mln. euro Per km 2-way (CROW-KpVV factors, 2016) 5.4-14.9 mln euro per km (CVOV, 2005)
PT station	(same as bus)
Maintenance vehicle	+20% normal bus (CROW-KpVV factors, 2016)
Energy	0.40euro per km (CROW-KpVV factors, 2016)
Driver	50k-55k euro a year (CROW-KpVV factors, 2016)

TABLE 78. CHARACTERISTICS LRT

LRT	
Investment vehicle	$4.0 mln. (Calgary Transit Planning, 2002)
Investment infra	$21 mln per km (Transit Technologies, n.d.)
Investment infra	24-40 mln 65-75 mln 45-60 mln 30-35 mln 25-30 mln 50-60 mln 95-100 mln 105-120 mln euro per km (CVOV, 2005)
Investment Infra upgrade	1.2-2.4 mln euro per km

	(CVOV, 2005)
Elektrification 1-way rail	1.2 mln euro per km (CROW-KpVV factors, 2016)
Driver	50k-55k a year (CROW-KpVV factors, 2016)
Steward	40k a year (CROW-KpVV factors, 2016)
Operational costs	198.180 euro per year 218.000 euro per year 244.420 euro per year
Maintenance vehicle	€1.84 (OV Monitor Source Excel)

Operational costs = energy/fuel costs + salary employees

Driver salary: €55k per year

Steward salary: €45k per year

TABLE 79. OPERATIONAL COST CALCULATION

Modality	Energy costs	Km per year	Driver	Steward	Total per km
Metro	€ 0.15 per km	51,502	€1.07	---	€1.22
Tram	€ 0.35 per km	55,397	€0.99	€0.81	€2.15
Bus	€ 0.40 per km	64.000	€0.86	---	€1.26
BRT	€ 0.50 per km	64,000	€0.86	---	€1.36
LRT	€ 0.20 per km	78,494	€0.70	---	€0.90
eBus	€ 0.12 per km	64,000	€0.86	---	€0.98

The energy costs of a BRT are 25% higher compared to bus, the energy costs for LRT is calculated by the taking average of Metro and Tram and the energy costs calculation for the eBus is 30% of the regular bus (no diesel as fuel needed).

TABLE 80. ENERGY COST CALCULATION BRT, LRT, EBUS

Energy costs calculation	
BRT	125% of bus
LRT	Average metro + tram
eBus	30% of bus

TABLE 81. CHARACTERISTICS RAIL KM'S

Kms/vehicle	Amount vehicles	Vehicle km's	Km's per vehicle
HTM Tram	168	8,652,341	51,502
HTM LRT	71	5,573,095	78,494
RET Metro	145	8,600,000	59,310
RET Tram	113	6,720,000	59,292
Average Tram			55,397

Comparison of Transit Vehicle Technology

Type	Operating Environment	Power Source	Passenger Capacity	Service Life (years)	Unit Cost (2000 $Cdn)
Standard Bus	Urban roadway	Diesel	60 - 80	15+	$400,000
Trolley Bus	Urban roadway with catenary	Electric	60 - 80	20+	$850,000
Articulated Bus	Urban roadway	Diesel	110 - 120	15+	$700,000
Articulated Trolley Bus	Urban roadway with catenary	Electric	110 – 120	20+	$1.8 million
Double Decker Bus	Urban roadway with 14.3' vertical clearance	Diesel	110 - 120	15+	$600,000
Electric Street Car	Urban roadway with catenary	Electric	100 - 150	25+	$1.8 million
Tram	Urban roadway with overhead or in-ground power	Electric	150 - 200	30+	$3.0 million
Light Rail Vehicle	Separate R.O.W with track & catenary	Electric	180 - 220	30+	$4.0 million

FIGURE 31. CHARACTERISTICS PUBLIC TRANSPORT VEHICLES

Source: (Calgary Transit Planning, 2002)

TABLE 82. MEASURE UNIT GOVERNMENT COSTS

Government	
Criterion	Assumption
Operational costs	In € for 1 vehicle and per km
Investments costs	In € for 1 vehicle and infra per km
Maintenance costs	In € for 1 vehicle and infra per year per km

SECTION C. OPERATIONAL SPEED

The operational speed is calculated as follows:

TRAVEL SPEED RET

Tram 17,6 km.h

Metro 37,1 km.h

(MRDH-RailHTM, 2017)

(MRDH-RailRET, 2017)

	Average commercial speed (km/h)
EU-15	22.76
NMS	15.71
beyond EU-27	21.10
TOTAL	19.86

LRT 25km/h

(UITP, 2012)

(Stadsgewest Haaglanden-RR, 2009)

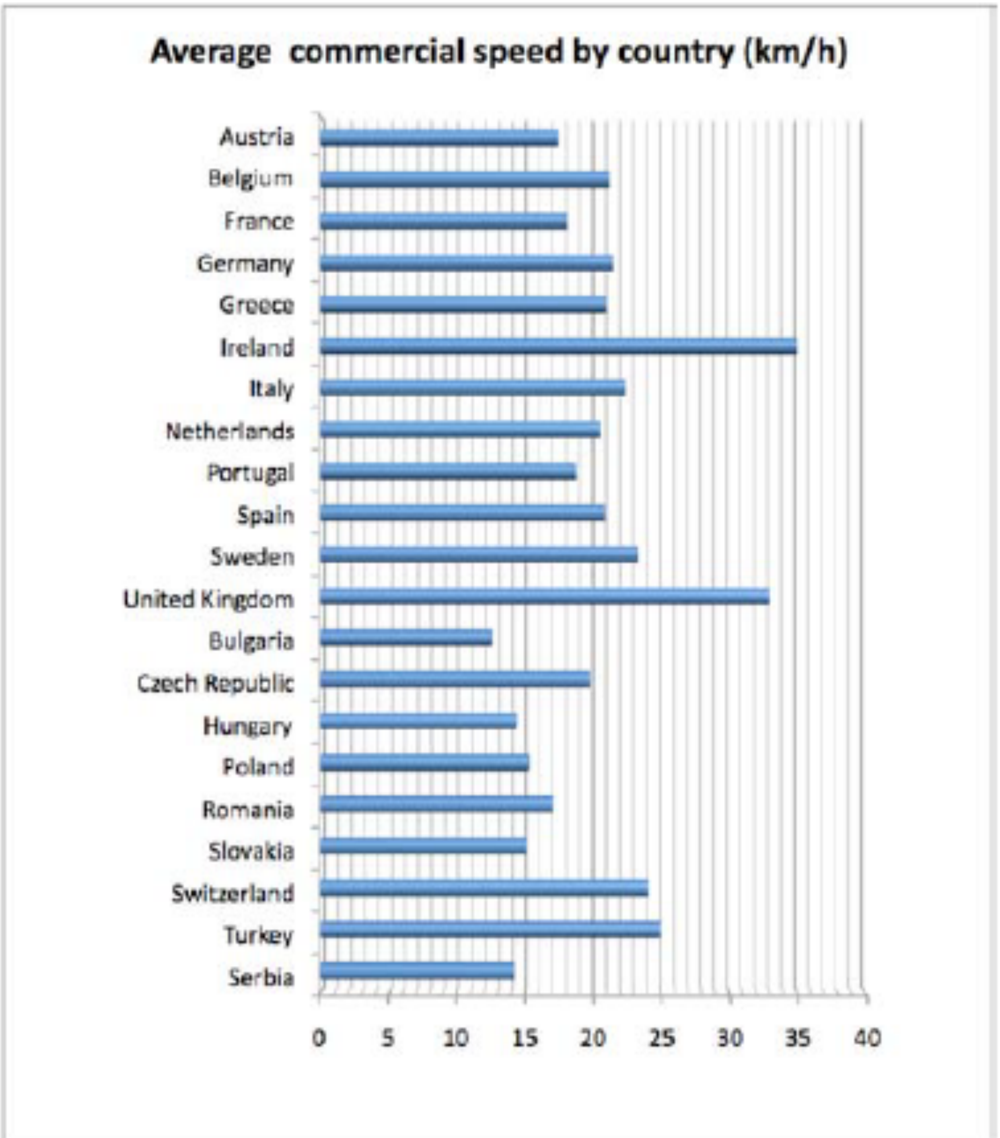


FIGURE 32. AVERAGE SPEED LRT

Source:

1	2	3	4
	snelheid (km/u)	aantal	aantal
lijn 11	**beide richtingen**	n=	bussen per dag
CS-Neude	**10,4**	1176	1870*
Neude-Janskerkhof	**20,1**	1213	>1700
Nobelstraat	**12,9**	1211	>1700
Kruisstraat	**14,7**	1224	>1400
CS-Neude + halte Vredenburg	**9,6**		1870*
lijn 12			
Bleekstraat-Sterrenwijk	**11,6**	1120	ca 1000
lijn 7			
CS-Rozenstraat	**7,6**	1150	1020*
Rozenstraat-Jacobsstraat	**10,5**	1134	1020
Jacobsstraat-Oudenoord	**15,4**	1141	1020

*tussen CS en Vredenburg rijden 2890 bussen per dag.

Average	12.5

(Wijk C, 2012)

BRT

24,11 km/h average (BRT Data speed, 2017)

SECTION D. TICKET PRICE

Travel costs are calculated as follows:

TABLE 83. TRAVEL COSTS PT SYSTEMS (MRDH-OV, 2017)

Instaptarief	€ 0,89
Tram and LRT	€ 0,155 per km
Bus HTM	€ 0,155 per km
Metro line E RET	€ 0,155 per km
Metro, bus and tram RET	€ 0,137 per km
	€ 0,146 per km

SECTION E. PUNCTUALITY

Punctualities are derived from the following sources:

Rail Rotterdam (MRDH-PvE RET, 2016)

Rail Haaglanden (MRDH-PvE HTM, 2016)

Bus all: (MRDH-PvE Bus, 2016)

Busconcessions

- Voorne-Putten en Rozenburg
- Haaglanden Streek
- Rotterdam en omstreken
- Haaglanden Stad

TABLE 84. PUNCTUALITY DEFINITIONS

RET Metro	< 0 sec.	Starting point
	> 120 sec.	Starting point, Important stops and transfer stops
RET Tram	< 0 sec.	Starting point or important stop.
	> 180 sec.	Important stops
HTM Tram	< 0 sec.	Starting point
	> 120 sec.	Starting point
Bus	< 0 sec.	Starting point, Important stops and transfer stops
	> 120 sec.	Starting point
	> 180 sec.	Important stop

To calculate the average of a tram: average of HTM and RET because:

HTM only from starting point and lower margin compared to RET which has also important stops and higher margin; could be seen as on

The punctuality is a measure to define the amount of times a vehicle arrives on time at the designated stop, according to its schedule (Rudnicki, 1997). For example Table 85 shows that in 2014, the RET metro had a punctuality of 94% meaning that 94% of the times the metro arrived on time, according to its schedule.

TABLE 85. PUNCTUALITY CALCULATION

<table>
<tr><th></th><th>2014</th><th>2015</th><th>2016</th><th>Average</th></tr>
<tr><td>RET Metro</td><td>94%</td><td>94%</td><td>95%</td><td>94%</td></tr>
<tr><td>RET tram</td><td>84%</td><td>88%</td><td>90%</td><td rowspan="2">91.30%</td></tr>
<tr><td>HTM Tram</td><td>94.10%</td><td>95.50%</td><td>96.18%</td></tr>
<tr><td>RET Bus</td><td>--</td><td>92%</td><td>93%</td><td rowspan="2"></td></tr>
<tr><td>Conexxion Bus</td><td>89%</td><td>86%</td><td>86%</td></tr>
</table>

Rdam				85.82
HTM Bus	90%	93%	93%	
Conexxion DH	73%	74%	75%	

(MRDH-concessie, 2017)

Punctuality of BRT is 90% , which is higher compared to conventional bus lines (Deng & Nelson, 2013)

Punctuality LRT 95% (van Oort & van der Bijl, 2014)

SECTION F. FREQUENCIES

Metro RET

Ochtendspits 7-9 (Morning peak)

Dagfreq = 9-15u (daily frequency)

Avond vanaf 19u (Evening from 7pm)

Source:

(RET-vervoerplan 2018, 2016)

(Conexxion-vervoerplan 2018, 2016)

(HTM-vervoerplan 2018, 2016)

(HTM-vervoerplan rail 2018, 2016)

Metro		WERKDAG Jaardienst					
Lijn	Route	Aanvang dienst	Ochtend-spits	Daluren	Middag-spits	Avond	Einde dienst
A	Vlaardingen West - Binnenhof	7:00	10'	---	10'	---	18:00
A	Schiedam Centrum - Binnenhof	6:00	---	10'	---	---	19:15
A	Kralingse Zoom - Binnenhof	19:00	---	---	---	15'	0:00
B	Hoek van Holland Haven - Nesselande	5:30	20'	20'	20'	30'	23:45
B	Steendijkpolder - Nesselande	6:15	20'	20'	20'	30'	0:00
B	Schiedam Centrum - Capelsebrug	---	---	---	---	---	---
C	De Akkers - De Terp	6:00	10'	10'	10'	15'	0:00
D	De Akkers - Rotterdam Centraal	6:00	2x10'	10'	2x10'	15'	0:00
D	Slinge - Rotterdam Centraal	---	---	---	---	---	---
E	Slinge - Den Haag Centraal	5:45	10'	10'	10'	15'	0:00
E	Leidschenveen/Pijnacker – Slinge	7:45	3 ritten	---	---	---	8:15
Stamtrajecten							
ABC	Schiedam Centrum - Capelsebrug		3,3'	3,3'	3,3'	7,5'	
DE	Slinge - Rotterdam Centraal		2,5'-3,3'	5'	3,3'	7,5'	

FIGURE 33. METRO TIMETABLE RET

Tram		WERKDAG Jaardienst					
Lijn	*Route*	Aanvang dienst	Ochtend-spits	Daluren	Middag-spits	Avond (2)	Einde dienst
2	Charlois - Keizerswaard	**6:00**	10'	10'	10'	20'	**0:00**
4	Marconiplein - Molenlaan	**6:00**	10'	10'	10'	20'	**0:00**
7	Willemsplein - Erasmus Universiteit	**6:00**	10'	10'	10'	20'	**23:30**
8	Spangen - Kleiweg	**6:00**	10'	10'	10'	20'	**0:00**
20	Lombardijen - Rotterdam Centraal	**7:00**	7,5'		7,5'		**18:30**
21	Woudhoek - De Esch	**6:00**	15'	15'	15'		**19:00**
23	Marconiplein - Beverwaard	**6:00**	7,5'	7,5'	7,5'	15'-20'	**0:00**
24	Holy - De Esch	**6:00**	15'	15'	15'	15'-20'	**23:30**
25	Schiebroek - Carnisselande	**6:00**	7,5'	7,5'	7,5'	15'-20'	**0:00**
121	Hof van Spaland -Woudhoek	**19:00**				15'	**0:30**

FIGURE 34. FREQUENCY TABLE RET TRAM

Bus		**WERKDAG Jaardienst**					
Lijn	**Route**	**Aanvang dienst**	**Ochtend-spits**	**Daluren**	**Middag-spits**	**Avond**	**Einde dienst**
30	Station Alexander - Schollevaar	**6:00**	10'	15'	10'	15'-30'	**0:00**
31	Station Alexander - Oostgaarde	**6:00**	15'	30'	30'	---	**19:30**
32	Overschie - Station Zuid	**6:00**	7½'-10'	10'	10'	20'	**0:00**
33	Rotterdam Centraal- Meijersplein	**5:30**	10'	10'	10'	15'	**0:00**
35	Station Alexander - Melanchthonweg	**6:00**	20'	20'	20'	30'	**0:00**
36	Station Alexander - Kralingse Zoom	**6:00**	15'	15'	15'	30'	**0:00**
37	Station Alexander - Capelsebrug	**7:30**	60'	60'	60'	---	**19:45**
38A	Schiedam Centrum - Rotterdam Centraal	**6:00**	7½'	10'	7½'	15´-30´	**0:00**
38B	Rotterdam Centraal - Crooswijk	**6:00**	15'	20'	15'	20'-60'	**23:30**
40	Rotterdam Centraal - Delft	**6:30**	15'	30'	20'	---	**19:30**
42	Marconiplein – Bedr.ter. Noord-West	**6:00**	7½'	30'	10'	---	**19:00**
44	Rotterdam Centraal - Zuidplein	**6:00**	5'-10'	10'	7½'	20'	**0:00**
47	Shuttle Noordereiland	**6:30**	20'	20'	20'	20'	**22:00**
51	Schiedam Centrum - Woudhoek	**7:30**	30'	30'	30'	---	**18:00**
53	Schiedam Centrum - Woudhoek	**6:00**	20'	30'	30'	---	**19:30**
54	Schiedam Centrum - De Gorzen	**6:00**	20'	30'	20'	30'	**0:00**
56	Holy Noord - Vlaardingen West	**6:00**	10'	10'	10'	15'-30'	**0:00**
66	Zuidplein - Feijenoord	**6:00**	6'	10'	7½'	20'	**0:00**
67	Zuidplein - Pendrecht	**6:00**	15'-30'	20'	15'	30'	**22:00**
68	Zuidplein - Heijplaat	**6:00**	3'-10'	15'	10'	30'	**0:00**
68	Slinge - Waalhaven	**7:30**	n.t.b.	---	---	---	**8:30**
69	Zuidplein - Pernis	**6:30**	30'	---	30'	---	**18:00**
69	Zuidplein - Waalhaven	**7:30**	15'	---	15'-30'	---	**18:00**
70	Charlois - Keizerswaard	**6:00**	6'	7½'	7½'	20'	**0:30**
72	Zuidplein - Sluisjesdijk	**7:00**	20'-30'	---	30'	---	**18:00**
74	Zuidplein - Charloisse Lagedijk	**10:00**	---	30'	30'	---	**17:00**
76	Zuidplein - Keizerswaard	**6:00**	10'	10'	10'	20'	**0:00**
77A	ss Rotterdam - Rijnhaven	**6:00**	7½'	15'	7½'	15'	**0:30**

