Bus Rapid Transit

Establishment of a BRT design model to design and evaluate BRT configurations

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Establishment of a BRT design model to design and evaluate BRT configurations

By

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Preface

This thesis is the result of my graduation research concerning the topic of Bus Rapid Transit. This is a conclusion of the Master study Transport, Infrastructure & Logistics at the Delft University of Technology.

A research is conducted into the applicability of different Bus Rapid Transit (BRT) configurations. Based on knowledge acquired from researching a set of reference systems, a BRT design model is formulated, which is subsequently implemented into a tool, the BRT design scanner. This scanner provides the possibility to investigate, based on the local conditions, the applicable BRT-configuration. Finally, to assess the quality of the scanner, it is applied on the BRT service through Leidsche Rijn.

The research is conducted on behalf of Movares, a leading engineering consultancy company covering the fields of infrastructure, public transport, mobility, power, waterways and urban development. I am grateful I have been given the opportunity to conduct this research as a graduation project, and work there as an intern.

I would like to thank some people who helped me during the execution of this project. First of all I would like to thank, Mario Genot as supervisor of Movares and Niels van Oort, Jan Anne Annema and Bart van Arem from the TU Delft for their helpful comments during the execution of this project.

Furthermore, conducting the evaluation of the BRT design scanner based on the bus service through Leidsche Rijn would have been difficult without the help of Rob Tiemersma from the Municipality of Utrecht and Fabian Wegewijs form the former Bestuur Regio Utrecht. The knowledge and data they provided about the area, and in particular the bus service, was key to the successful execution of this evaluation.

Last but not least, I would like to thank my parents, sister and girlfriend who always supported me during the execution of this research.

Patrick van der Meijs
June, 2015

Summary

It has been observed that the popularity of Bus Rapid Transit (BRT) is increasing. With that, its difference in appearances naturally also is increasing. However, the knowledge about the applicability of these different forms seems to be lagging behind. It is expected that, just like worldwide, the demand for high quality bus services in the Netherlands will continue to grow. This can partly be devoted to the high costs of light rail projects, in combination with the lack of available funds caused by the current economic situation. Also, the demographic characteristics of the Netherlands encourage bus systems. With a lot of relatively small cities (where a tram connection is often not cost-effective) and many people who daily are using bicycles that form a potential group of new bus users. Therefore, additional insight in the relation between different appearances of these systems and their applicability in different situations is desirable. By conducting research on this topic, a better insight in opportunities, risks, costs and benefits of the possible design choices can acquired and the decision making process can be enriched. An associated higher goal is to enrich the insight in the applicability of different BRT configurations, compared to various other public transport applications, in different situations.

In this research the drivers behind, and results of, design choices in BRT systems worldwide are researched. The final goal is to obtain insight in the applicability of different BRT configurations. These insights will be translated into a BRT design model presenting the appropriate design decisions adapted to the local conditions. To make the model easy and attractive to work with, the model will be implemented in a software tool, the BRT design scanner. This scanner will be able to indicate the appropriate BRT configuration for new systems. Also, the scanner can be used to evaluate the configuration of existing systems.

The main research question identified for this research is: *How to decide on the applicable configuration of a BRT system?*

This main research question will be answered based on the approach as presented in Figure i.

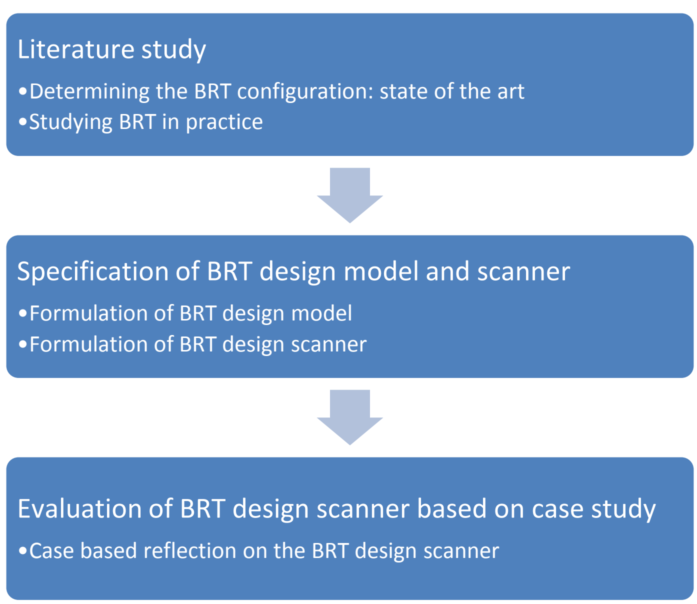

Figure i: Research approach to answer main research question

Determining the BRT configuration: state of the art

From a diversity of definitions, BRT has been identified as a bus-based public transport service that performs well in terms of speed, reliability, comfort and capacity and beside that is associated with a high flexibility and relatively low costs. It has also been identified that this performance is generally reached by making improvements to the system elements: infrastructure, stations, vehicles, fare collection, Intelligent Transport Systems (passenger information, signal priority), distinctive identity.

From researching the appearance of BRT systems all over the world, it was concluded that a great variety of different design variables are associated to these system elements. It also appeared that the configuration of these design variables differs greatly.

From an investigation of four available models that advice about the appropriate BRT configuration; none is identified to use the same approach as this research.

Studying BRT in practice

The performance of a set of 20 reference systems is assessed. These are BRT systems in the cities of Rouen, Utrecht, Almere, Urumqi, Metz, Nantes, Paris, Beijing, Changzhou, Los Angeles, Johannesburg, Mexico City, Lanzhou, Nagoya, Istanbul, Guangzhou, Bogota, Amsterdam and Brisbane.

For this assessment, the performance indicators *infrastructure costs*, *operational speed*, *passengers per hour per direction*, and *passengers per day* are used. Also a set of 24 design/context variables has been determined. Subsequently the characteristics (by design variables), and performances (by performance indicators) of the reference systems were examined. By subsequently researching the relation between these two insights are gathered about how these systems perform.

The main lesson that could be extracted from this research is the importance of commitment. In this context, commitment is explained as the willingness to create a system that first of all conforms to the primary goals of the system: pleasant experience, clear, comfortable and fast, but most importantly, reliable and safe. Each element should be cost-effectively configured to such a level that the primary performance is reached. This level is however dependent on the local conditions. These founding's confirmed that the approach, to separately match the implementation of each specific design variable with the local conditions is appropriate.

Formulation of a BRT design model

The research into the performances of the set of reference systems provided inputs for the formulation of a BRT design model. 12 design variables have been eventually implemented in the BRT design model. These 12 design variables are recognised to be significant determinants of the primary performance of the system (speed, reliability,..).

The BRT design model is intended to advice on the applicable configuration of a BRT service, considering the local conditions. By using this model, in the exploratory stage of a (potential) project, within a few minutes, an advice is presented about the organization of a set of design variables that mainly determine the primary quality of the bus service. The model can also be used to assess the qualities of an existing BRT system.

Two categories of design variables are distinguished in the model. Design variables of which the optimal configuration is identified to be relatively insensitive to the local conditions (4 variables), and design variables of which the optimal configuration is identified to be sensitive to the local conditions (8 variables).

For the 4 design variables, notwithstanding the local conditions, the following is recommended:

- **Fare collection**: To reduce the dwell times, locating the fare collection process at to the stop is identified as an effective measure. For the Dutch situation, this implies that check in devices should be located on stops, and buying tickets from bus drivers should be discouraged.

- **Enhanced stations**: It is identified that it is preferable to enhance the quality of the stations, more than just providing the basic facilities shelter and seating. By (potential) customers, the stations should be identified as an access point of a high quality mode of public transport.

- **Station level boarding**: It is identified that to speed up the dwell procedure, providing station level boarding is a basic requirement.

- **Dynamic travel time information**: Considering the current state of art of vehicle following techniques, and the customer satisfaction it adds, dynamic travel time information is identified as a requirement.