FIGURE 35. BUS RET FREQUENCY-1

Bus		WERKDAG Jaardienst					
Lijn	Route	Aanvang dienst	Ochtend-spits	Daluren	Middag-spits	Avond	Einde dienst
77B	Rijnhaven - Zuidplein	6:00	15'	15'	15'	30'	22:00
78	Hoogvliet	6:00	15'	20'	20'	30'-60'	0:30
79	Poortugaal - Delta Psych.Centrum	7:00	20'	30'	30'	---	20:00
80	Hoogvliet Metro - Binnenban	6:30	30'	30'	30'	60'	23:30
82	Zuidplein - Portland	6:00	15'	30'	15'	30'	0:00
83	Keizerswaard - Kralingse Zoom	6:00	30'	30'	30'	30'	0:00
84	Zuidplein - Station Barendrecht	6:00	15'-10'	15'	15'-10'	30'	0:00
95	Capelsebrug - Rivivum/Capelle West						
96	Busstation Krimpen - Stormpolder	6:30	30'	---	30'	---	18:00
97	Capelsebrug - Krimpen a/d IJssel	5:30	6'	15'	10'	30'	0:00
98	Capelsebrug - Krimpen a/d IJssel	5:30	7½'	15'	6'	30'	0:30
121	Pendelbusje tram Woudhoek	19:00	---	---	---	15'	0:15
126	Schiedam Centrum - Maassluis West	6:00	30'	30'	30'	---	19:00
140	Kralingse Zoom - Slikkerveer	6:30	15'	30'	30'	30'	20:00
143	Zuidplein - Dordrecht	6:30	30'	60'	30'	---	19:00
144	Zuidplein – Ridderkerk	6:00	10'	15'	10'	30'	0:00
146	Zuidplein - Ridderkerk	6:00	10'	15'	10'	30'	0:30
170	Rodenrijs - Zoetermeer	6:00	10'	20'	10'	30'	0:00
173	Rodenrijs - Bleiswijk	6:00	10'	20'	10'	30'	0:30
174	Rotterdam Noord - Westpolder – Delft	6:00	30'	30'	30'	60'-90'(3)	23:30
183	Zuidplein - Kralingse Zoom	6:00	30'	30'	30'	---	20:00
187	Zuidplein - Barendrecht	6:30	30'	---	30'	---	17:30
188	Barendrecht	7:00	15'	---	15'	---	18:00
245	Kralingse Zoom - Ridderkerk	7:00	15'	30'	15'	---	19:00
283	Zuidplein - Kralingse Zoom	7:30	30'	---	30'	---	18:00
290	Zuidplein - Ridderkerk	6:30	30'	---	30'	---	17:30
ST1	Kleinschalig vervoer Maassluis*	19:30	---	---	---		23:30
ST2	Kleinschalig vervoer Vlaardingen*	7:30				---	19:00
P1	Pendelbus Vijfsluizen – Vlaardingen oost*	6:30	10'	---	10'	---	18:30

FIGURE 36. BUS RET FREQUENCY-2

Source: Vervoerplan RET 2017

BUS htm

Werkdagen jaardienst						
Lijn:	1e rit	Ochtend-spits	Overdag	Middag-spits	Avond	Laatste rit
18 Rijswijk de Schilp > Clingendael	6:00	'15	'15	'15	'30	23:30
18 Clingendael > Rijswijk de Schilp	6:00	'15	'15	'15	'30	24:00
18k Rijswijk de Schilp > Centraal Station	7:00	'15	-	-	-	9:00
18k Centraal Station > Rijswijk de Schilp	16:00	-	-	'15	-	18:00
21 Vrederust > Scheveningen Noorderstrand	6:00	'15/'10	'15	'15	'30	24:00
21 Scheveningen Noorderstrand > Vrederust	6:00	'15	'15/'10	'15	'30	24:30
22 Duindorp > Duinzigt	5:45	'15	'15	'15	'30	24:00
22 Duinzigt > Duindorp	6:00	'15	'15	'15	'30	24:00
22k Centraal Station > Oude Waalsdorperweg	7:00	'15	-	'15	-	17:30
22k Oude Waalsdorperweg > Centraal Station	7:00	'15	-	'15*	-	17:30
23 Kijkduin > Scheveningen Noorderstrand	6:00	'7,5	'15/'10/'7,5	'7,5	'30	23:30
23 Scheveningen Noorderstrand > Kijkduin	6:00	'7,5	'15/'10/'7,5	'7,5	'30	24:00
24 Kijkduin > Mariahoeve	6:00	'7,5	'10/'7,5	'6	'30	24:00
24 Mariahoeve > Kijkduin	6:00	'7,5	'10/'7,5	'6	'30	24:00
25 Grote Markt > Vrederust	6:00	'7,5	'7,5	'7,5	'30	24:00
25 Vrederust > Grote Markt	6:00	'7,5	'7,5	'7,5	'30	24:00
26 Kijkduin > Voorburg Station***	6:00	'10	'15	'15	'30	24:00
26 Voorburg Station > Kijkduin***	6:00	'10	'15	'15	'30	24:00
26k Leyenburg > Voorburg Station	7:00	'10	-/'15	'15	-	17:30
26k Voorburg Station > Leyenburg	16:00	-	-/'15	'15	-	18:00
28 CS > Voorburg > Laan van NOI > CS	7:15	'15	-	-	-	9:15
28 CS > Laan van NOI > Voorburg > CS	16:00	-	-	'15	-	18:00

In schoolvakanties rijden 18k en 26k niet. 22k en 28 rijden in schoolvakanties 2x per uur ('30).

* Middagspitsritten worden ingezet tussen 15:00 en 17:00 uur

*** Na 20:00 uur doordeweeks en in het weekend traject Station Hollands Spoor – Kijkduin

FIGURE 37. TRAM HTM FREQUENCY

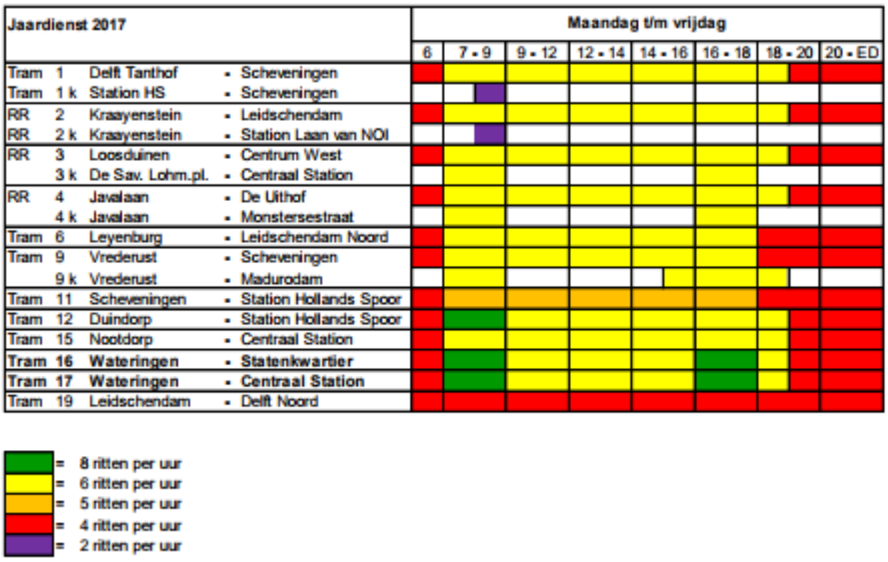


FIGURE 38. TRAM HTM FREQUENCY

WERKDAGEN	Frequenties:					
Lijn:	1e rit	Ochtend -spits	overdag	Middag-spits	avond	Laatste rit
81 Spijkenisse Elementen – Spijkenisse Sterrenkwartier	5:45	'10	'15	'10	'30	23:45
84 Spijkenisse Metro Centrum – Spijkenisse Maaswijk	5:30	'5	'15	'7,5	'30	23:45
84 Spijkenisse Metro Centrum – Spijkenisse Akkers	5:30	'30	'30	'30	'30	23:45
87 Spijkenisse Metro Centrum – Hofweg	7:00	'15/20	-	'20	-	18:00
101 Spijkenisse – Hellevoetsluis	5:15	'15	'15	'30	'30	23:45
102 Spijkenisse – Hellevoetsluis	6:00	'15	'15	'30	'30	23:45
103 Spijkenisse – Brielle – Rockanje	5:00	'7,5*	'15	'7,5*	'30	23:45
104 (Renesse-) Hellevoetsluis - Spijkenisse	6:30	'30	-	'30	-	18:30
105 Spijkenisse Akkers – Rozenburg	5:15	'15	'15	'15	'30	23:30
106 Spijkenisse – Hellevoetsluis – Brielle – Rozenburg	5:45	'30	'30	'60	'60	23:15
107 Oudenhoorn – Abbenbroek – Geervliet (belbus)	7:00	'60	'60	'60	-	18:30
110 Oostvoorne- Rockanje – Hellevoetsluis	7:30	'60	-	'50	-	16:00
111 Spijkenisse – Hellevoetsluis (spitslijn)	6:30	'4/'5**	-	'5/'10**	-	18:15
115 Spijkenisse – Rozenburg (spitslijn)	6:45	'15	-	'15	-	18:00
192 Vierpolders – Brielle – Tinte (Buurtbus)	8:00	'60	'60	'60	-	17:30
205 Spijkenisse – Botlek	6:30	'30	-	'30	-	17:45

* = gedeelte Brielle – Spijkenisse
** = samen met lijn 104

FIGURE 39. BUS HTM FREQUENCY

Converting the above information into tables results in tables 35 until 42 below:

TABLE 86. FREQUENCY TABLE METRO RET

METRO RET	Morning peak	Afternoon	Mid-peak	Evening	Average
Metro line A	6	6	6	4	5,5
Metro line B	6	6	6	4	5,5
Metro line C	6	6	6	4	5,5
Metro line D	12	6	12	4	8,5
Metro line E	6	6	6	4	5,5
Average Metro	---	---	---	---	6,1

TABLE 87. FREQUENCY TABLE TRAM RET

TRAM RET	Morning peak	Afternoon	Mid-peak	Evening	Average
Tram line 2	6	6	6	3	5,25
Tram line 4	6	6	6	3	5,25
Tram line 7	6	6	6	3	5,25

Tram line 8	6	6	6	3	5,25
Tram line 20	8		8		8
Tram line 21	4	4	4		4
Tram line 23	8	8	8	3	6,75
Tram line 24	4	4	4	3	3,75
Tram line 25	8	8	8	3	6,75
Average	---	---	---	---	5,58

TABLE 88. FREQUENCY TABLE TRAM HTM

TRAM HTM	Morning peak	Afternoon	Mid-peak	Evening	Average
Tram line 1	4	6	6	4	5
Tram line 6	4	6	6	4	5
Tram line 9	4	6	6	4	5
Tram line 11	4	5	5	4	4,5
Tram line 12	7	6	6	4	5,75
Tram line 15	5	6	6	4	5,25
Tram line 16	7	6	8	4	6,25
Tram line 17	7	6	8	4	6,25
Tram line 19	4	4	4	4	4
Average	---	---	---	---	5,22

TABLE 89. FREQUENCY TABLE LIGHT RAIL HTM

LRT HTM	Morning peak	Afternoon	Mid-peak	Evening	Average
RR1	4	6	6	4	5
RR2	4	6	6	4	5
RR3	4	6	6	4	5
RR4	4	6	6	4	5
Average	---	---	---	---	5

TABLE 90. FREQUENCY TABLE BUS RET

BUS RET	Morning peak	Afternoon	Mid-peak	Evening	Average
Bus line 30	6	4	6	3	4.75
Bus line 31	4	2	2		2.67
Bus line 32	7	6	6	3	5.50
Bus line 33	6	6	6	4	5.50
Bus line 35	3	3	3	2	2.75
Bus line 36	4	4	4	2	3.50
Bus line 37	1	1	1		1.00
Bus line 38A	8	6	8	3	6.25
Bus line 38B	4	3	4	2	3.25
Bus line 40	4	2	3		3.00
Bus line 42	8	2	6		5.33
Bus line 44	9	6	8	3	6.50

Bus line 47	3	3	3	3	3.00
Bus line 51	2	2	2		2.00
Bus line 53	3	2	2		2.33
Bus line 54	3	2	3	2	2.50
Bus line 56	6	6	6	3	5.25
Bus line 66	10	6	8	3	6.75
Bus line 67	3	3	4	2	3.00
Bus line 68	13	4	6	2	6.25
Bus line 69	2		2		2.00
Bus line 70	10	8	8	3	7.25
Bus line 72	2.5		2		2.25
Bus line 74		2	2		2.00
Bus line 76	6	6	6	3	5.25
Bus line 77A	8	4	8	4	6.00
Bus line 77B	4	4	4	2	3.50
Bus line 78	4	3	3	1.5	2.88
Bus line 79	3	2	2		2.33
Bus line 80	2	2	2	1	1.75
Bus line 82	4	2	4	2	3.00
Bus line 83	2	2	2	2	2.00
Bus line 84	5	4	5	2	4.00
Bus line 96	2		2		2.00
Bus line 97	10	4	6	2	5.50
Bus line 98	8	4	10	2	6.00
Bus line 126	2	2	2		2.00
Bus line 140	4	2	2	2	2.50
Bus line 143	2	1	2		1.67
Bus line 144	6	4	6	2	4.50
Bus line 146	6	4	6	2	4.50
Bus line 170	6	3	6	2	4.25
Bus line 173	6	3	6	2	4.25
Bus line 174	2	2	2	1	1.75
Bus line 183	2	2	2		2.00
Bus line 187	2		2		2.00
Bus line 188	4		4		4.00
Bus line 245	4	2	4		3.33
Bus line 283	2		2		2.00
Bus line 290	2		2		2.00
Bus line P1	6		6		6.00
Average					3.64

TABLE 91. FREQUENCY TABLE HTM BUS

BUS HTM	Morning peak	Afternoon	Mid-peak	Evening	Average
Bus line 18	4	4	4	2	3,5
Bus line 21	4	4	4	2	3,5
Bus line 22	4	4	4	2	3,5
Bus line 23	8	6	8	2	6
Bus line 24	8	7	10	2	6,75
Bus line 25	8	8	8	2	6,5
Bus line 26	6	4	4	2	4
Bus line 28	4	---	4	---	4
Average	---	---	---	---	4,71

TABLE 92. CONEXXION BUS FREQUENCY

Bus Conexxion	Morning peak	Afternoon	Mid-peak	Evening	Average
Bus line 81	6	4	6	2	4,5
Bus line 84	12	4	8	2	6,5
Bus line 84b	2	2	2	2	2
Bus line 87	4	---	3	---	3,5
Bus line 101	4	4	2	2	3
Bus line 102	4	4	2	2	3
Bus line 103	8	4	8	2	5,5
Bus line 104	2	---	2	---	2
Bus line 105	4	4	4	2	3,5
Bus line 106	2	2	1	1	1,5
Bus line 107	1	1	1	---	1
Bus line 110	1	---	1,2	---	1,1
Bus line 111	12	---	8	---	10
Bus line 115	4	---	4	---	4
Bus line 192	1	1	1	---	1
Bus line 205	2	---	2	---	2
Average	---	---	---	---	3,38

TABLE 93. FREQUENCY METRO, LRT, BUS, TRAM

System	Frequency	Average
Metro RET	6.1	
LRT HTM	5	
Tram HTM	5.22	
Tram RET	5.58	5.4
Bus RET	3.64	
Bus HTM	4.71	
Bus Conexxion	3.38	3.91

BRT

12x per hour (Transit Bangkok, n.d.)

6, 10 and 12x per hour (Calgary Transit Planning, 2002)

between 8 and 12 with some exceptions, average of europe is 13x per hour (BRT Data freq, 2017)

taking into account the ZORO bus with a frequency of just 4,25, the average freq for a BRT in the Metropolitan region Rdam-The Hague is 8x per hour

SECTION G. PASSENGER FORECAST

Now that the frequencies (Section F) and system capacities (Section A) are known, the passenger forecast can be calculated. The table below shows the calculation of the passenger forecast based on the average frequency and capacity of the system and the

TABLE 94. MODALITY FREQUENCIES AND FORECAST FOR THE METROPOLITAN REGION

Modality	Frequency (per hour)	Vehicle capacity	Passenger forecast
Metro	6	250	1500 passengers/hr.
Tram	5,5	182	1001 passengers/hr.
Bus	3,75	90	337,5 passengers/hr.
E-Bus	3,75	60	225 passengers/hr.
BRT	8	142	1136 Passengers/hr.
LRT	5	216	1080 passengers/hr.

SECTION H. SUBSIDY

The subsidy criterion for the public transport operators is estimated to be the sum of the investment costs, maintenance costs and operational costs (from the governments table). This assumption can be made due to the fact that the government grants subsidies to the public transport operators. These subsidies are meant for investment, maintenance and operational costs for public transport systems. The three above-mentioned costs are calculated in Section I and are shown in Table 95, below.

TABLE 95. SUBSIDY CALCULATION

	Bus	Tram	Metro	BRT	eBus	LRT
Investment costs	€78.000	€600.000	€6.712.000	€230.400	€114.300	€2.640.000
Maintenance costs	€ 159.000	€ 461.731	€ 806.517	€ 175.000	€ 111.000	€ 794.837
Operational costs	€307.200	€598.288	€558.700	€428.800	€215.040	€764.532
Subsidy	**€544.200**	**€1.660.018**	**€8.077.217**	**€834.200**	**€440.340**	**€4.199.369**

SECTION I. TOTAL COST OF OWNERSHIP

As mentioned in section 3.3 and Appendix VI, the public transport operators highly value TCO in their choice concerning public transport investments. This section will elaborate more on this criterion and explain the corresponding calculations.

The total costs of ownership, also known as life-cycle costs (Mälkki, 2010) are costs that occur during the entire life cycle of the product, service or system (Nurhadi, Boren, & Ny , 2014). The following data needs to be known for TCO calculation:

- Life span of the system (infrastructure) in [years]
- Life span of the vehicle in [years]
- Investment costs infrastructure in [€ per km]
- Investment costs vehicle in [€ per vehicle]
- Maintenance costs infrastructure in [€ per year per km]
- Maintenance costs vehicle in [€ per km]
- Operational costs in [€ per year]
- Average km per year in [km]
- TCO in [€ per year]

	Bus	Tram	Metro	BRT	eBus	LRT
Life span infra	50 years	50 years	50 years	50 years	50 years	50 years
Life span vehicle	10 years	25 years	30 years	10 years	12 years	30 years
Investment costs infra	€2.4mln/km	€24 mln/km	€325.6 mln/km	€9.27 mln/km	€ 2.81 mln/km	€124 mln/km
Investment costs vehicle	€0.300 mln	€3.0 mln	€5.0 mln	€0.450 mln	€0.581 mln	€4.0 mln
Maintenance costs infra per year	€ 0.079 mln	€ 0.290 mln	€ 0.765 mln	€0.079 mln	€ 0.087 mln	€0.630 mln
Maintenance costs vehicle per km	€ 0.25	€ 1.59	€ 1.05	€ 0.33	€ 0.175	€ 1.84
Operational costs per year	€ 1.26 per km	€ 2.15 per km	€ 1.22 per km	€1.36 per km	€0.98 per km	€ 0.90 per km
Average Km per year	64.000	55,397	59,310	64.000	64.000	78,494
TCO [€/yr]						

The assumption is made that the life span of the systems is about 50 years. This is done, firstly because of consistency reasons and secondly because the infrastructure of the bus and eBus is maintained by the government. Furthermore, the infrastructure of the rest of the systems keeps getting maintained throughout its entire life span.

Investment cost vehicle

Bus is the average of table 73 in Section B, is 300.000 euro

eBus is average of the table 73 in Section B, amounts 581.000 euro

BRT = +25% of normal bus (CROW-KpVV factors, 2016) is 375.000

Metro Investment costs – purchase: 31 mln. euro for 6 vehicles = 5 mln. euro per vehicle (MRDH-metro, 2016).

Tram is the average of tabe 35 and €210 mln. Euro for 60 trams = 3.5 mln. euro per tram (MRDH-tram, 2016)

LRT is the average of table 36.

Investment costs infra

Section B shows that the infrastructure investment costs for bus vary between 0.3- 4.1 mln. euro per km. Averaging these numbers gives an average investment costs of infrastructure for bus of 2.15 mln. euro per km.

Furthermore, the investment costs of a bus stop (= 1 stop on each side of the road) are also shown in this table and amount between 50.000-400.000 euro. Averaging these numbers gives us an average investment cost per bus stop of 225.000 euro, which is almost 10% of the investment infrastructure costs. Costs for making these stops accessible vary between 20.000-35.000 euro, (average = 27.500 euro). The total investment for one (pair) bus stop amounts 252.500 euro. The average bus stop of an eBus is 90.000 euro higher due to the charging stations at each stop (also taking 10% of the investment costs for the eBus stop). The average investment costs for bus per 1 km infrastructure including bus stops are 2.4 mln. euro. For the eBus this amounts 2.81 mln euro, taking into account the extra 320.000 euro for a charging depot and charging stations at each stop. For the BRT, the average investment costs for infrastructure vary between 4.7-12 mln euro per km, 5.4 and 14.9 mln euro per km and around 8.575 mln euro per km. averaging all these numbers gives an average of 9.02 mln euro per km for 1 km. Assuming the costs for a bus stop amount the same, the average cost per km for a BRT system amounts 9.27 mln euro.

Million euro per km	Bus	eBus	BRT
Investment infrastructure	2.15	2.47	9.02
Investment bus stop	0.25	0.34	0.25
Average Investment costs per km	2.40	2.81	9.27

With regards to the investment costs for rail, the table shown below can be derived from Section B. Taking the average of the tram using the information provided by CROW, results in 23.5 mln. euro per km infrastructure costs for the tram.

The total costs for the Noord/Zuid-line in Amsterdam are estimated at 3.1 bln. Euros with a length of 9.7 km (NRC, 2012) & (Het Parool, 2016). This results in an average of 320 mln euro per km. Averaging the amounts for the stops of Metro and Tram results in

0.5 mln euro costs for 1 stop for the tram and 5.6 mln euro for the metro. Assuming that the stops for the metro are build underground, which results in higher costs, the costs for one stop for the LRT amount roughly the same. The only difference is that a LRT system is build above ground resulting in lower costs. For this reason, the lower benchmark is chosen for the metro and rounded up, resulting in costs of 2 mln euro per stop for LRT.

Taking the average from all the projects regarding investments costs for infrastructure for LRT results in 122 mln. euro per km.

Million euro per km	Tram	Metro	LRT
Investment infrastructure	23.5	320	122
Investment stop	0.5	5.6	2.0
Average Investment costs per km	24	325.6	124

Life Span

Life span of a bus amounts 10 jaar and for a tram this number amounts 30 jaar (eindhoven.raadsinformatie, n.d.)

Life span of a bus 8 jaar (Schroten & Kortmann, 2006)

According to the customer service of RET (Figure 40), the life span of a metro is 30 years, a tram 25 and a bus 12.5 years.

Taking the average of these life spans for the bus results in 10 years life span for a bus.

For an eBus, the average life span is 12 years (Chicago Transit Authority, n.d)

The average life span of a Light Rail vehicle is 30 years (Valley Metro, 2013)

FIGURE 40. DATA COLLECTION CUSTOMER SERVICE RET (2017)

Maintenance costs infra per year per km

The maintenance costs for infrastructure of a bus amounts on average 79.000 euro per km per year. Taking into account that an eBus is 10% more due to charging stations etc. results in 86.000 euro per km per year. For the BRT system, the maintenance costs for infrastructure is assumed to be the same for a normal bus.

Infra Million euro per km	Bus	eBus	BRT
Regular Maintenance	0.079	0.086	0.079

With regards to rail, the maintenance infrastructure costs are assumed 55.000 euro per km per year for an one-way track, converting this to a two-way track results in 110.000 euro a year per km for regular infrastructure maintenance. Adding the replacement maintenance infrastructure (180.000 euro a year per km two-way) results in 290.000 euro per year per km maintenance infrastructure for tram.

For the metro the following applies:

435.000 euro per year per km for replacement maintenance plus the 330.000 euro for regular maintenance, brings the average maintenance costs for infrastructure to 765.000 euro per km per year for two-way track.

For the LRT, again the lower boundary of the metro (€ 185.000 and € 130.000) is used. For a two-way track, the maintenance costs for infrastructure amounts 630.000 euro per km per year.

Infra maintenance Million euro per km	Tram	Metro	LRT
Regular Maintenance	0.110	0.330	0.260
Replacement maintenance	0.180	0.435	0.370
Total	0.290	0.765	0.630

Maintenance costs vehicles
Maintenance for an eBus amounts 70% of a normal bus (Clean fleets, 2015), which is 70% of €0.25 per km resulting in € 0.175 per km. For the BRT system, the maintenance of the vehicle is 125% compared to a normal bus (CROW-KpVV factors, 2016), which amounts €0.33 per km.

The maintenance costs of the metro can be found in the report of KpVV and amounts €0.35 per km per small vehicle, the metro most of the time drives with 3 vehicles on average making the maintenance costs, €1.05 euro per km.

Operational costs

Operational costs = energy/fuel costs + salary employees

Driver salary: €55k per year

Steward salary: €45k per year

TABLE 96. OPERATIONAL COST CALCULATION

Modality	Energy costs	Km per year	Driver	Steward	Total per km
Metro	€ 0.15 per km	51,502	€1.07	---	€1.22
Tram	€ 0.35 per km	55,397	€0.99	€0.81	€2.15
Bus	€ 0.40 per km	64.000	€0.86	---	€1.26
BRT	€ 0.50 per km	64,000	€0.86	---	€1.36
LRT	€ 0.20 per km	78,494	€0.70	---	€ 0.90
eBus	€ 0.12 per km	64,000	€0.86	---	€0.98

The energy costs of a BRT are 25% higher compared to bus, the energy costs for LRT is calculated by the taking average of Metro and Tram and the energy costs calculation for the eBus is 30% of the regular bus (no diesel as fuel needed).

Kms/vehicle	Amount vehicles	Vehicle km's	Km's per vehicle
HTM Tram	168	8,652,341	51,502
HTM LRT	71	5,573,095	78,494
RET Metro	145	8,600,000	59,310
RET Tram	113	6,720,000	59,292
Average Tram			55,397

FIGURE 41. KM PER VEHICLE AVERAGE TRAM

TABLE 97. OPERATIONAL COSTS

Planned Operational costs	2017	2018	2019	Average
RET Tram	€5.52	€5.52	€5.54	€5.53
RET Metro	€4.87	€4.65	€4.62	€4.71
HTM Tram	€5.29	€5.24	€5.26	€5.26
HTM LRT	€4,89	€4,85	€4,87	€4,87
Average Tram				€5.40

Summarizing the above information:

	Bus	Tram	Metro	BRT	eBus	LRT
Operational costs per year	€ 0.96 per km	€ 5.40 per km	€ 4.71 per km	€1.34 per km	€0.67 per km	€ 4.87 per km

FIGURE 42. OPERATIONAL COSTS PER MODE

Km per year

TABLE 98. KM PER YEAR PER MODALITY

Provider	Modality	Km per year	Source
	Bus	64,000	(MRDH-kmBus, 2017)
	eBus	64,000	(Same as bus)
	BRT	64,000	(Same as bus)

Assumption is made that the eBus and BRT drive the same amount of yearly km's compared to bus. These assumptions are standard and generally accepted within MRDH concerning the conventional bus and BRT.

Cijfers van 2017

Kms/vehicle	Amount vehicles	Vehicle km's	Km's per vehicle
HTM Tram	168	8,652,341	51,502
HTM LRT	71	5,573,095	78,494
RET Metro	145	8,600,000	59,310
RET Tram	113	6,720,000	59,292
Average Tram			55,397

FIGURE 43. CHARACTERISTICS 2017 RAIL

Aantal metro's en trams ret Source = OV monitor

Aantal HTM LRT en Trams = Subsidieverleningsbeschikking Concessie Rail Haaglanden 2017

Aantal km per jaar is RET concessie….

TABLE 99. RAIL KM

Modality	Km infra	Source
RET Tram	194km Rail	(RET-Infra, 2017)
RET Metro	162km Rail	(RET-Infra, 2017)
HTM Tram	259km Rail	(HTM jaarverslag, 2012) & (Mott MacDonald, 2017)
HTM Light Rail	78km Rail	(HTM jaarverslag, 2012) & (Mott MacDonald, 2017)
Zoro Bus	7.4km Road	(Mensonides, 2012) & (Fietsersbond, n.d.) & (Verkeersnet, 2012)

TCO

For a period of 50 years, in total there are 5 buses needed who each on average drive 64,000 km per year.

Amount of vehicles needed over a period of 50 years

Investment infra = Investment costs for 1 km of infrastructure

Investment costs for vehicles is amount of vehicles multiplied by the purchase costs.

Maintenance costs infrastructure for 1 km is calculated by the maintenance costs for 1 km of infrastructure.

Maintenance costs of vehicles is calculated by:

amount of vehicles* average km driven by vehicle*maintenance costs vehicle

Operational costs is calculated by performing the following equation:

Amount of vehicles* *average km of vehicle*operational costs.

TABLE 100. TCO CALCULATION

€ in millions per year	Bus	Tram	Metro	BRT	eBus	LRT
Vehicles needed	5	2	2	5	5	2
Investment costs	**€0.51**	**€4.92**	**€65.32**	**€1.90**	**€0.62**	**€24.96**
Investment infra	€0.48	€4.80	€65.12	€1.85	€0.56	€24.80
Investment vehicles	€0.03	€0.12	€0.20	€0.05	€0.06	€0.16
Maintenance costs	**€0.87**	**€3.07**	**€7.69**	**€0.89**	**€0.89**	**€6.46**
Maintenance infra	€0.79	€2.90	€7.65	€0.79	€0.87	€6.30
Maintenance vehicles	€0.08	€0.17	€0.04	€0.10	€0.02	€0.16
Operational costs	**€0.40**	**€0.24**	**€0.14**	**€0.44**	**€0.31**	**€0.14**
TCO	**€1.78**	**€8.23**	**€73.16**	**€3.22**	**€1.83**	**€31.57**

TABLE 101. TCO SUMMARY

in € million per year	Bus	Tram	Metro	BRT	eBus	LRT
TCO	€1.78	€8.23	€73.16	€3.22	€1.83	€31.57
Investment costs	**€0.51**	**€4.92**	**€65.32**	**€1.90**	**€0.62**	**€24.96**
Maintenance costs	**€0.87**	**€3.07**	**€7.69**	**€0.89**	**€0.89**	**€6.46**
Operational costs	**€0.40**	**€0.24**	**€0.14**	**€0.44**	**€0.31**	**€0.14**

SECTION J. LIVABILITY INHABITANTS

The liveability of inhabitants (non-passengers) is measured in 1-10 where a 1 indicates that the system has a very negative influence on the liveability and a 10 indicates that the system has only very positive influence. A 5 indicates a neutral effect, no positive, no negative. The liveability is measured in the increase in property values.

The liveability is distinguished in 3 categories:

1. Emissions; the emissions of the vehicle (Puchalsky, 2005).
2. Accessibility region; the growth of accessibility of the region due to the system
3. Property values; the increase in property values due to the new system

The emissions are derived from ' De waaier van Brogt (Brogt, 2013), Figure 44. As can be seen, from the 6 modalities in Table 102, the emissions of the metro are the lowest, very closely followed by the tram and then the bus. The emissions of the BRT amount around the same as the conventional bus. Emissions of the LRT amount the same as the metro and tram.

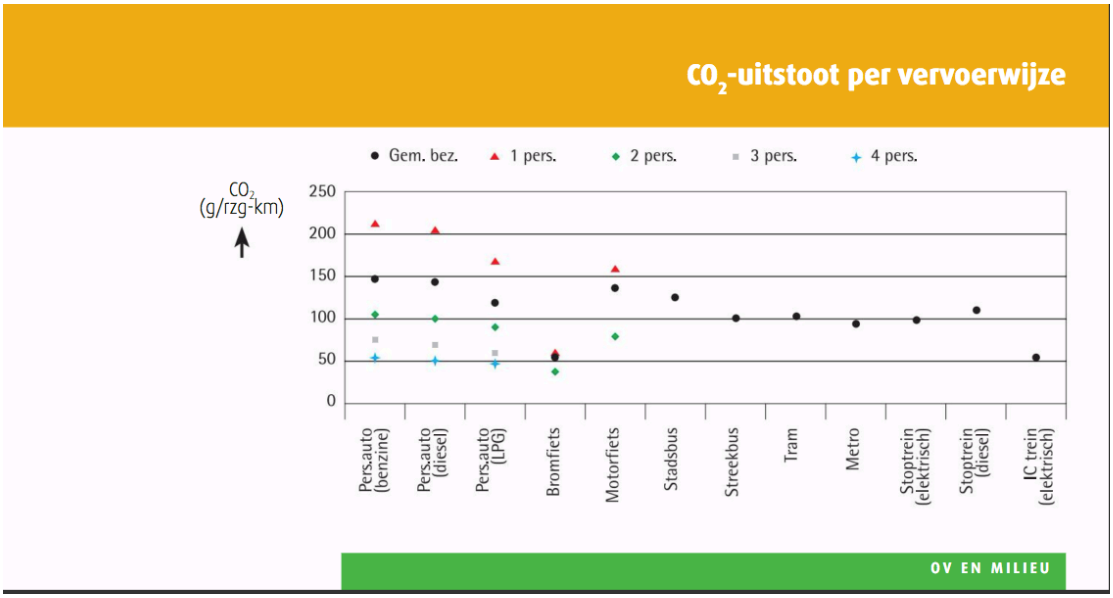


FIGURE 44. EMISSIONS INFORMATION PER MODALITY

The impact of the emissions is shown in Table 102. As can be seen, the emisssions for the metro, tram, eBus and LRT amount about the same, as the systems are all electric. The emissions for the conventional bus and eBus amount the same.

TABLE 102. LIVEABILITY CALCULATION MODALITIES

System	Emissions	Accessibility	Property value	Average
Metro	8	9	9	9
LRT	8	9	9	9
BRT	6	8	8	7
Tram	8	8	7	8
Bus	6	6	6	6
eBus	8	6	6	7

With regards to the accessibility, these numbers are derived from the passenger forecast, also shown in Table 103. As can be seen, if a system can transfer more than 1499 passenger per hour, a 9 (between 1 and 10) is given. Around 1000 passengers per hour, receives an 8 and below 500 passengers per hour receives a 6.

TABLE 103. ACCESSIBILITY CALCULATION

System	Accessibility	Passenger forecast
Metro	9	1500
LRT	9	1755
BRT	8	1080
Tram	8	1001
Bus	6	338
eBus	6	225

With regards to the property values, the higher the values (are expected to increase), the more positive this influences the liveability. As can be seen from Table 104, the effect on the property values of the metro and LRT are the highest, followed by the BRT. The Bus (and therefore the eBus) almost has no effect on the property values (Des Rosiers, Theriault, Voisin, & Dube, 2010).

TABLE 104. PROPERTY VALUES CALCULATION

System	Property values	Increase
Metro	9	---
LRT	9	7-22%
BRT	8	7.6-14%
Tram	7	±12%
Bus	6	<3%
eBus	6	<3%

BRT 7.6%-14% en LRT 7%-22% (FTA-BRT, 2009), (Stokenberga, 2014), (Wagner, Komarek, & Martin, 2017).

Tram 12% (Lloyds Bank, 2017)

Metro accessibility (Dewees, 1976), (Sun, Wang, & Li, 2016), (Agostini & Palmucci, 2008), (Dai, Bai, & Xu, 2016).

SECTION K. FLEXIBILITY OF THE SYSTEM

The flexibility, as a criterion, is defined as a the extent in which a system is dependent on its infrastructure and has the possibility to divert from its route, while still maintaining around the same level of quality. This attribute is measured with a number between 1-10, 1 indicating no flexibility at all possible, totally dependent on its infrastructure and 10 meaning no dependency. The flexibility of modes is indicated using own analysis and are rough estimates.

The modes can be characterized in two categories: the first one is the Rail, among which Metro, Tram and LRT. The second one is Road, among which Bus, eBus and BRT.

The rail modes are 100% dependent on their infrastructure and therefore all have a very low flexibility. For this reason, the flexibility of all rail-based systems are indicated with a 1.

The bus is the modality that has the lowest dependency on its infrastructure, however it still needs infrastructure, therefore the bus scores on flexibility an 8. The BRT system is a little more dependent on its infrastructure, however, still can divert when needed. Therefore the BRT scores a 7. The eBus also has a lower dependency compared to rail, however, because it needs charging stations at each stop and at the depot, it is more dependant on its infrastructure compared to a BRT system. For this reason, the eBus scores an 6 on flexibility.

Metro = 1 = 100% dependent

Bus = 8 = dependent on road infrastructure, however is easy to divert and maintain the same level of quality

Tram	=1 = 100% dependent
BRT	= 7 ; had dedicated infra, however very easy to divert from its route, just like conventional bus, but less quality to offer when diverting…
LRT	= 1 = 100% dependent

eBus = almost same as bus, however, a little more dependent due to charging stations lead to more dependency. = 6

SECTION L. EARNINGS

The earnings are calculated by multiplying ticket price with passenger forecast

TABLE 105. PASSENGER FORECAST CALCULATION

Modality	Frequency (per hour)	Vehicle capacity	Passenger forecast
Metro	6	250	1500 passengers/hr.
Tram	5,5	182	1001 passengers/hr.
Bus	3,75	90	337,5 passengers/hr.
E-Bus	3,75	60	225 passengers/hr.
BRT	8	142	1136 Passengers/hr.
LRT	5	216	1080 passengers/hr.

TABLE 106. PRICE PER KM CALCULATION

Instaptarief	€ 0,89
Tram and LRT	€ 0,155 per km
Bus HTM	€ 0,155 per km
Metro line E RET	€ 0,155 per km
Metro, bus and tram RET	€ 0,137 per km
Average	€ 0,146 per km

(MRDH-OV, 2017)

TABLE 107. EARNINGS/ REVENUES CALCULATION

	Bus	Tram	Metro	BRT	eBus	LRT
Forecast (pass.)	337.5	1001	1500	1136	337.5	1080
Ticket price	€0.146	€0.146	€0.146	€0.146	€0.146	€0.146
Earnings (€/km)	€49	€146	€219	€166	€49	€158

Earnings in € per km.

SECTION M. PASSENGER SAFETY (COSTS)

For the passenger safety for BRT, the same number is used as for the bus based on the following two sources:

The overall safety is not increased with a BRT system (Duduta, Adriazola-Steil, Hidalgo, Lindau, & dos Santos, 2013). According to various sources examined by Vecino-Ortiz and Hyder, conclusions regarding BRT systems were mixed about safety increase (Vecino-Ortiz & Hyder, 2015).

The light rail system of HTM also makes use of the infrastructure of the tram. Metro line E (Randstadrail) also makes use of the RET metro infrastructure. In this case, LRT can be seen as a mixed system (HTM-RR, 2017). For this reason, the assumption is made that the average of the passenger safety of tram (7.6) and metro (7.4) is going to be used as passenger safety for LRT (7.5)

For the operators and government, the Passenger safety costs are measured in (safety investments in) euro per passenger. For the transport systems, this number can be calculated using the forecast and multiplying this with the safety costs per passenger.

Yearly Passenger safety costs: €55,000,000 (Weijdt & Brussen, 2016).

RET Rail	Passenger safety	€36,303,562 per year	
HTM Rail	Passenger safety	€20,500,000 per year	(HTM2016, 2017)

The table below shows the passenger safety costs per day, calculated using the above-mentioned costs.

TABLE 108. AVERAGE PASSENGER SAFETY COSTS (HTM2016, 2017), (JACOBS, 2016),

HTM	Passengers per day	Safety costs per day	Safety costs per passenger
2016	258,000	€56,164.38	€0.22
2015	257,000	€56,164.38	€0.22
2014	254,000	€56,164.38	€0.22
RET			
2015	500,000	€99,461.81	€0.20
Average Passenger safety costs			€0.21

Assumption: One operational day = 18 hours (from 06:00-24:00) based on (HTM-vervoerplan rail 2018, 2016), (RET-vervoerplan 2018, 2016), (Conexxion-vervoerplan 2018, 2016).