To generate recommendations for the 8 design variables of which implementation depends on the local conditions, 11 input variables have been identified. These input variables are intended to capture the local conditions. For these 8 design variables, the following is recommended:

- **Type of infrastructure**: Depending on the traffic flow on the trajectory and the priority to reach a high level of speed and reliability, the suitable infrastructure type can be assessed.

- **Type of intersection**: The type of intersection is identified to be crucial to the systems success. It is identified that in case the type of intersection is not adjusted to the local conditions, this can result in a service that performs badly in terms of speed and reliability. In many occasions this means that, to realize competitive levels of speed and reliability, full priority or grade separation on intersections is required.

- **Open or closed system**: To be able to define if either an open (operational mode is direct service) or closed system (operational model is trunk only or trunk feeder) is optimal, it is identified that it is essential to evaluate the origins and destinations of the users of the systems.

- **Express service**: Depending on the distribution of the travel demand and the stop spacing of the service, it is identified that express services sometimes can provide significant travel time profits. However, the reduction of the clearness of the system appears to be a disadvantage.

- **Branding of elements**: It is identified that the branding and identity is a vital aspect of a BRT system. The type of system (open or closed) appeared to be decisive when recommending the elements that should be branded.

- **Positioning of system in market**: As stated above, it is identified that the branding and identity is a vital aspect of a BRT system. It appeared that the presence of existing high quality public transport systems in the surrounding determine the optimal way the system is positioned in the market. Options are connecting it to, or differentiating from, these existing systems.

- **Access and egress transport by bicycle**: It has been identified that with larger stop spacings, the bicycle becomes a more attractive mode for access and egress transport. To capture this potential travel demand, as the stop spacing increases, high quality bicycle parking facilities become more necessary.

- **Passing opportunities**: It is identified that that in case expresses services are incorporated; the need for passing opportunities should be assessed.

Formulation of a BRT design scanner

The BRT design scanner is developed to make the BRT design model easy and attractive to work with. The scanner is constructed in Microsoft Excel and is supported by a graphical interface, constructed with Excel's supported programming language: Visual Basic for Applications (VBA). The scanner implements and automates the relations of the BRT design model. By this, an interactive tool is created that links the input variables to the output variables. Figure ii presents a screenshot of the BRT design scanner.