TABLE 109. CALCULATION SAFETY COSTS

Modality	Passenger forecast	Passenger Safety	Safety costs per day
Metro	1500 passengers/hr.	€0.21 per pass.	€5,670
Tram	1001 passengers/hr.	€0.21 per pass.	€3,784
Bus	337,5 passengers/hr.	€0.21 per pass.	€1,276
eBus	225 passengers/hr.	€0.21 per pass.	€851
BRT	1136 passengers/hr.	€0.21 per pass.	€4,294
LRT	1080 passengers/hr.	€0.21 per pass.	€4,082

APPENDIX VIII. INDICATORS

The following tables show the calculations of the perceptions. First the passengers table is presented, with the corresponding criteria, weights and values derived from the 'OV-Klantenbaromenter.'

TABLE 110. PASSENGER INDICATOR VALUES GENERAL

Passengers	Weight	Bus	Tram	Metro	BRT	LRT	eBus
Criterion		Factor	Factor	Factor	Factor	Factor	Factor
Frequency	0.184	7.2	7.3	7.5	7.25	7.4	7.2
Punctuality	0.113	7.2	7.2	7.5	7.2	7.35	7.2
Passenger Safety	0.104	7.9	7.6	7.4	7.85	7.5	7.9
Travel time	0.178	7.6	7.5	7.8	7.55	7.65	7.6
Accessibility of PT system	0.074	8.6	8.3	8.8	8.45	8.55	8.6
Travel information	0.093	7.7	7.4	7.9	7.55	7.65	7.7
Image	0.047	7.6	7.5	7.5	7.55	7.5	7.79
Travel comfort	0.087	7.5	7.2	7.1	7.35	7.15	7.875
Ticket price	0.120	5.6	5.1	5.1	5.35	5.1	5.6

For the government and operators, costs need to be calculated. Investment, operational and maintenance cost per system are 3 of the important criteria for the government. The operators identified the TCO as an important criterion. The following table shows the calculation of these costs. The costs are calculated using a 50 year life span. For a bus system, this means that in 50 years, 5 buses are needed because of the 10 year life span of the vehicle.

TABLE 111. KEY FIGURES FOR TCO CALCULATION

€ in millions	Bus	Tram	Metro	BRT	eBus	LRT
Life span infra	50	50	50	50	50	50
Life span vehicle	10	25	30	10	12	30
Investment costs infra per km	€2,400,000	€24,000,000	€325,600,000	€9,270,000	€2,810,000	€124,000,000
Investment costs vehicle	€300,000	€3,000,000	€5,000,000	€450,000	€581,000	€4,000,000
Maintenance costs infra per km	€79,000	€290,000	€765,000	€79,000	€87,000	€630,000
Maintenance costs vehicle per km	€0.25	€1.55	€0.35	€0.30	€0.075	€1.05
Operational costs per km	€1.26	€2.15	€1.22	€1.36	€0.98	€0.90
Average Km per year driven	64,000	55,397	59,310	64,000	64,000	78,494

Assuming a 10 km length road, the following equations show how the costs in the table below are calculated.

- Investment costs = investment infra * investment vehicles
- Investment infra = (investment cost per km * 10 km)/50 years
- Investment vehicles =(amount of vehiclces needed in 50 years * price 1 vehicle)/50
- Maintenance costs = maintenance infra + maintenance vehicles
- Maintenance infra = maintenance costs per km infra per year * 10 km
- Maintenance vehicles = amount of vehicles * maint. costs per veh. * km's driven per veh.
- Operational costs = amount of vehicles * operational costs per km * km's driven per veh.

- TCO = Operational costs + maintenance costs + Investment costs

TABLE 112. TCO CALCULATION GENERAL

€ in millions per year	Bus	Tram	Metro	BRT	eBus	LRT
Vehicles needed	5	2	2	5	5	2
Investment costs	**€0.51**	**€4.92**	**€65.32**	**€1.90**	**€0.62**	**€24.96**
Investment infra	€0.48	€4.80	€65.12	€1.85	€0.56	€24.80
Investment vehicles	€0.03	€0.12	€0.20	€0.05	€0.06	€0.16
Maintenance costs	**€0.87**	**€3.07**	**€7.69**	**€0.89**	**€0.89**	**€6.46**
Maintenance infra	€0.79	€2.90	€7.65	€0.79	€0.87	€6.30
Maintenance vehicles	€0.08	€0.17	€0.04	€0.10	€0.02	€0.16
Operational costs	**€0.40**	**€0.24**	**€0.14**	**€0.44**	**€0.31**	**€0.14**
TCO	**€1.78**	**€8.23**	**€73.16**	**€3.22**	**€1.83**	**€31.57**

After calculating the costs, the two tables below show the values, criteria and the corresponding weights of the government and the transport systems.

TABLE 113. GOVERNMENT INDICATOR VALUES GENERAL PART 1

Government		Bus	Tram	Metro	
Criterion	Weight	Factor	Factor	Factor	Unit
Operational costs	0.142	0.4	0.24	0.14	€mln./yr.
Investments costs	0.155	0.51	4.92	65.32	€mln./yr.
Maintenance costs	0.117	0.87	3.07	7.69	€mln./yr.
Liveability inhabitants	0.083	6	8	9	[1-10]
Forecast	0.147	337.5	1001	1500	Pass/hr.
Punctuality	0.063	85.82	91.3	94	%
Passenger safety	0.063	1276	3784	5670	€/day
Flexibility	0.107	8	1	1	[1-10]
System Capacity	0.125	90	182	250	Passengers

TABLE 114. GOVERNMENT INDICATOR VALUES GENERAL PART 2

Government		BRT	LRT	eBus	
Criterion	Weight	Factor	Factor	Factor	Unit
Operational costs	0.142	0.44	0.14	0.31	€mln./yr.
Investments costs	0.155	1.9	24.96	0.62	€mln./yr.
Maintenance costs	0.117	0.89	6.46	0.89	€mln./yr.
Liveability inhabitants	0.083	7	9	7	[1-10]
Forecast	0.147	1080	1755	225	Pass./hr.
Punctuality	0.063	90	95	85.82	%
Passenger safety	0.063	4294	4082	851	€/day
Flexibility	0.107	6	1	7	[1-10]
System Capacity	0.125	142	216	60	Passengers

The values for the operators are presented in the tables below.

TABLE 115. OPERATORS INDICATOR VALUES GENERAL PART 1

Public transport operators		Bus	Tram	Metro	
Criterion	Weight	Factor	Factor	Factor	Unit
Passenger forecast	0.213	337.5	1001	1500	Pass/hr.
Earnings	0.121	49	146	219	€/km
~~Politics~~	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.12	90	180	250	Passengers
Frequency	0.129	3.91	5.4	6.1	Dep./hr./dr.
Operational speed	0.108	12.5	17.6	37.1	Km/h.
TCO	0.158	1.78	8.23	73.16	€mln./yr.
Passenger safety	0.107	1276	3784	5670	€/day

TABLE 116. OPERATORS INDICATOR VALUES GENERAL PART 2

Public transport operators		BRT	LRT	eBus	
Criterion	Weight	Factor	Factor	Factor	Unit
Passenger forecast	0.213	1080	1755	225	Passengers
Earnings	0.121	158	166	49	€/km
~~Politics~~	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.12	216	142	60	Passengers
Frequency	0.129	5	8	3.91	Dep./hr./dr.
Operational speed	0.108	30	24.11	12.5	Km/h.
TCO	0.158	3.22	31.57	1.83	€mln./yr.
Passenger safety	0.107	4082	4294	851	€/day

Normalising the values, the table below is presented. These numbers are calculated by dividing the value of each system, by the largest number in the row. For a criterion that is indicated with red, an inverse equation is used. The higher this number, the lower the perception. Both equations (1 and 2) are shown below.

Positive factor: $\frac{X_1}{MAX}$ (1)

Negative factor: $1 - \frac{X_1}{MAX}$ (2)

TABLE 117. GOVERNMENT NORMALISED VALUES GENERAL

Government	Weights	Bus	Tram	Metro	BRT	LRT	eBus
Criterion							
Operational costs	0.142	0.091	0.455	0.682	0.000	0.682	0.295
Investments costs	0.155	0.992	0.925	0.000	0.971	0.618	0.991
Maintenance costs	0.117	0.887	0.601	0.000	0.884	0.160	0.884
Liveability inhabitants	0.083	0.667	0.889	1.000	0.778	1.000	0.778
Forecast	0.147	0.192	0.570	0.855	0.615	1.000	0.128
Punctuality	0.063	0.903	0.961	0.989	0.947	1.000	0.903
Passenger safety	0.063	0.775	0.333	0.000	0.243	0.280	0.850
Flexibility	0.107	1.000	0.125	0.125	0.750	0.125	0.875
System Capacity	0.125	0.360	0.728	1.000	0.568	0.864	0.240

TABLE 118. OPERATORS NORMALISED VALUES GENERAL

PT Operators	Weights	Bus	Tram	Metro	BRT	LRT	eBus
Criterion							
Passenger forecast	0.213	0.192	0.570	0.855	0.615	1.000	0.128
Subsidy	0.121	0.224	0.667	1.000	0.721	0.758	0.224
~~Politics~~	~~---~~	~~---~~	~~---~~	~~---~~	~~---~~	~~---~~	~~---~~
Ticket price	0.044	1.000	1.000	1.000	1.000	1.000	1.000
System capacity	0.12	0.360	0.720	1.000	0.864	0.568	0.240
Frequency	0.129	0.489	0.675	0.763	0.625	1.000	0.489
Operational speed	0.108	0.337	0.474	1.000	0.809	0.650	0.337
TCO	0.158	0.976	0.888	0.000	0.956	0.568	0.975
Passenger safety	0.107	0.775	0.333	0.000	0.280	0.243	0.850

Multiplying the weights with normalised values the tables below are obtained.

TABLE 119. PASSENGERS RESULTS

Passengers	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Frequency	1.32	1.34	1.38	1.33	1.36	1.32
Punctuality	0.81	0.81	0.85	0.81	0.83	0.81
Passenger Safety	0.82	0.79	0.77	0.82	0.78	0.82
Operational speed	1.35	1.34	1.39	1.34	1.36	1.35

Accessibility of PT system	0.64	0.61	0.65	0.63	0.63	0.64
Travel information	0.72	0.69	0.73	0.70	0.71	0.72
Image	0.36	0.35	0.35	0.35	0.35	0.37
Travel comfort	0.65	0.63	0.62	0.64	0.62	0.69
Ticket price	0.67	0.61	0.61	0.64	0.61	0.67
Result	7.35	7.18	7.35	7.27	7.26	7.39

TABLE 120. PASSENGER RESULTS IN %

Passengers	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Frequency	0%	1%	4%	1%	3%	0%
Punctuality	0%	0%	4%	0%	2%	0%
Passenger Safety	0%	-4%	-6%	-1%	-5%	0%
Operational speed	0%	-1%	3%	-1%	1%	0%
Accessibility of PT system	0%	-3%	2%	-2%	-1%	0%
Travel information	0%	-4%	3%	-2%	-1%	0%
Image	0%	-1%	-1%	-1%	-1%	3%
Travel comfort	0%	-4%	-5%	-2%	-5%	5%
Ticket price	0%	-9%	-9%	-4%	-9%	0%
Result	0%	-2%	0%	-1%	-1%	1%

TABLE 121. GOVERNMENT RESULTS VALUES

Government	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Operational costs	0.01	0.06	0.10	0.00	0.10	0.04
Investments costs	0.15	0.14	0.00	0.15	0.10	0.15
Maintenance costs	0.10	0.07	0.00	0.10	0.02	0.10
Liveability inhabitants	0.06	0.07	0.08	0.06	0.08	0.06
Forecast	0.03	0.08	0.13	0.09	0.15	0.02
Punctuality	0.06	0.06	0.06	0.06	0.06	0.06
Passenger safety	0.05	0.02	0.00	0.02	0.02	0.05
Flexibility	0.11	0.01	0.01	0.08	0.01	0.09
System Capacity	0.05	0.09	0.13	0.07	0.11	0.03
Result	0.61	0.62	0.51	0.64	0.64	0.62

TABLE 122. GOVERNMENT RESULT IN %

Government	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Operational costs	0%	400%	650%	-100%	650%	225%
Investments costs	0%	-7%	-100%	-2%	-38%	0%
Maintenance costs	0%	-32%	-100%	0%	-82%	0%
Liveability inhabitants	0%	33%	50%	17%	50%	17%
Forecast	0%	197%	344%	220%	420%	-33%
Punctuality	0%	6%	10%	5%	11%	0%
Passenger safety	0%	-57%	-100%	-69%	-64%	10%
Flexibility	0%	9%	9%	3%	9%	1%

System Capacity	0%	102%	178%	58%	140%	-33%
Result	0%	2%	-17%	4%	5%	1%

TABLE 123. OPERATORS RESULTS GENERAL

PT Operators	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Passenger forecast	0.04	0.12	0.18	0.13	0.21	0.03
Subsidy	0.03	0.08	0.12	0.09	0.09	0.03
~~Politics~~	---	---	---	---	---	---
Ticket price	0.04	0.04	0.04	0.04	0.04	0.04
System capacity	0.04	0.09	0.12	0.10	0.07	0.03
Frequency	0.06	0.09	0.10	0.08	0.13	0.06
Operational speed	0.04	0.05	0.11	0.09	0.07	0.04
TCO	0.15	0.14	0.00	0.15	0.09	0.15
Passenger safety	0.08	0.04	0.00	0.03	0.03	0.09
Results	0.49	0.65	0.67	0.72	0.73	0.47

TABLE 124. OPERATORS RESULTS GENERAL IN %

PT Operators	Bus	Tram	Metro	BRT	LRT	eBus
Criterion						
Passenger forecast	0%	197%	344%	220%	420%	-33%
Subsidy	0%	198%	347%	222%	239%	0%
~~Politics~~	---	---	---	---	---	---
Ticket price	0%	0%	0%	0%	0%	0%
System capacity	0%	100%	178%	140%	58%	-33%
Frequency	0%	38%	56%	28%	105%	0%
Operational speed	0%	41%	197%	140%	93%	0%
TCO	0%	-9%	-100%	-2%	-42%	0%
Passenger safety	0%	-57%	-100%	-64%	-69%	10%
Results	0%	32%	37%	45%	49%	-4%

Summarizing the above perceptions, results in the table below.

TABLE 125. RESULTS PERCEPTION

Stakeholders\Modality	Bus	Tram	Metro	BRT	LRT	eBus
Passengers	0%	-2%	0%	-1%	-1%	1%
Government	0%	2%	-17%	4%	19%	-13%
PT operators	0%	32%	37%	45%	49%	-4%

APPENDIX IX. COMPARISON METROPOLITAN REGION VS. NATIONAL

The data from the OV-Barometer can also be filtered in terms of results of the Metropolitan region. Instead of using national data, the following regions are taken into account when filtering survey data only for the metropolitan region:

- Rotterdam en omgeving
- Regiovervoer Haaglanden
- Stadsvervoer Den Haag
- Zuid Holland Noord
- Den Haag
- Rotterdam
- Randstadrail Haaglanden
- Metro en randstadrail Rotterdam

Table 126 below shows the results for the above-mentioned regions.

TABLE 126. METROPOLITAN REGION OV-BAROMETER (CROW-KPVV, 2016)

Criterion\Modality	Bus	Bus	Bus	Bus	Tram	Tram	Metro	Metro
	Rotterdam en omgeving	Regiovervoer Haaglanden	Stadsvervoer Den Haag	Zuid Holland Noord	Den Haag	Rotterdam	Randstadrail Haaglanden	metro en randstadrail Rotterdam
Geluid	6,7	6,7	6,8	6,7	6,6	6,8	6,6	6,6
Stiptheid	7,4	7,4	7,6	7,1	7,5	7,6	7,6	7,7
Info halte	7,7	7,6	7,6	7,7	7,7	8	7,8	8,1
Algemeen sociale veiligheid	7,6	7,8	7,7	8,1	7,3	7,7	7,4	7,3
Zitplaats	8,6	8,6	8,5	8,9	8,4	8,5	7,8	8,1
Klantvriendelijkheid	7,6	7,9	7,7	7,9	7,2	7,9	7,1	7,2
Snelheid	7,6	7,7	7,7	7,7	7,6	7,7	7,7	7,9
Info vertraging	6,2	5,3	5,7	5,7	5,8	6,5	5,8	6,5
Rit- sociale veiligheid	7,9	8,1	8	8,4	7,7	8	7,8	7,7
Netheid	7	7,6	7,5	7,7	7,1	7,7	6,9	6,6
Rijstijl	7,4	7,5	7,2	7,6	7,3	7,4	7,2	7,4
frequentie	7,2	7	7,4	7,1	7,4	7,6	7,5	7,6
Aankoop kaartje	7,7	8	7,8	8,1	7,5	7,8	7,1	8
In-en uitstappen	8,3	8,7	8,5	8,8	8,1	8,7	8,8	8,9
prijs	5,7	5,6	5,5	6	4,9	5,7	4,9	5,3
halte- sociale veiligheid	7,7	7,9	7,8	8,2	7,5	7,8	7,6	7,5
Enquetes	621	953	735	934	1745	2160	2044	2513
Totaal (= Image)	7,39	7,46	7,44	7,61	7,22	7,59	7,23	7,42

When taking only the 9 important criteria for the passengers group into account, the following table is obtained:

TABLE 127. RESULTS OV-BAROMETER NL VS. MR (CROW-KPVV, 2016)

	Metropolitan area			National level		
Passengers	Bus	Tram	Metro	Bus	Tram	Metro
Criterion	Factor	Factor	Factor	Factor	Factor	Factor
Frequency	7.18	7.50	7.55	7.2	7.3	7.5
Punctuality	7.38	7.55	7.65	7.2	7.2	7.5
Passenger Safety	7.93	7.67	7.55	7.9	7.6	7.4
Travel time	7.68	7.65	7.80	7.6	7.5	7.8
Accessibility PT system	8.58	8.40	8.85	8.6	8.3	8.8
Travel information	6.69	7.00	7.05	7.7	7.4	7.9
Image	7.48	7.41	7.31	7.6	7.5	7.5
Travel comfort	7.56	7.48	7.15	7.5	7.2	7.1
Ticket price	5.70	5.30	5.10	5.6	5.1	5.1

The criterion **Travel Information** shows 1 whole point difference between the metropolitan region and the national survey results. This criterion scores better on a national level. Furthermore, we see that the results do not differ that much.