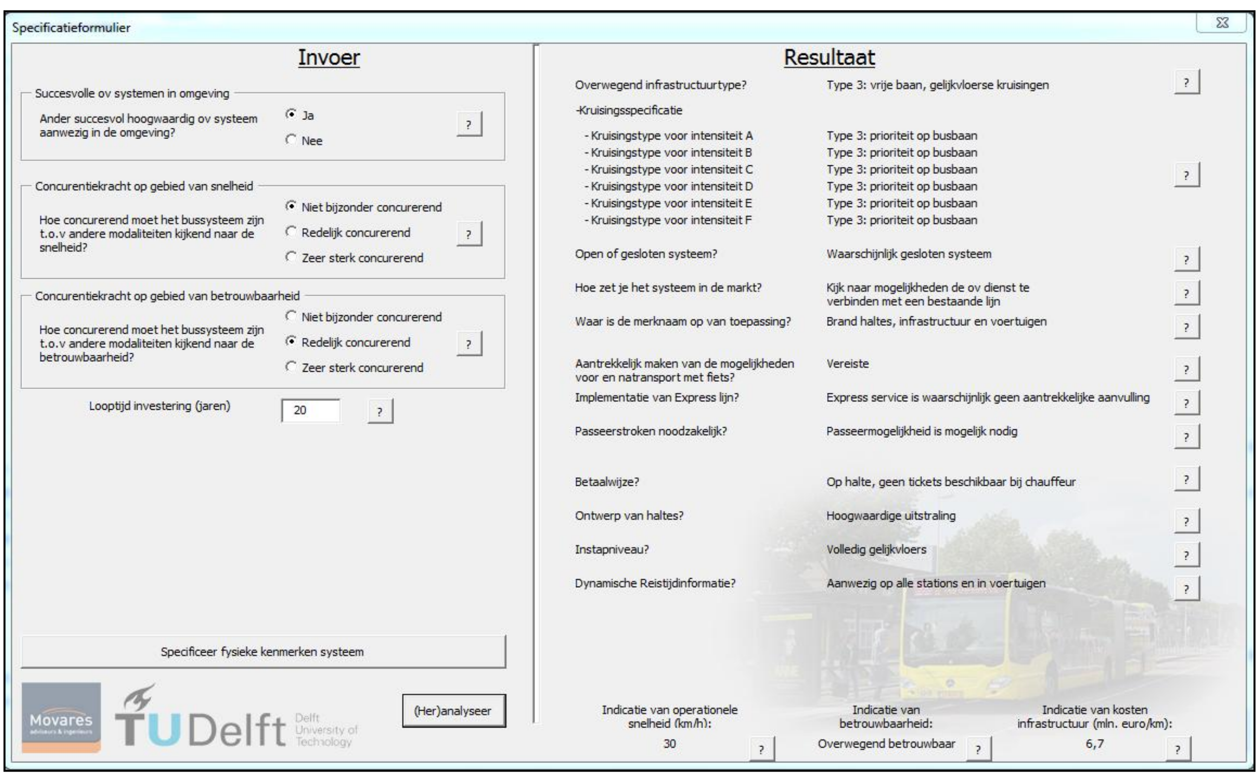

Figure ii: Screenshot of the BRT design scanner

Case study based reflection on BRT design scanner

The constructed BRT design scanner has been reviewed based on a case study. The goal of this case study was to reflect on the quality of the advices generated by the scanner and to generate potential improvements to the scanner (and underlying model). The case studied was the high quality bus service between Station Vleuten through Leidsche Rijn to Utrecht CS (see Figure iii).

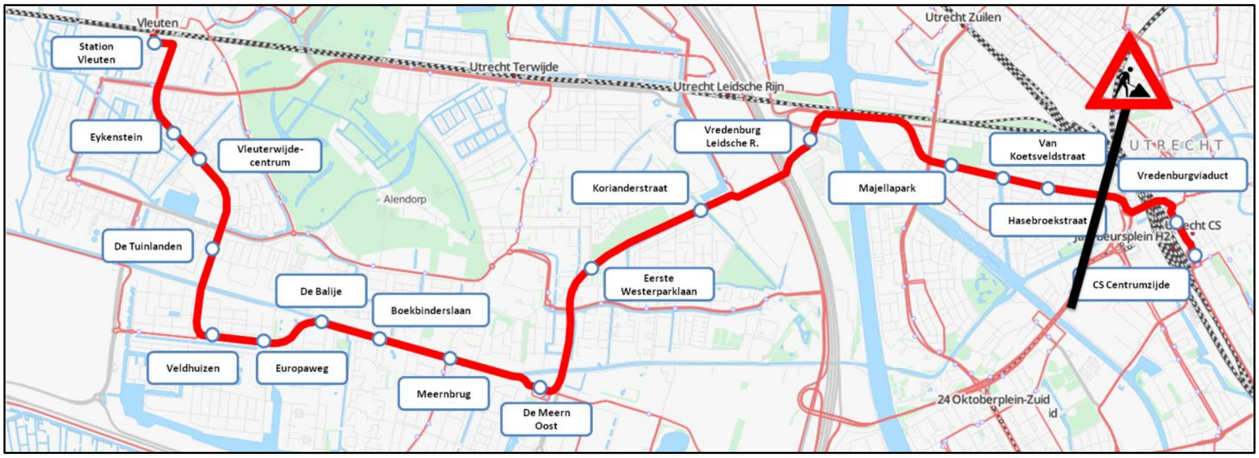

Figure iii: Trajectory of the bus service through Leidsche Rijn

The quality of advices, for this particular case of the BRT system of Leidsche Rijn, as provided by the scanner, has been assessed by a comparison of the differences between the advised and realized configuration. Based on this reflection, the optimal configuration as outcome of the scanner seems to be plausible.