TABLE 128. METROPOLITAN REGION ANALYSIS

Passengers		Bus	Tram	Metro
Criterion	Weight	Factor	Factor	Factor
Frequency	0.178	7.18	7.50	7.55
Punctuality	0.119	7.38	7.55	7.65
Passenger Safety	0.116	7.93	7.67	7.55
Travel time	0.152	7.68	7.65	7.80
Accessibility of PT system	0.064	8.58	8.40	8.85
Travel information	0.092	6.69	7.00	7.05
Image	0.042	7.48	7.41	7.31
Travel comfort	0.090	7.56	7.48	7.15
Ticket price	0.147	5.70	5.30	5.10

After calculations of the weights and factors, Table 129 (below) is obtained:

TABLE 129. METROPOLITAN REGION RESULTS

Passengers	Bus	Tram	Metro
Criterion	Factor	Factor	Factor
Frequency	1.277	1.335	1.344
Punctuality	0.878	0.898	0.910
Passenger Safety	0.920	0.889	0.876
Travel time	1.167	1.163	1.186
Accessibility of PT system	0.549	0.538	0.566
Travel information	0.615	0.644	0.649
Image	0.314	0.311	0.307
Travel comfort	0.681	0.673	0.644
Ticket price	0.838	0.779	0.750
Result	7.238	7.230	7.231

TABLE 130. METROPOLITAN REGION VS. NATIONAL

Passengers	Bus	Tram	Metro
National	7.286	7.103	7.265
Metropolitan area	7.238	7.230	7.231

TABLE 131. METROPOLITAN VS. NATIONAL %

Passengers	Bus	Tram	Metro
National	0%	-2%	0%
MRDH region	0%	0%	0%

The results show a various number of interesting observations. Firstly, the ratings of the public transport systems are closer together in the metropolitan area compared to National. The difference between the highest and lowest is just, 0.006, while the difference on national level is 0.21. Secondly, the ranking of the systems is exactly the same. On national level, the bus scores highest followed by the metro and tram. The same ranking is found in the metropolitan area. Another interesting observation is the difference in perception of the metro. The metropolitan area where the metro actually is in operation scores lower (7.23) compared to national (7.27), where data is taken into account from regions where no metro is operational.

APPENDIX X. CALCULATIONS CASE STUDY

For each case study, the current frequency will be compared to the average frequency of the modes, in general and for the operator specific.

The case studies will be tested on these two aspects to investigate whether it is realistic and feasible to even conduct such an analysis.

The frequency bonus is calculated using Brogt (Brogt, 2013).

TABLE 132. PASSENGER TIME GAINS AS AN EFFECT OF FREQUENCY CHANGE

Frequency change	Passengers growth	Time gains
0.5-->1	60%	60 min
1-->2	40%	30 min
2-->4	25%	15 min
4-->8	15%	7.5 min

Instead of every 9 minutes, a vehicle arrives every 15 minutes, which is a time loss of 6 min. as can be seen from the table, a 6-minute time loss can be associated with 30% less passengers.

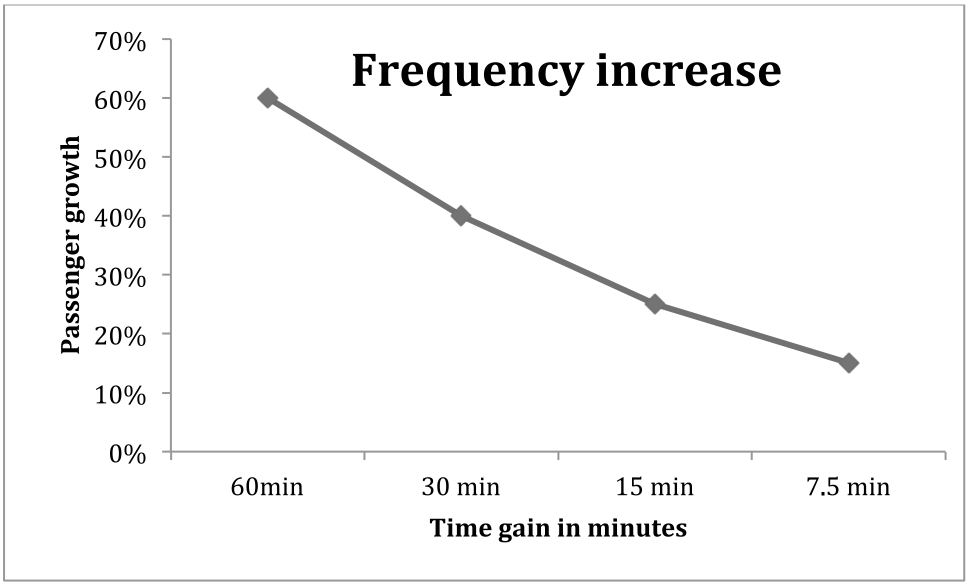


FIGURE 45. PASSENGER GROWTH AND FREQUENCY INCREASE

TABLE 133. PASSENGER TIME LOSS AS AN EFFECT OF FREQUENCY CHANGE

Frequency change	Passengers growth	Time loss
8-->4	-35%	7.5 min
4-->2	-45%	15 min
2-->1	-60%	30 min
1-->0.5	-80%	60 min

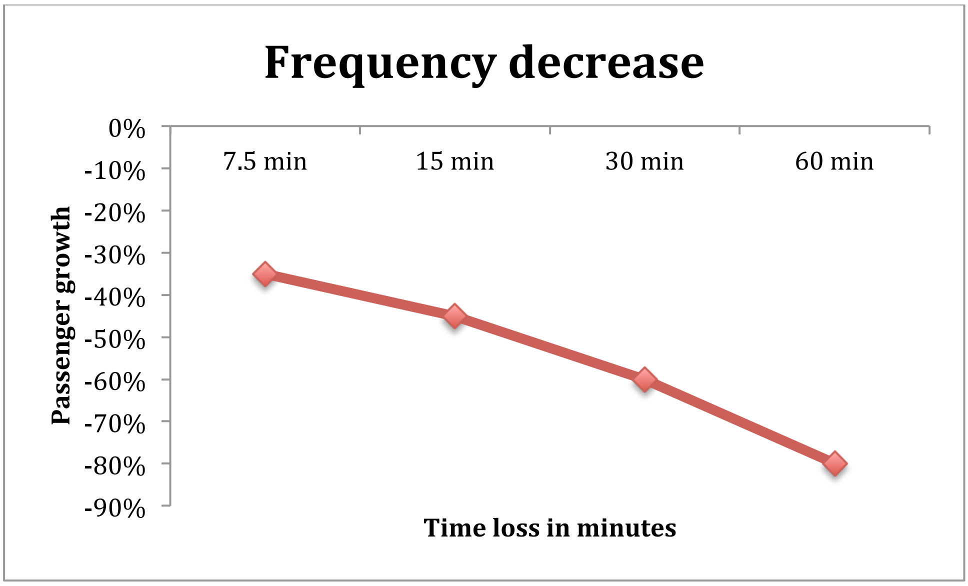


FIGURE 46. PASSENGER LOSS DUE TO FREQUENCY DECREASE

For the first case, the table below shows the average needed frequency of the new bus systems to transfer 445 passengers per hour.

TABLE 134. CASE A: FREQUENCY OF THE SYSTEM TO TRANSFER 445 PASSENGERS

	Current situation	Scenario 1	Scenario 2
Vehicle	Tram	Bus 12 meter	Bus 18 meter
Frequency	4.2	6.5	5.2

Case Study A: The amount of expected passengers is calculated as follows:

Line 12 from tram to bus 12m with a freq of 8.5

An increase in frequency from 4 to 6-7 per hour means instead of every 15 min, a vehicle now arrives every 9 minutes. This means a time gain of around 6 min, which looking at the table, means 10% more passengers….

445*(1-0.043)*1.10 = 490

Line 12 from tram to 18m bus with freq of 5.2

Frequency does not change, however rail bonus:

445*(1-0.043) = 426

Case study B:

Bus line 44 tram, freq from 6.5 to 2.4

Means instead of every 9 min now a vehicle arrives every 25 min meaning a time loss of around 16 min…. which equals a passenger loss of 45%

325*1.043*0.55 = 187

6.5 to 4

instead of every 9 min now every 15 min is a 6 min loss equals passenger loss of around 30%

325*1.043*0.7 = 237

6.5 to 5

instead of every 9 min now every 12 minutes is 3 min time loss is a passenger loss of 5%...

325*1.043*0.95 = 322

CASE STUDY A: TRAM LINE 12 HTM THE HAGUE

Tram line 12 from HTM has about 24 stops and a total length of 8 km. The trams' starting point is at Markenseplein and ends about 40 minutes later at Kalvermarkt/Stadhuis station. A tram is in general more expensive in maintenance and operational costs compared to a bus.

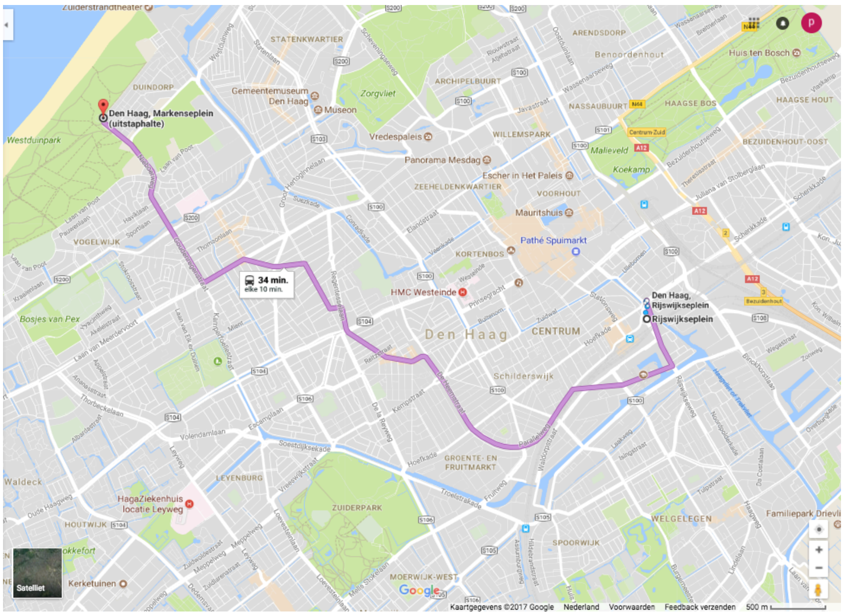


FIGURE 47. MAP TRAMLINE 12 HTM THE HAGUE

Because Public transport already needs to be subsidized by the government, the goal is to make the least amount of loss as possible.

The (average) frequency and operational time of the line are shown in Table 135 below.

TABLE 135. FREQUENCY TRAM LINE 12 HTM

		Frequency				
Start	End	Morning	Afternoon	Evening	Night	Average
06:00	0:00	4.3	4	4.5	4	4.2

As can be derived from the table, the current average frequency (4.2) is lower compared to the average tram frequency (5.5). This shows that this specific line is underperforming compared to average, with regards to frequency. When taking a closer look at the passenger flow, more information will be gathered and a more suitable conclusion can be drawn regarding the performance of this system.

The graph (Figure 48) shows that in total 8000 passengers use this line per direction, per day.

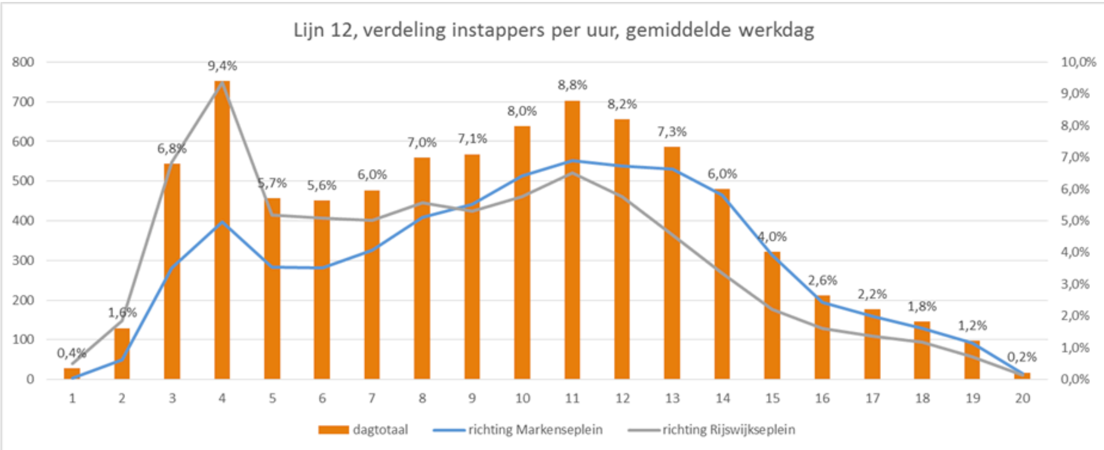


FIGURE 48. PASSENGER GRAPH TRAM LINE 12 HTM

According to the Product Manager Market Exploration and Transport Development of HTM (appendix VI) an "inzetnorm" is used to calculate the average needed capacity for vehicles. This "inzetnorm" is a kind of standard or margin to keep the company from fully utilizing the occupancy rate of a vehicle. This standard is calculated by summing the amount of seats and 50% of the standing places of a vehicle. For an average tram, this standard is 138 passengers, which is about 75% of the maximum capacity of an average tram vehicle. The capacities of the HTM trams can be seen in table 69, below.

TABLE 136. VEHICLE CAPACITY HTM TRAMS

HTM Tram	GTL8-I	GTL8-II	Avenio	Average
Seats	71	76	69	72
Standing places	118	112	168	133
Total	189	188	237	---
Length (m)	28.6	29	35	---

The graph shows that 8000 passengers per day are being transferred with the tram line, per direction. Spread over a whole day, assuming an operational day is 18 hours (06:00-0:00), results in an average capacity of 445 passengers per hour. The new system should, on average, provide the same amount of hourly capacity, the current system delivers.

The hourly capacity of this line can be calculated by multiplying the average frequency of this line (4.2) with the standard of 138 passengers per vehicle, which results in 580 passengers per hour. When changing the tram system with a bus system, the buses should be able to handle 580 passengers per hour. However, as can be seen from the graph, the new system also should be able to deal with peak-hours. The highest peak in the graph shows around 750 passengers. Assuming one 12m bus has a capacity of 68 people, there are 11 buses needed. When using an 18m bus, 7 buses are needed to transfer at least 750 passengers.

Peak hours between: 07:00 – 09:00 and 17:00 – 19:00; dividing the costs into: operational costs during peak hours and operational costs outside of peak hours.

The following scenarios can be distinguished:

TABLE 137. SCENARIOS TRAM LINE 12 CASE A

	Current situation	Scenario 1	Scenario 2
Vehicle	Tram	Bus 12 meter	Bus 18 meter
Frequency	4.2	6.5	4
# of vehicles	---	9	6
# of vehicles during peak hours	---	11	7

Scenario 1: Bus 12m – 90 pass; calculating using the ''inzetnorm'', 75% of the maximum capacity is a system capacity of 68 passengers.

To transport 580 passengers per hour, the frequency needs to be up scaled to 580/68 = 8.5 buses per hour.

Scenario 2: Bus 18m – 149 pass, 75% 'inzetnorm' = 112 passengers;

580/112 = 5.2x per hour (frequency upscale) to transfer at least 580 passengers per hour.

Tram line 12: The Hague HTM – use of Barometer Haaglanden which represents the

TABLE 138. PASSENGERS INDICATORS CASE A

Passengers	Weights	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Frequency	0.178	4.2	6.5	4	Dep./hr./dr.
Punctuality	0.119	91.3	85.82	85.82	%
Passenger Safety	0.116	7.8	7.5	7.5	[1-10]
Operational speed	0.152	17.6	12.5	12.5	Km/h
Accessibility of PT system	0.064	8.5	8.1	8.1	[1-10]
Travel information	0.092	6.7	6.8	6.8	[1-10]
Image	0.042	7.4	7.2	7.2	[1-10]
Travel comfort	0.090	7.5	7.4	7.4	[1-10]
Ticket price	0.147	5.5	4.9	4.9	[1-10]

TABLE 139. PASSENGERS NORMALISED VALUES CASE A

Passengers	Weights	Tram	Bus	Bus
Criterion		Current	12m	18m
Frequency	0.178	0.646	1.000	0.615
Punctuality	0.119	1.000	0.940	0.940
Passenger Safety	0.116	1.000	0.949	0.949
Operational speed	0.152	1.000	0.710	0.710
Accessibility of PT system	0.064	1.000	0.953	0.953
Travel information	0.092	0.985	1.000	1.000
Image	0.042	1.000	0.973	0.973
Travel comfort	0.090	1.000	0.987	0.987
Ticket price	0.147	1.000	0.891	0.891

TABLE 140. PASSENGERS RESULTS CASE A

Passengers	Tram	Bus	Bus
Criterion	Current	12m	18m
Frequency	0.119	0.184	0.113
Punctuality	0.113	0.106	0.106
Passenger Safety	0.104	0.099	0.099
Operational speed	0.178	0.126	0.126
Accessibility of PT system	0.074	0.071	0.071
Travel information	0.092	0.093	0.093
Image	0.047	0.046	0.046
Travel comfort	0.087	0.086	0.086
Ticket price	0.120	0.107	0.107
Result	0.934	0.917	0.847

Change compared to current scenario:

TABLE 141. PASSENGER PERFORMANCE

Passengers	Tram	Bus	Bus
Criterion	Current	12m	18m
Frequency	0%	55%	-5%
Punctuality	0%	-6%	-6%
Passenger Safety	0%	-5%	-5%
Operational speed	0%	-29%	-29%
Accessibility of PT system	0%	-5%	-5%
Travel information	0%	1%	1%
Image	0%	-3%	-3%
Travel comfort	0%	-1%	-1%
Ticket price	0%	-11%	-11%
Result	0%	-2%	-9%

For the calculation of the costs, the following information is used:

- The average frequency of the tram for this case is 4.2
- The average frequency of the bus in scenario 1 is 6.5
- The average frequency for the bus in scenario 2 is 4.0

For calculation purposes, the assumption is made that the frequency equals the number of buses needed.

Operational costs 18m: €1.36 per km / 12m: €1.26 per km

Operational costs during peak hours:

TABLE 142. OPERATIONAL COSTS DURING PEAK HOURS

Bus	During peak (6hours/18)	Outside peak (14 hours/18)	Total
12m	11	9	
18m	7	6	
12m	€887,040 *6/18 = 295,680	€725,760 * 12/18 = 483,840	€779,520
18m	€609,280 *6/18 = 203,093	€522,240 * 12/18 = 348,160	€551,253

Maintenance costs

Peak hour = 07-09 uur en 16-18uur = 4 hrs 22%

Off peak hours = 14 hrs = 78%

TABLE 143. COSTS CALCULATION CASE A

Length line 12 = 8km				
Avg. frequency	4.2	6.5	4	Dep./hr./direction
peak frequency	5.5	11.2	6.7	Dep./hr./direction
System	Tram	Bus 12m	Bus 18m	
Investment total	**€4,200,000**	**€450,000**	**€447,000**	**Per year**
Investment infra	€3,840,000	€384,000	€384,000	Per year for 8 km
Investment vehicle	€360,000	€66,000	€63,000	Per year
Maintenance total	**€2,768,217**	**€758,080**	**€721,472**	**Per year**
Maintenance Peak	€113,342	€38,720	€29,568	Per year
Maintenance off peak	€334,875	€87,360	€59,904	Per year
Maintenance infra	€2,320,000	€632,000	€632,000	Per year
Operational total	**€11.22**	**€9.93**	**€6.34**	**Per year per km**

Operational Peak	€2.84	€3.05	€2.09	Per km
Operational off peak	€8.39	€6.88	€4.24	Per km
Operational costs per year	€621,721	€635,443	€405,606	Per year
TCO	€7,589,938	€1,843,523	€1,574,078	**Per year**

Calculations:

Investment total = investment infra + investment vehicles
Investment infra = investment costs infra per km * length of the system (8km)
Investment vehicles = investment costs vehicle (3mln)* vehicles needed in peak hour (5.5)
Maintenance total = maintenance peak + maintenance off peak + maintenance infra
Maintenance peak = 22% * vehicles needed in peak *km driven per vehicle* maintenance cost per km.
Maintenance off peak = 78% * vehicles needed in off-peak *km driven per vehicle* maintenance cost per km.
Maintenance infra = maintenance costs per km * length of the system (8km)
Operational total = Operational peak + Operational off-peak
Operational peak = 22% * vehicles in peak * operational costs per km
Operational off-peak = 78% * vehicles in off-peak* operational costs per km
Operational costs per year = operational total * km's driven per vehicle
TCO = investment total + maintenance total + operational costs per year

TABLE 144. GOVERNMENT INDICATORS CASE A

Government	Weight	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Operational costs	0.142	0.62	0.64	0.41	€/km
Investments costs	0.155	4.20	0.46	0.45	€mln/km
Maintenance costs	0.177	2.77	0.76	0.72	€mln/km
Liveability inhabitants	0.083	7	6	6	[1-10]
Passenger Forecast	0.147	445	469	426	Passengers
Punctuality	0.063	91.3	85.82	85.82	%
Passenger safety	0.063	3784	1276	1276	€/day
Flexibility	0.107	1	8	8	[1-10]
System Capacity	0.125	138	68	112	passengers

Positive factor: $\frac{X_1}{MAX}$

Negative factor: $1 - \frac{X_1}{MAX}$

TABLE 145. GOVERNMENT NORMALISED VALUES CASE A

Government	Weight	Tram	Bus	Bus
Criterion		Current	12m	18m
Operational costs	0.142	0.022	0.000	0.362
Investments costs	0.155	0.000	0.890	0.894
Maintenance costs	0.177	0.000	0.726	0.739
Liveability inhabitants	0.083	1.000	0.857	0.857
Passenger Forecast	0.147	0.949	1.000	0.908
Punctuality	0.063	1.000	0.940	0.940
Passenger safety	0.063	0.000	0.663	0.663
Flexibility	0.107	0.125	1.000	1.000
System Capacity	0.125	1.000	0.493	0.812

TABLE 146. GOVERNMENT RESULTS CASE A

Government	Tram	Bus	Bus
Criterion	Current	12m	18m
Operational costs	0.003	0.000	0.051
Investments costs	0.000	0.138	0.139
Maintenance costs	0.000	0.129	0.131
Liveability inhabitants	0.083	0.071	0.071
Passenger Forecast	0.139	0.147	0.134
Punctuality	0.063	0.059	0.059
Passenger safety	0.000	0.042	0.042
Flexibility	0.013	0.107	0.107
System Capacity	0.125	0.062	0.101
Result	0.427	0.75	0.835

The percentage shows how much the scenario, as seen from the perception of the government, scores better compared the current situation (Tram). For example, the forecast scores for the 12m Bus scenario 15% better compared to tram scenario, whereas the system capacity scores 51% worse.

Government	Tram	Bus	Bus
Criterion	Current	12m	18m
Operational costs	0%	-2%	153%
Investments costs	0%	913%	940%
Maintenance costs	0%	365%	384%
Liveability inhabitants	0%	-14%	-14%
Passenger Forecast	0%	5%	-4%
Punctuality	0%	-6%	-6%
Passenger safety	0%	297%	297%
Flexibility	0%	700%	700%
System Capacity	0%	-51%	-19%
Result	0%	77%	96%

Result percentage (last row) is calculated by measuring the increase from the current scenario (Tram). For example, the Scenario where a 12 meter bus is used instead of the current tram, scores (in the eyes of the government/as seen from the perception of the government) 111% better (more than 2 times).

Government without investment costs of tram costs

Government	Tram	Bus	Bus
Criterion	Current	12m	18m
Operational costs	0.003	0.000	0.051
Investments costs	0.155	0.000	0.000
Maintenance costs	0.000	0.129	0.131
Liveability inhabitants	0.083	0.071	0.071
Passenger Forecast	0.128	0.135	0.123
Punctuality	0.063	0.059	0.059
Passenger safety	0.000	0.042	0.042
Flexibility	0.013	0.107	0.107
System Capacity	0.125	0.062	0.101
Result	0.570	0.604	0.685

Government without investment costs for tram

Government	Tram	Bus	Bus
Criterion	Current	12m	18m
Operational costs	0%	-2%	153%
Investments costs	0%	N/A	N/A
Maintenance costs	0%	365%	384%
Liveability inhabitants	0%	-14%	-14%
Passenger Forecast	0%	5%	-4%
Punctuality	0%	-6%	-6%
Passenger safety	0%	297%	297%
Flexibility	0%	700%	700%
System Capacity	0%	-51%	-19%
Result	0%	6%	20%

N/A cannot be calculated due to the fact that the investment costs equal 0. Calculation of the improvement therefore is not possible.

TABLE 147. PTO INDICATORS CASE A

Public transport operators	Weight	Tram	Bus	Bus	Unit
Criterion		Current	12m	18m	
Passenger forecast	0.213	445	469	426	Passengers/hr
Earnings	0.121	65.0	74.6	67.7	€/km
~~Politics~~	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	€/km
System capacity	0.12	138	68	112	passengers
Frequency	0.129	3.2	6.5	4	Dep./hr/dir.
Operational speed	0.108	17.6	12.5	12.5	Km/h
TCO	0.158	7.59	1.84	1.57	€mln./year

Passenger safety	0.107	3784	1276	1276	€/day

TABLE 148. PTO NORMALISED VALUES CASE A

Public transport operators	Weight	Tram	Bus	Bus
Criterion		Current	12m	18m
Passenger forecast	0.213	0.949	1.000	0.908
Earnings	0.121	0.871	1.000	0.918
~~Politics~~	---	---	---	---
Ticket price	0.044	1.000	1.000	1.000
System capacity	0.12	1.000	0.493	0.812
Frequency	0.129	0.492	1.000	0.615
Operational speed	0.108	1.000	0.710	0.710
TCO	0.158	0.000	0.757	0.793
Passenger safety	0.107	0.000	0.663	0.663

TABLE 149. PTO RESULTS CASE A

Public transport operators	Tram	Bus	Bus
Criterion	Current	12m	18m
Passenger forecast	0.202	0.213	0.193
Earnings	0.105	0.111	0.101
~~Politics~~			
Ticket price	0.044	0.044	0.044
System capacity	0.120	0.059	0.097
Frequency	0.083	0.129	0.079
Operational speed	0.108	0.077	0.077
TCO	0.000	0.119	0.125
Passenger safety	0.000	0.071	0.071
Results	0.663	0.823	0.788

TABLE 150. OPERATORS PERFORMANCE

Public transport operators	Tram	Bus	Bus
Criterion	Current	12m	18m
Passenger forecast	0%	5%	-4%
Earnings	0%	5%	-4%
~~Politics~~	0%	---	---
Ticket price	0%	0%	0%
System capacity	0%	-51%	-19%
Frequency	0%	55%	-5%
Operational speed	0%	-29%	-29%
TCO	0%	406%	482%
Passenger safety	0%	297%	297%
Results	0%	24%	19%

WITHOUT INVESTMENT PTO

TABLE 151. OPERATORS WITHOUT INVESTMENTS COSTS

Public transport operators	Tram	Bus	Bus
Criterion	Current	12m	18m
Passenger forecast	0.202	0.213	0.193
Earnings	0.115	0.121	0.110
~~Politics~~			
Ticket price	0.044	0.044	0.044
System capacity	0.120	0.059	0.097
Frequency	0.064	0.129	0.079
Operational speed	0.108	0.077	0.077
TCO	0.000	0.072	0.085
Passenger safety	0.000	0.071	0.071
Results	0.652	0.786	0.756

TABLE 152. PERFORMANCE RESULTS OPERATORS WITHOUT INVESTMENTS COSTS

Public transport operators	Tram	Bus	Bus
Criterion	Current	12m	18m
Passenger forecast	0%	5%	-4%
Earnings	0%	5%	-4%
~~Politics~~	0%	~~---~~	~~---~~
Ticket price	0%	0%	0%
System capacity	0%	-51%	-19%
Frequency	0%	55%	-5%
Operational speed	0%	-29%	-29%
TCO	0%	181%	215%
Passenger safety	0%	297%	297%
Results	0%	20%	16%

TABLE 153. RESULTS CASE A TRAMLINE 12 HTM THE HAGUE

Stakeholders	**Tram Current**	**Bus 12m Scenario 1**	**Bus 18m Scenario 2**
Passengers	0%	1%	-6%
Government	0%	77%	96%
Government (- investment)	0%	6%	20%
Operators	0%	24%	19%
Operators (- investment)	0%	20%	16%

Without investments for the tram, the situation seems a little different.

CASE STUDY B: BUS LINE 44 RET ROTTERDAM

Rotterdam – Central station

Length 9.5 km

Plan is to transform into a tram line.

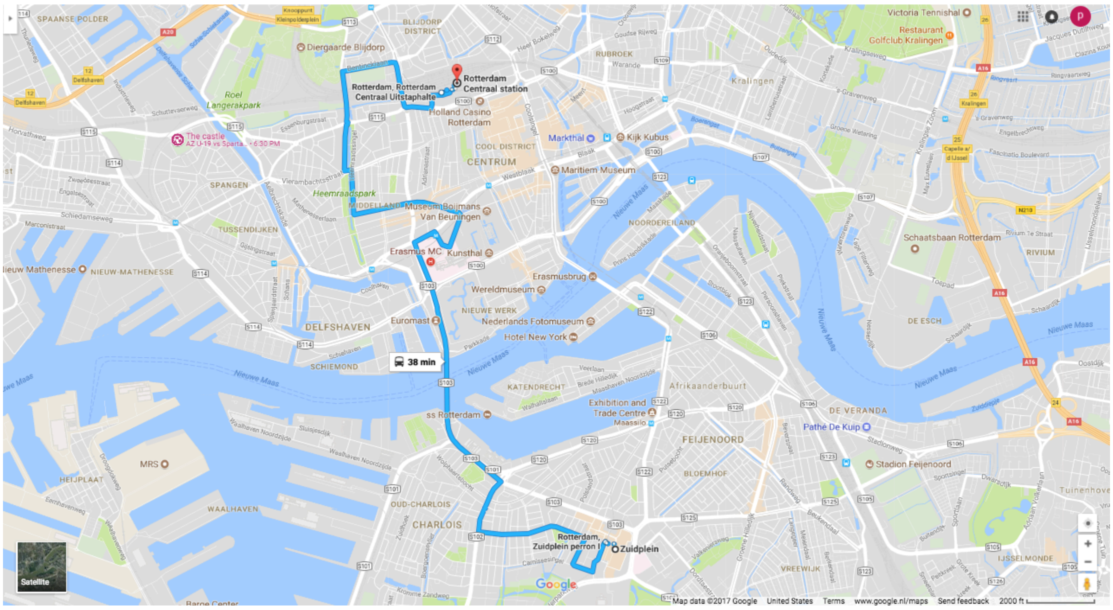


FIGURE 49. ROUTE BUS LINE 44 RET ROTTERDAM

Assumption: just like case A: 9.5% passengers in peak = 556 passengers per hour in peak = 556/138 = 4 trams are needed = max frequency

325 passengers off peak

Duration of the peak = 4 hrs .and the duration of the off-peak = 14 hrs.

Frequency of the current bus line:

TABLE 154. AVERAGE FREQUENCY BUS LINE 44 RET

		Frequency				
Start	End	Morning	Afternoon	Evening	Night	Average
06:00	0:00	9	6	8	3	6.5

Average frequency bus all operators: 3.91 and average frequency RET bus: 3.64. As can be seen this bus drives more frequently compared to the average buses (of RET). The table below, table 86, shows that the daily average of the bus amounts 5847 passengers. Assuming an average daily operational time of 18 hours, the passenger flow amounts: 325 passengers per hour.

To calculate the needed capacity of the new tramline, the current standard capacity of a bus is needed. One bus has a capacity of 90 passengers, assuming the "inzetnorm" standard of 75%, the capacity amounts 68 passengers per bus.

TABLE 155. BUS LINE 44 PASSENGERS (EXCEL

Daily average	Passengers/month
2016-01	5852
2016-02	5797
2016-03	6238
2016-04	5908
2016-05	5433
2017-01	5525
2017-02	6417
2017-03	6375
2017-04	5154
2017-05	5766
Average	5847

The bus line operates 6.5 times per hour per direction, meaning 6.5 multiplied with 68 passengers = 442 passengers per hour. The new tram line, should at least handle the same amount of passengers. As can be derived from the first Case Study, the standard capacity of a tram is 138 (75% of the maximum 180). To transport 442 passengers per hour, the new tramline should have an average frequency of at least 3.2 departures per hour per direction.

TABLE 156. PASSENGERS INDICATOR VALUES CASE B

Passengers	Weights	Bus	Tram	Unit
Criterion		Current	Scenario 1	
Frequency	0.178	6.5	2.4	Dep./hr./dr.
Punctuality	0.119	85.82	91.3	%
Passenger Safety	0.116	7.7	7.8	[1-10]
Operational speed	0.152	12.5	17.6	Km/h
Accessibility of PT system	0.064	8.3	8.7	[1-10]
Travel information	0.092	7	7.3	[1-10]
Image	0.042	7.4	7.6	[1-10]
Travel comfort	0.09	7.4	7.6	[1-10]
Ticket price	0.147	5.7	5.7	[1-10]

Positive factor: $\frac{X_1}{MAX}$

Negative factor: $1 - \frac{X_1}{MAX}$

TABLE 157. PASSENGERS NORMALISED VALUES CASE B

Passengers	Weights	Bus	Tram
Criterion		Current	Scenario 1
Frequency	0.178	1.000	0.369
Punctuality	0.119	0.940	1.000
Passenger Safety	0.116	0.987	1.000

Operational speed	0.152	0.710	1.000
Accessibility of PT system	0.064	0.954	1.000
Travel information	0.092	0.959	1.000
Image	0.042	0.974	1.000
Travel comfort	0.090	0.974	1.000
Ticket price	0.147	1.000	1.000

TABLE 158. PASSENGERS RESULTS CASE B

Passengers	Bus	Tram
Criterion	Current	Scenario 1
Frequency	0.178	0.066
Punctuality	0.112	0.119
Passenger Safety	0.115	0.116
Operational speed	0.108	0.152
Accessibility of PT system	0.061	0.064
Travel information	0.088	0.092
Image	0.041	0.042
Travel comfort	0.088	0.090
Ticket price	0.147	0.147
Result	0.937	0.888

TABLE 159. PERFORMANCE PASSENGERS

Passengers	Bus	Tram
Criterion	Current	Scenario 1
Frequency	0%	-63%
Punctuality	0%	6%
Passenger Safety	0%	1%
Operational speed	0%	41%
Accessibility of PT system	0%	5%
Travel information	0%	4%
Image	0%	3%
Travel comfort	0%	3%
Ticket price	0%	0%
Result	0%	-5%

With regards to the costs to calculate the criteria for the government and public transport operators, the table below, table 160, is used. The same assumption is made as in the first case study, that the amount of vehicles needed equals the capacity (rounding up).

TABLE 160. COSTS BUS LINE 44 TO TRAM CASE B

Length Bus line 44 = 9.5km					
Avg. freq	6.5	2.4	4	5	
peak freq	8.5	4	4	5	
System	Bus	Tram 2.4	Tram 4	Tram 5	
Investment total	**€510,000**	**€4,800,000**	**€4,800,000**	**€4,860,000**	**per year**
Investment infra	€456,000	€4,560,000	€4,560,000	€4,560,000	per yr 9.5 km

Investment vehicle	€54,000	€240,000	€240,000	€300,000	per year for
Maintenance total	**€869,540**	**€331,586**	**€398,561**	**€484,427**	**per year**
Maintenance Peak	€31,680	€75,562	€75,562	€94,452	per year
Maintenance off peak	€87,360	€200,925	€267,900	€334,875	per year
Maintenance infra	€750,500	€55,100	€55,100	€55,100	per year
Operational total	**€11.34**	**€6.45**	**€8.60**	**€10.75**	**per year**
Operational Peak	€2.49	€1.42	€1.89	€2.37	Per km
Operational off peak	€8.85	€5.03	€6.71	€8.39	Per km
Operational costs per year	€725,760	€357,311	€476,414	€595,518	Per year
TCO	€2,105,300	€5,488,897	€5,674,976	€5,939,945	per year

TABLE 161. GOVERNMENT INDICATORS CASE B

Government	Weight	Bus	Tram	Unit
Criterion		Current	Scenario1	
Operational costs	0.142	28.224	17.866	€mln./km
Investments costs	0.155	4.5	33	€mln./km
Maintenance costs	0.117	9.550	27.380	€mln./km
Liveability inhabitants	0.083	6	7	[1-10]
Passenger Forecast	0.147	442	442	Pass/hr.
Punctuality	0.063	85.82	91.30	%
Passenger safety	0.063	1276	3784	€/day
Flexibility	0.107	8	1	[1-10]
System Capacity	0.125	68	138	Pass/vehicle

TABLE 162. GOVERNMENT NORMALISED VALUES CASE B

Government	Weight	Bus	Tram
Criterion		Current	Scenario1
Operational costs	0.142	0.00	0.37
Investments costs	0.155	0.06	0.00
Maintenance costs	0.117	0.66	0.00
Liveability inhabitants	0.083	0.86	1.00
Passenger Forecast	0.147	1.00	0.58
Punctuality	0.063	0.94	1.00
Passenger safety	0.063	0.66	0.00
Flexibility	0.107	1.00	0.13
System Capacity	0.125	0.49	1.00

TABLE 163. GOVERNMENT RESULTS CASE B

Government	Bus	Tram
Criterion	Current	Scenario1
Operational costs	0.000	0.052
Investments costs	0.010	0.000
Maintenance costs	0.077	0.000
Liveability inhabitants	0.071	0.083

Passenger Forecast	0.147	0.085
Punctuality	0.059	0.063
Passenger safety	0.042	0.000
Flexibility	0.107	0.013
System Capacity	0.062	0.125
Result	0.574	0.421

TABLE 164. GOVERNMENT PERFORMANCE MEASUREMENT

Government	Bus	Tram
Criterion	Current	Scenario1
Operational costs	0%	49%
Investments costs	0%	-941%
Maintenance costs	0%	65%
Liveability inhabitants	0%	17%
Passenger Forecast	0%	-42%
Punctuality	0%	6%
Passenger safety	0%	-297%
Flexibility	0%	-88%
System Capacity	0%	103%
Result	0%	-27%

The Earnings is calculated by multiplying the passenger forecast with the ticket price per km of € 0.146. The passenger forecast, in this case amounts 442 passengers per hour.

TABLE 165. OPERATORS INDICATORS CASE B

Public transport operators	Weight	Bus	Tram	Unit
Criterion		Current	Scenario 1	
Passenger forecast	0.213	325	187	Pass/hr.
Earnings	0.121	47	27	€/km
~~Politics~~	~~---~~	~~---~~	~~---~~	~~---~~
Ticket price	0.044	0.146	0.146	€/km
System capacity	0.12	68	138	Pass/veh.
Frequency	0.129	6.5	2.4	Dep./hr./dr.
Operational speed	0.108	12.5	17.6	Km/h
TCO	0.158	2.11	5.49	€mln./yr.
Passenger safety	0.107	1276	3784	€/day

TABLE 166. OPERATORS NORMALISED VALUES CASE B

Public transport operators	Weight	Bus	Tram
Criterion		Current	Scenario 1
Passenger forecast	0.213	1.000	0.575
Earnings	0.121	1.000	0.575
~~Politics~~	~~---~~	~~---~~	
Ticket price	0.044	1.000	1.000
System capacity	0.12	0.493	1.000
Frequency	0.129	1.000	0.369

Operational speed	0.108	0.710	1.000
TCO	0.158	0.646	0.076
Passenger safety	0.107	0.663	0.000

TABLE 167. OPERATORS RESULTS CASE B

Public transport operators	**Bus**	**Tram**
Criterion	Current	Scenario 1
Passenger forecast	0.213	0.123
Earnings	0.121	0.070
~~Politics~~	~~---~~	~~---~~
Ticket price	0.044	0.044
System capacity	0.059	0.120
Frequency	0.129	0.048
Operational speed	0.077	0.108
TCO	0.102	0.012
Passenger safety	0.071	0.000
Result	0.816	0.524

TABLE 168. OPERATORS PERFORMANCE MEASUREMENT

Public transport operators	**Bus**	**Tram**
Criterion	Current	Scenario 1
Passenger forecast	0%	-42%
Earnings	0%	-42%
~~Politics~~	~~---~~	~~---~~
Ticket price	0%	0%
System capacity	0%	103%
Frequency	0%	-63%
Operational speed	0%	41%
TCO	0%	-100%
Passenger safety	0%	-100%
Result	0%	-30%

Table 169, below shows the results of the case study.

TABLE 169. RESULTS CASE B BUS LINE 44 RET ROTTERDAM

Stakeholders	Bus – Current	Tram – Scenario 1
Passengers	0%	-5%
Government	0%	-27%
Operators	0%	-30%

As can be derived from the table, all three groups have a preference for the current situation. The criterion, frequency, scores high for the passengers group, the new case, assumes a frequency decrease from 6.5 to 3.2 vehicle departures per hour. The higher capacity of the tram will result in a situation where, on average, every 20 minutes a tram will arrive instead of every 10 minutes a bus. The waiting time becomes twice as long, explaining the preference for the current situation.

From the government's perspective, the flexibility scores high and the investment costs for the tram are extremely high compared to that of the bus. This makes sense because new railways need to be constructed for the new situation. Both the investment costs as the maintenance costs of the infrastructure contributes highly to the preference for bus.

With regards to the public transport operators, the preference goes to the new alternative, the tram. This observation can be made based on the following three criteria:

System capacity, frequency and passenger safety investments. The system capacity scores higher and in combination with the lower frequency, the same amount of passengers can be transferred.

Change in frequency

Government not taken into account because they already prefer a tram, higher frequency means more trams, means higher costs means lower values for government.

TABLE 170. PASSENGERS INDICATORS WITH TRAM FREQUENCY VARIANTS BUS LINE 44

Passengers	Weights	Bus	Tram	Tram	Tram
Criterion		Current	freq=3.2	freq =4	freq = 5
Frequency	0.178	6.5	2.4	4	5
Punctuality	0.119	85.82	91.3	91.3	91.3
Passenger Safety	0.116	7.7	7.8	7.8	7.8
Operational speed	0.152	12.5	17.6	17.6	17.6
Accessibility of PT system	0.064	8.3	8.7	8.7	8.7
Travel information	0.092	7	7.3	7.3	7.3
Image	0.042	7.4	7.6	7.6	7.6
Travel comfort	0.09	7.4	7.6	7.6	7.6
Ticket price	0.147	5.7	5.7	5.7	5.7

TABLE 171. PASSENGERS NORMALISED VALUES FREQUENCY VARIANTS BUS LINE 44

Passengers	Weights	Bus	Tram	Tram	Tram
Criterion		Current	freq=3.2	freq =4	freq = 5
Frequency	0.178	1.000	0.369	0.615	0.769
Punctuality	0.119	0.940	1.000	1.000	1.000
Passenger Safety	0.116	0.987	1.000	1.000	1.000
Operational speed	0.152	0.710	1.000	1.000	1.000
Accessibility of PT system	0.064	0.954	1.000	1.000	1.000
Travel information	0.092	0.959	1.000	1.000	1.000
Image	0.042	0.974	1.000	1.000	1.000
Travel comfort	0.09	0.974	1.000	1.000	1.000
Ticket price	0.147	1.000	1.000	1.000	1.000

TABLE 172. PASSENGERS RESULTS FREQUENCY VARIANTS BUS LINE 44

Passengers	Bus	Tram	Tram	Tram
Criterion	Current	freq = 2.4	freq =4	freq = 5
Frequency	0.178	0.066	0.110	0.137
Punctuality	0.112	0.119	0.119	0.119
Passenger Safety	0.115	0.116	0.116	0.116
Operational speed	0.108	0.152	0.152	0.152
Accessibility of PT system	0.061	0.064	0.064	0.064
Travel information	0.088	0.092	0.092	0.092
Image	0.041	0.042	0.042	0.042
Travel comfort	0.088	0.090	0.090	0.090
Ticket price	0.147	0.147	0.147	0.147
Results	**0.937**	**0.888**	**0.932**	**0.959**

TABLE 173. PASSENGERS PERFORMANCE MEASUREMENT TRAM FREQUENCIES CASE B

Passengers	Bus	Tram	Tram	Tram
Criterion	Current	freq = 2.4	freq =4	freq = 5
Frequency	0%	-63%	-38%	-23%
Punctuality	0%	6%	6%	6%
Passenger Safety	0%	1%	1%	1%
Operational speed	0%	41%	41%	41%
Accessibility of PT system	0%	5%	5%	5%
Travel information	0%	4%	4%	4%
Image	0%	3%	3%	3%
Travel comfort	0%	3%	3%	3%
Ticket price	0%	0%	0%	0%
Results	0%	-5%	-1%	2%

Change in TCO:

TABLE 174. TCO CALCULATION FREQUENCY VARIANTS BUS LINE 44

System	Bus	Tram 2.4	Tram 4	Tram 5	
Vehicles needed off peak	7	3	4	4	
Length line 44 = 9.5km	9	3	4	5	
avg freq	6.5	2.4	4	5	
peak freq	8.5	4	4	5	
System	Bus	Tram 2.4	Tram 4	Tram 5	
Investment total	**€510,000**	**€4,800,000**	**€4,800,000**	**€4,860,000**	**per year**
Investment infra	€456,000	€4,560,000	€4,560,000	€4,560,000	per year for 9.5 km
Investment vehicle	€54,000	€240,000	€240,000	€300,000	per year
Maintenance total	**€869,540**	**€331,586**	**€398,561**	**€484,427**	**per year**
Maintenance Peak	€31,680	€75,562	€75,562	€94,452	per year

Maintenance off peak	€87,360	€200,925	€267,900	€334,875	per year
Maintenance infra	€750,500	€55,100	€55,100	€55,100	per year
Operational total	**€11.34**	**€6.45**	**€8.60**	**€10.75**	**per year**
Operational Peak	€2.49	€1.42	€1.89	€2.37	Per km
Operational off peak	€8.85	€5.03	€6.71	€8.39	Per km
Operational costs tot.	€725,760	€357,311	€476,414	€595,518	Per year
TCO	**€2,105,300**	**€5,488,897**	**€5,674,976**	**€5,939,945**	**per year**

	Bus	Tram 2.4	Tram 4	Tram 5	
Investment	€0.51	€4.80	€4.80	€4.86	per year
Maintenance	€0.87	€0.33	€0.40	€0.48	per year
Operational	€0.73	€0.36	€0.48	€0.60	per year
TCO	€2.11	€5.49	€5.67	€5.94	mln euro per year

TABLE 175. OPERATORS INDICATORS FREQUENCY VARIANTS BUS LINE 44

Public transport operators	Weight	Bus	Tram	Tram	Tram
Criterion		Current	freq = 2.4	freq = 4	freq = 5
Passenger forecast	0.213	325	187	237	322
Earnings	0.121	47	27	35	47
~~Politics~~	---	---	---	---	---
Ticket price	0.044	0.146	0.146	0.146	0.146
System capacity	0.12	68	138	138	138
Frequency	0.129	6.5	2.4	4	5
Operational speed	0.108	12.5	17.6	17.6	17.6
TCO	0.158	2.11	5.49	5.67	5.94
Passenger safety	0.107	1276	3784	3784	3784

TABLE 176. OPERATORS NORMALISED VALUES FREQUENCY VARIANTS BUS LINE 44

Public transport operators	Weight	Bus	Tram	Tram	Tram
Criterion		Current	freq = 2.4	freq =4	freq = 5
Passenger forecast	0.213	1.000	0.575	0.729	0.991
Earnings	0.121	1.000	0.575	0.729	0.991
~~Politics~~	---	---	---	---	---
Ticket price	0.044	1.000	1.000	1.000	1.000
System capacity	0.12	0.493	1.000	1.000	1.000

Frequency	0.129	1.000	0.369	0.615	0.769
Operational speed	0.108	0.710	1.000	1.000	1.000
TCO	0.158	0.646	0.076	0.045	0.000
Passenger safety	0.107	0.663	0.000	0.000	0.000

TABLE 177. OPERATORS RESULT TABLE FREQUENCY VARIANTS BUS LINE 44

Public transport operators	Bus	Tram	Tram	Tram
Criterion	Current	freq = 3.2	freq =4	freq = 5
Passenger forecast	0.213	0.123	0.155	0.211
Earnings	0.121	0.070	0.088	0.120
~~Politics~~	---	---	---	---
Ticket price	0.044	0.044	0.044	0.044
System capacity	0.059	0.120	0.120	0.120
Frequency	0.129	0.048	0.079	0.099
Operational speed	0.077	0.108	0.108	0.108
TCO	0.102	0.006	0.007	0.000
Passenger safety	0.071	0.000	0.000	0.000
Result	0.816	0.518	0.602	0.702

TABLE 178. OPERATORS CASE B TRAM FREQUENCIES PERFORMANCE

Public transport operators	Bus	Tram	Tram	Tram
Criterion	Current	freq = 2.4	freq =4	freq = 5
Passenger forecast	0%	-42%	-27%	-1%
Earnings	0%	-42%	-27%	-1%
~~Politics~~	---	---	---	---
Ticket price	0%	0%	0%	0%
System capacity	0%	103%	103%	103%
Frequency	0%	-63%	-38%	-23%
Operational speed	0%	41%	41%	41%
TCO	0%	-94%	-93%	-100%
Passenger safety	0%	-100%	-100%	-100%
Result	0%	-36%	-26%	-14%

TABLE 179. INDICATORS GOVERNMENT CASE B

Government	Weight	Bus	Tram	Tram	Tram
Criterion		Current	freq =2.4	freq =4	freq = 5
Operational costs	0.142	0.73	0.36	0.48	0.60
Investments costs	0.155	0.51	4.80	4.80	4.86
Maintenance costs	0.117	0.87	0.33	0.40	0.48
Liveability inhabitants	0.083	6	7	7	7
Passenger Forecast	0.147	325	187	237	322
Punctuality	0.063	85.82	91.3	91.3	91.3

Passenger safety	0.063	1276	3784	3784	3784
Flexibility	0.107	8	1	1	1
System Capacity	0.125	68	138	138	138

TABLE 180. NORMALISED VALUES GOVERNMENT CASE B

Government	Weight	Bus	Tram	Tram	Tram
Criterion		Current	freq =2.4	freq =4	freq = 5
Operational costs	0.142	0.000	0.508	0.344	0.179
Investments costs	0.155	0.895	0.012	0.012	0.000
Maintenance costs	0.117	0.000	0.619	0.542	0.443
Liveability inhabitants	0.083	0.857	1.000	1.000	1.000
Passenger Forecast	0.147	1.000	0.575	0.729	0.991
Punctuality	0.063	0.940	1.000	1.000	1.000
Passenger safety	0.063	0.663	0.000	0.000	0.000
Flexibility	0.107	1.000	0.125	0.125	0.125
System Capacity	0.125	0.493	1.000	1.000	1.000

TABLE 181. RESULTS GOVERNMENT CASE B TRAM FREQUENCIES

Government	Bus	Tram	Tram	Tram
Criterion	Current	freq =2.4	freq =4	freq = 5
Operational costs	0.000	0.072	0.049	0.025
Investments costs	0.139	0.002	0.002	0.000
Maintenance costs	0.000	0.072	0.063	0.052
Liveability inhabitants	0.071	0.083	0.083	0.083
Passenger Forecast	0.147	0.085	0.107	0.146
Punctuality	0.059	0.063	0.063	0.063
Passenger safety	0.042	0.000	0.000	0.000
Flexibility	0.107	0.013	0.013	0.013
System Capacity	0.062	0.125	0.125	0.125
Results	0.626	0.515	0.506	0.507

TABLE 182. GOVERNMENT PERFORMANCE RESULTS CASE B

Government	Bus	Tram	Tram	Tram
Criterion	Current	freq =2.4	freq =4	freq = 5
Operational costs	0%	49%	66%	82%
Investments costs	0%	-941%	-941%	-953%
Maintenance costs	0%	-262%	-218%	-179%
Liveability inhabitants	0%	117%	117%	117%
Passenger Forecast	0%	58%	73%	99%
Punctuality	0%	106%	106%	106%
Passenger safety	0%	-297%	-297%	-297%

Flexibility	0%	13%	13%	13%
System Capacity	0%	203%	203%	203%
Results	0%	-23%	-19%	-19%

IF GOVERNMENT INVESTMENTS COSTS ARE 0:

TABLE 183. CASE B GOVERNMENT WITHOUT INVESTMENT COSTS

Government	Bus	Tram	Tram	Tram
Criterion	Current	freq =2.4	freq =4	freq = 5
Operational costs	0.000	0.072	0.049	0.025
Investments costs	0.155	0.002	0.002	0.000
Maintenance costs	0.000	0.041	0.063	0.052
Liveability inhabitants	0.071	0.083	0.083	0.083
Passenger Forecast	0.147	0.085	0.107	0.146
Punctuality	0.059	0.063	0.063	0.063
Passenger safety	0.042	0.000	0.000	0.000
Flexibility	0.107	0.013	0.013	0.013
System Capacity	0.062	0.125	0.125	0.125
Results	0.643	0.484	0.506	0.507

TABLE 184. GOVERNMENT PERFORMANCE CASE B FREQUENCIES

Government	Bus	Tram	Tram	Tram
Criterion	Current	freq =2.4	freq =4	freq = 5
Operational costs	0%	49%	66%	82%
Investments costs	0%	N/A	N/A	N/A
Maintenance costs	0%	-262%	-218%	-179%
Liveability inhabitants	0%	117%	117%	117%
Passenger Forecast	0%	58%	73%	99%
Punctuality	0%	106%	106%	106%
Passenger safety	0%	-297%	-297%	-297%
Flexibility	0%	13%	13%	13%
System Capacity	0%	203%	203%	203%
Results	0%	-25%	-21%	-21%

TABLE 185. RESULTS FREQUENCY VARIANTS BUS LINE 44

Results	Bus	Tram 2.4	Tram 4	Tram 5
Passengers	0%	-5%	-1%	2%
Government	0%	-23%	-19%	-19%
Government (-investments)	0%	-25%	-21%	-21%
PT Operators	0%	-37%	-26%	-14%

APPENDIX XI. SENSITIVITY ANALYSIS

This appendix presents the sensitivity analysis. The first sensitivity analysis that is performed is the change of the criteria **Image** and **Travel Comfort** of the eBus. These criteria were estimated using input from the interviews with the public transport operators.

The second analysis changes the estimated flexibility values for all modalities to 1. After this, the same is done with the criterion liveability.

The fourth analysis changes the average operational speed of the bus. This value is calculated using data from the Utrecht region. From Brogt (2013) can be derived that the average operational speed of a bus amounts 15-20 km/h. So, this analysis uses an operational speed of 20 km/h to analyse if and how this influences the results.

The final sensitivity analysis compares the results when using data from the MRDH region instead of national data. The 'OV-Klantenbarometer' shows information how in general, passengers perceive public transport. This data can also be filtered using only data from the MRDH Region.

TABLE 186. SENSITIVITY ANALYSIS EBUS VALUES EQUAL TO BUS PASSENGERS

eBus	Bus	Tram	Metro	BRT	LRT	eBus
Normal	0%	-2%	0%	-1%	-1%	1%
eBus = Bus	0%	-2%	0%	-1%	-1%	0%

As can be seen, the result does not differ that much in a sense that the passengers still are indifferent with regards to the system choice.

If the value of liveability is changed to 1 compared to normal: only applicable to government:

TABLE 187. SENSITIVITY ANALYSIS LIVEABILITY GOVERNMENT

Liveability	Bus	Tram	Metro	BRT	LRT	eBus
Normal	0%	2%	-17%	4%	19%	-13%
Liveability = 1	0%	-1%	-21%	2%	14%	-14%

The table shows that the results do not vary that much. The biggest difference that can be observed is the positive perception of the tram to a negative one.

If flexibility is changed to 1:

TABLE 188. SENSITIVITY ANALYSIS FLEXIBILITY GOVERNMENT

Flexibility	Bus	Tram	Metro	BRT	LRT	eBus
Normal	0%	2%	-17%	4%	19%	-13%
Flexibility = 1	0%	17%	-2%	8%	34%	-11%

The flexibility shows a high difference for the Rail-based systems.

Higher operational speed of bus, as stated by Brogt, only operators:

TABLE 189. SENSITIVITY ANALYSIS FLEXIBILITY OPERATORS

Speed	Bus	Tram	Metro	BRT	LRT	eBus
Normal (12.5)	0%	32%	37%	45%	49%	-4%
20 km/h	0%	26%	31%	39%	42%	-8%

The table shows a very low variance in results comparing the modalities to one another.

Passengers National vs. MRDH region

TABLE 190. SENSITIVITY ANALYSIS PASSENGERS NATIONAL VS. MRDH REGION

Passengers	Bus	Tram	Metro
National	0%	-2%	0%
MRDH region	0%	0%	0%

TABLE 191. MRDH VS. NATIONAL RESULTS

Passengers	Bus	Tram	Metro
National	7.347	7.176	7.354
Metropolitan area	7.238	7.23	7.231

Using MRDH region data shows that the perception of the tram changes positive. It seems like the passengers in the MRDH region have a more positive effect regarding rail-based systems.

Taking into account a frequency of 8 trams per hour per direction for the second case study results in the following TCO calculation table:

System	Tram 8 frequency	
Investment total	**€5,040,000**	**per year**
Investment infra	€4,560,000	per year for 9.5 km
Investment vehicle	€480,000	per year for # vehicles
Maintenance total	**€742,023**	**per year**
Maintenance vehicles	€686,923	per year
Maintenance infra	€55,100	per year
Operational total	**€17.20**	**per year for # vehicles**
Operational costs per year	€952,828	
TCO	€6,734,851	per year

A system with length 9.5 km is assumed with a life span of 50 years. Furthermore, the passenger forecast is calculated using the both the frequency bonus (2.5%) and the tram bonus (4.3%). A frequency change from 6.5 to 8 means a loss in waiting time from around 9 minutes to 7-8 minutes. This is a gain of almost 2 minutes with a passenger increase of 2.5%, derived from Appendix X. The number of passengers for a tram system with frequency 8 amounts: 325*1.043*1.025 = 347.

Calculating the perceptions for the three groups results in the following table:

TABLE 192. FREQUENCIES SENSITIVITY CASE B RESULTS

	Bus	Tram 3.2	Tram 4	Tram 5	Tram 8
Passengers	0%	-3%	1%	3%	11%
Government	0%	-18%	-19%	-18%	-31%
Operators	0%	-33%	-24%	-12%	-5%

APPENDIX XII. THE DECISION-MAKING PROCESS

Verkenning: Wat is het doel

Planstudie: wat zijn de kosten, uitvoering, wie financier mee als dit van toepassing is?

Uitwerkingsfase: financiele reservering moet gedaan worden, moment dat geld beschikbaar gested moet worden

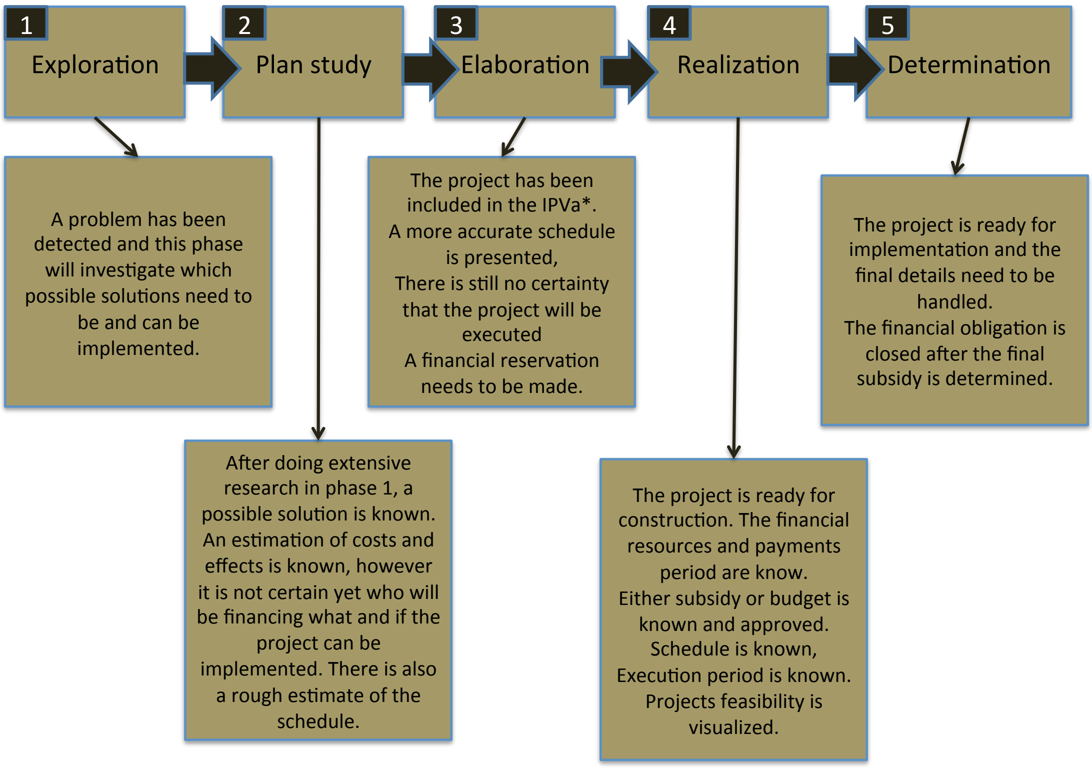
Realisatiefase: Haalbaarheid, wie betaalt wat…

Vaststelling:

Interview Decision-Maker Process

- Where in the process can this information be used?

- How important is the perception of passengers in the decision-making process?



APPENDIX XIII. CRITERIA EXPLANATION

This appendix will provide an explanation of all the criteria, presented in chapter 4.3.

1. Image

This criterion is defined as the image of each public transport system in the eyes of public transport users (van Oort N. , 2011). It is expected that the image of a bus, for example, is different compared to that of a metro or tram. The image of a system is measure in a grade between [1-10], with 1 meaning really negative and 10 really positive.

2. Emissions

Emissions are becoming more and more important nowadays. That is one of the biggest reasons that this is an important criterion to take into consideration when comparing different transport modes (Jain & Tiwari, 2016). Passengers and governmental organisations for example who value sustainability, strive for lower emissions (CROW-KpVV, 2016). The factor Emissions can be measured in grams CO_2 per km [CO_2/km] for each mode (Brogt, 2013).

3. Frequency

The frequency is measured in amount of (planned) departures per hour and also gives information regarding the waiting time for passengers (CROW-KpVV, 2016). It is expected that passengers value systems with a higher frequency higher compared to systems with a lower frequency. However, a higher frequency also means higher emissions, more maintenance costs as a result of wear, higher operational costs, but also a higher transport per capacity (per hour) (Putra & Sitanggang, 2016). The frequency is also a measure for the waiting time. The higher the waiting time, the lower the chance passengers will use this system. Increasing the frequency will lead to a lower waiting time. The frequency of each mode can be measured in amount of vehicles departing per hour in the same direction at the begin station [veh./hr./dir.].

4. Environmental nuisance

Environmental nuisance (Rijkswaterstaat, 2017) can be characterized as the noise public transport systems generate when operational (CROW-KpVV, 2016). This environmental nuisance can be a negative criterion for the inhabitants living nearby the access and egress points. For example, a higher frequency results in more busses, trams or metro's departing and arriving in a shorter time period (Jain & Tiwari, 2016). This will negatively contribute to the environmental nuisance. The environmental nuisance of each modality can be measured in amount of dB above the allowed boundary (NSG, 2004), which can differ per situation.

5. System capacity

System capacity is defined as the maximum amount of passengers that can be transported per bus, tram or metro (RET, 2017). It is expected that a higher capacity will result in the possibility of transporting more passengers. The system capacity of each vehicle can be measured as amount of maximum passengers that can be transported in one vehicle [passengers/vehicle].

6. Operational speed

The operational speed in this research is defined as the average velocity a system overpasses (CROW-KpVV, 2016). This information is important for calculating the total travel time of public transport (van Oort N. , 2011). When competing with cars and other transport modes, the travel time is one of the most important aspects passengers take into account (Wu & Pojani, 2016). The travel time in case of future transportation system is more difficult to calculate, especially when deciding upon different transport systems. The operational speed is measured in average speed of the system in [km/h].

7. Length of the System

The total length of the system can be used to calculate the investment per km. By calculating the investment costs per km, all systems can be compared with each other using the same level of measurement (Infrasite, 2015). The length of the system will influence the image of the city. A shorter length, in this case, directly means more stops which results in more areas becoming accessible. As explained in the text underneath criteria 28 Land and Economic development, higher accessibility contributes positively to the image of the city. The length of the system can be defined as the average distance between stops [km/stop].

8. Total cost of ownership - TCO

The total cost of ownership (TCO) is defined as the costs of a system over its life cycle. It is important to investigate which stakeholders are involved (section 3.2) and determine the costs they encounter throughout the total life cycle of the system (van Oort, van der Bijl, & Maartens, 2016). The total cost of ownership include Operational, Maintenance and Investment costs. The TCO can be measured as yearly cost per system [€/yr].

a) Operational costs

The operational costs are defined as the costs (in €) per km (MacKechnie, Bus and light rail costs, 2016). Information can be found regarding operating costs of public transport vehicles (United States Department of Transportation, 2016).

b) Investments costs

The investment costs is of high importance when comparing and deciding which public transport system suits best for implementation (Weisbrod, Mulley, & Hensher, 2016). The investment costs can be measured in € per year.

c) Maintenance costs

The maintenance costs can be divided into two different costs. The first one is preventive maintenance and can be defined as maintenance to prevent failure of the system (Schiavone, 2010). The second one is corrective maintenance and is conducted when there is a fault in the system (Stiles Machinery, 2012). The maintenance costs can be measured in € per year.

09. Livability inhabitants

A new transport project influences the view, quality and privacy of the nearby inhabitants. This factor is coherent with the environmental nuisance and may have a negative aspect on the livability in an area (van Oort N. , 2011). The livability is going to be measured on a [1-10] scale, where 1 means that the system has a very negative impact on the livability of the inhabitants and 10 meaning no negative impact at all.

10. Passenger safety

Information regarding the safety of passengers will give some insight in how safe the passenger feels when using a specific transport mode. It is also important to investigate how the public transport operators are trying to keep the safety high (Gray, 1979). These safety measures can be different within the systems and therefore also have another feeling of safety. Measuring the passenger safety is different for the groups, based on their perception. The passengers for example, see safety as a how they feel or perceive safety in while using the transport system. The passenger safety, in this case, can be defined in a grade between [1-10], with a 1 meaning very unsafe and a 10 very safe. However, the public transport operators and the government invest in passenger safety and therefore, it can be measured in € invested in safety measurements per day [€/day] (explained more extensively in Appendix VII, Section M).

11. Possibility for Autonomous system

When looking at future public transport services, it is expected that the majority, if not all, systems will become driverless (Fountain, 2016) (McDermott, 2017). When comparing different public transport systems, it is important to take into account the possibility and level of ease to change to an autonomous system. This criterion can be measured using a [1,10] scale with 10 representing easy to automate and a 1, no possibility to automate.

12. Flexibility

The flexibility of a system can be defined as the dependency on the infrastructure and the possibility to take de-routes if necessary, while maintaining around the same level of quality. A bus for example, has a very low dependency on the infrastructure, especially compared to rail based systems such as a tram or metro (Eisenkopf, Burgdorf, & Knorr, 2017). When there is an accident on the road or it is closed for maintenance, the bus can easily take another route having a high flexibility, while maintaining the same level of quality. Systems that have a high dependency on their infrastructure, such as the tram and metro for example, are less flexible. The flexibility can be measured with a [1,10] scale, with 1 meaning not flexible at all with a high dependency on its infrastructure and 10 meaning highly flexible, no dependency.

13. Travel (& Seat) comfort

The travel and seat comfort (CROW-KpVV, 2016) contributes to traveling experience (van Oort N. , 2011). The higher this comfort, the better the experience (Gray, 1979). This aspect will differ between the different modalities so passengers may prefer one mode over the other based on travel comfort. The OV Klantenbarometer (Customer Barometer) of 2016, conducted by the Kennisplatform Verkeer en Vervoer (KpVV) in the Netherlands is a survey which measures the experience, opinion and perception of passengers on public transport systems (CROW-KpVV, 2016). The following four criteria, among other ones, are measured and the average of these four is a grade for the overall travel comfort. The travel comfort is divided in the following four aspects:

Seating availability, Noise, Driving style and Cleanliness. The travel comfort can be defined with a grade between [1-10], with a 1 meaning highly uncomfortable and 10 highly comfortable.

14. Accessibility of PT System

Different modes all have different entry or exit barriers resulting in different accessibility levels (CROW-KpVV, 2016). A metro for example, operates most of the time underground making it less accessible compared to a standard bus. For passengers, this aspect may play an important role when making decisions about which transport system to choose. For other stakeholders who are involved in the construction of these systems and stops, the accessibility also may play an important role.

15. Ticket price

The ticket price is also an important aspect to take into account. The passengers for example, will likely to use public transport far easier at a lower price. The service operators however, such as RET and HTM experience more income at higher ticket prices (CROW-KpVV, 2016). Furthermore, this ticket price will influence the earnings. The ticket price can be measured in € per km.

16. Additional passenger services

Offering additional services, such as Wi-Fi in the metro or bus contributes to highly to a positive passenger experience (RET-wifi, 2015). Additional services, however, do come with extra costs for the service operators. Furthermore, different transport systems may be able to provide different additional services. The additional services can be defined with a grade between [1-10], 1 no additional services, 10 high amount of additional services.

17. Travel information (in system)

Providing travel information at stations and in the systems also contributes positively to passenger experience (CROW-KpVV, 2016). For the service operators, this will bring additional costs. When comparing different systems with each other, the provided information in the system may be different. The travel information can be defined with a grade between [1-10], 1 no information, 10 a great amount of information.

18. Driver/staff interaction (help) with passengers

The driver's interaction differs within each system. For example, in the bus, this interaction is higher compared to a metro, where the driver hardly interacts with its passengers. This interaction has an influence on the passengers travel experience. When thinking about autonomous vehicles, this interaction factor is being scaled out, which will save significantly in costs for the service operators. The drivers' interaction can be defined with a grade between [1-10], with 1 meaning (almost) no interaction and 10 full time interaction.

19. Parking availability at stops (car, bike)

With regards to passenger services, parking availability at stations is also an important factor that contributes to passenger experience/happiness. When more parking is available, the passenger has less trouble to park their bike or car and this increases the accessibility of the system. A bus station for example, almost always has lower parking availability. However, this is because the amount of passengers one bus stop has to serve is far lower compared to that of a metro station. This research will further investigate, if this criterion is chosen as important enough, how passengers value this aspect for each system. The importance of parking availability can be defined with a grade between [1-10], 1 no parking availabilities and 10 always parking spots available near the entrance.

20. Punctuality

The punctuality is a measure to define the amount of times a vehicle arrives on time at the designated stop, according to its schedule (Rudnicki, 1997). This is an important factor because the punctuality contributes to the reliability of the system. A high punctuality means that the public transport vehicle, most of the time, if not always, arrives at the predefined time, making the system more reliable. The punctualities for the various modes are defined differently, dependent on each operator. This definition is dependent on the departure stations, important nodes, time-stations and transfer stations. Furthermore, the punctuality also depends on the difference in real-time departure compared to the departure time in the timetable. Some systems or operators use a margin of 3 minutes, while other ones use margin of maximum 2 minutes. This is further discussed in the recommendations and Appendix VII, Section E. The punctuality can be measured in percentage [0-100%], however, via a survey, an image can be obtained how the passengers perceive the punctuality.

21. Forecast Passengers

The criterion Forecast Passengers can be characterized as the expected amount of passengers using the system (Andersson, Brundell-Freij, & Eliasson, 2017). This is an important aspect, mainly for municipalities and public transport operators. From this information they can derive the amount of expected passengers that will use the system and supply the correct amount of material and personnel. This will also give them insight in the overall expenses based on the demand. The forecast can be measured by amount of expected passengers, [passengers].

22. Earnings

Earnings could be an important aspect for the government and more importantly the public transport operators. This will give an estimation of the earnings of the tickets and will provide insight in the profits of the transport system. Most of the public transport systems are loss-making systems which means subsidies are needed from the government keep them operational. The higher the earnings, the less subsidy is needed meaning a healthier financial situation of the public transport operators. Assuming that a fixed amount of subsidy is received, the remaining could be used for improvements of/in the system. Another aspect which could be taken into account in the Earnings is the increase in land value. The earnings can be measured in € per km [€/km].

23. Political considerations

Political considerations is also an important aspect which influences the decision-making process (Carmen & Lidestam, 2016). There are examples of non-profitable projects where no-one exactly knows why and how they are implemented (Rosenberg, 2016), (Sturm, 2008). Another aspect that can be decisive is the Alderman and his/her wishes. The influence of an Alderman on the process can be quite important especially if his/her intentions are to leave a landmark behind (Wijmenga, Veeneman, & Hirschhorn, 2017).

This factor can be characterized under the E5. Equity element of the 5xE framework, because this element describes the equality of public transport. This political pressure should serve as a tool to connect all parts of the city with each other and making facilities in and around the city as accessible as possible.

The political considerations factor is not taken into account, also explained in section 5.2, due to the difficulty in estimating this criterion. It is still a highly important factor, especially in the decision-making process. However, almost impossible to quantify and therefore will be left out of scope in this research.

24. Robustness

Robustness in public transport can be defined as the extent in which the system and its performance can cope with disruptions and disturbances (Cats, Koppenol, & Warnier, 2017). This is an important aspect to take into account when deciding upon public transport. Not only for operational purposes but also from an investment point of view, this can be an important factor to look at. The more robust the system usually means higher investment and/or maintenance costs. From a passengers point of view, a system that could deal with more disturbances compared to other ones is more interesting because of the higher likelihood of arriving at the destination on the specified time. Robustness can be measured, as described by Snelder (2010) and Yap (2014), by vehicle loss hours [vehicle loss hours].

25. Security

The security of public transport also differs per modality. A metro for example has higher capacity and therefore is able to transport more people in the same time period. A higher density of people increases the risk of, for example, a terrorist attack. Besides the capacity, one of the aspects that also play an important role is the dependency on the infrastructure. The higher the dependency, the less ways passengers are able to escape in case something bad happens. A system that can transport a high amount of people, on a dedicated infrastructure having a low flexibility looks a like an easy target. This should be more than enough reason that a system that meets the above-mentioned requirements should have a higher security level (Civitas, 2011).

26. Spatial quality

Spatial quality can be defined as the influence of transportation projects on land use (Leendertse, Langbroek, Arts, & Nijhuis, 2016). A new transport project influences the not only the surrounding area, but also the area where the stops and infrastructure is constructed. The development of these stops and infrastructure are built at the expense of greenery. The space that is lost when implementing a new system and its influence on its environment, should also be a factor to take into account (NCEA, n.d.)

27. Life span

Life span of the systems in years is dependent not only on the infrastructure but also on the vehicles. The life span of the infrastructure usually is higher compared to the life span of the vehicles. Both the life span of the infrastructure and the vehicles differs per modality. A bus for example has a lower life span compared to a metro (Kay, Clark, Duffy, Laube, & Lian), (MacKechnie, 2017), (Singal, 2015) & (Wijmenga, Veeneman, & Hirschhorn, 2017). A higher life span increases the value of the city and some systems are built for decades to operate within and around the city. The life span of the system be measured in years and will be indicated by the life span of the vehicles [years].

28. Land and economic development

The factor land and economic development can also be seen as one of the wider economic benefits of public transport. As explained above, in the introduction of section 3.2.1, this factor measures, in what way the new public transport system contributes to land and economic development. One example can be derived from the observation made by Schafer & Viktor (1998), that faster modes of transport lead to people living further away from their work. Higher income leads to spending relatively more on travelling which results in increasing distances between home and work. If people commute further away from home and travel times decrease, cities become larger making more areas better accessible. This directly has a positive effect on the economic development of these and surrounding areas (van Oort & van der Bijl, 2014).

In literature, various effects can be found regarding the influence of public transport (systems) on the surrounding environment. Boarnet (2011) states that major transport infrastructure investments do contribute to the economic conditions and are powerful determinant of urban development patterns. Bollinger and Ihlanfeldt (1997) make two distinctions in land use impact:

1. Regional growth due to increased productivity
2. Local growth, around the station(s), due to higher accessibility

One example of the above-mentioned observations can be seen in a study conducted by by Catala, Reader and Perk (2012), the vast majority of the studies find positive impacts on property values from nearby rail transit. Another example was found by Mullins, Washington & Stokes (1987) that the BRT in Ottawa had some positive effect on land development in areas surrounding stations. In a report of the Federal Transit Authority, land use impacts of BRT are examined (FTA-BRT, 2009). They identified that property values near a BRT station (or system) increased between 7.6% and 14% in cities all over the world, from Los Angeles to Beijing. Other studies regarding the effect of LRT on property values found an increase in value between 7%-22% (Wienberger, 2001), (Mohammad, Graham, Melo, & Anderson, 2013). The land and economic development can be measured in [€ per m^2].

29. (Carrying of) extra and special luggage

Carrying extra or special luggage can also be a factor influencing the mode choice. This aspect mainly is applicable to passengers (Eisenkopf, Christian Burgdorf, & Andreas Knorr, 2017). One example is taking your bike in public transport. According to the RET for example, bikes are allows in busses and trams and only in the metro before 16:00 or after 18:30 (RET-fiets, n.d.). This factor is measured using a scale between [1-10] with a 1 meaning not allowed or possible in the system and 10 fully and always allowed.