Also three of the advised improvements to the bus service have been analyzed by means of a Societal Cost Benefit Analysis (SCBA). An in dept analysis of three design variables (*express service, intersection treatment and fare collection procedure*), indicated that the suggestions of the scanner for these design variables were useful for the investigated service. From this analysis is has been concluded that the suggested measures can significantly reduce the travel time and result in very high profits on a yearly basis. Additional to these calculated travel time profits of around € 2.200.000 per year, also the reliability is greatly improved. On the other hand, the investment costs and the nuisance for other traffic will increase.

During the execution of this case study, also a set of improvements have been formulated to the interface and internals of the BRT design scanner. These improvements were identified to be able to enrich the usability and predictive quality of the scanner, but were however not implemented because of the restricted time available for this study.

Conclusions

From this research it has become clear that BRT provides the possibilities to create well functioning public transport systems, which are able to attract a lot of users. The implementations of design variables, to create these well functioning systems, however differ among these systems. From the diversity in BRT configurations, of which some with a 'light' configuration are functioning well, and others with a 'full' configuration do not, it is concluded that there is no standard recipe to achieve such a well functioning BRT system.

It appeared that the local conditions of the system (the policy context and the system/spatial characteristics) are especially determining the applicable configuration of a set of design variables. In addition, also for a set of design variables, the optimal configuration appeared to be to be relatively insensitive to different local conditions.

In total 12 design variables have been identified, on which the emphasis should be, in an early stage of the design procedure. The BRT design scanner and its underlying model, as formulated in this research, can be consulted to provide an insight in the applicable configuration, based on the specific local conditions.

The BRT design scanner suggests the applicable configuration for 12 important design variables. However, in the complex playing field a system is designed, compromising between different interests is more the norm than the exception. Therefore, key to a successful design is commitment, commitment to create a high quality system.

Although commitment to avoid compromises for each of the 12 design variables, the design variables impacting the speed and reliability are even less desired to be compromised on. These are identified to be the fare collection location, level of boarding, type of infrastructure and most importantly, the type of intersection.

Discussion and recommendations

Discussion of applicability of BRT design scanner

This research is focused on the applicability of BRT, the spectrum of public transport solutions is however much larger. Beside BRT, also Tram, Light Rail, Metro or even heavy rail services can be used to accommodate the wish for a high quality urban public transport service. Lots of research is available about the applicability of BRT compared to other modalities. Among other (Cain & Flynn, 2013; Cervero, 2013; Currie, 2005; Hidalgo, Muñoz, King, & Shastry, 2013; Tirachini, Hensher, & Jara-Díaz, 2010) researched this topic. This research assumes the decision for BRT as fixed, and studies the applicability of BRT within its own modality.

The focus in this research is on the optimal design of a BRT service form the perception of the user. Focusing on the design from the perspective of the society can provide additional insights. It is not researched how the implementation of a BRT service have an as high as possible positive effect, on the environment it is situated in. Several sources suggest that the effects of a service on its environment are however recognizable (Cervero & Kang, 2009; Deng & Nelson, 2012; Lindau, Hidalgo, & Facchini, n.d.). It is recommended to research the implementation of design variables also from this perspective.

Although the model is effectively able to reduce the design space so that only the most promising options remain, further analysis would be necessary for each of the relevant design variables.

Within the available time, this research aimed to address the most important design variable from the perspective of the user. However, considering the complexities and flexibilities of the BRT mode, there are also many aspect of BRT that were not addressed. As such, the BRT scanner should be valued as preliminary version, which can be further expanded and improved.

Discussion of validation procedure of the BRT design scanner

The evaluation of the BRT design scanner is currently based on the evaluation of one case only, the case of Leidsche Rijn. It is recognized that by using more cases to review the scanner on, the validity of the suggested configuration of the output variables can be assessed.

Also, by testing the scanner on more cases, the validity of the input variables can be assessed further. By using more cases to review the scanner on, it can be investigated if the used input variables are also applicable and sufficient to capture the local conditions of other systems.

For the case of Leidsche Rijn, the case the scanner is currently reviewed on, it was a priory expected that a certain improvements could be suggested. In this way the quality of the advices provided by the scanner are evaluated. Another way to test the quality of the advices of the scanner is by trying to reproduce a BRT system that is considered to be of 'high quality'. By identifying the input variables of such a system, of which it is the idea that the design choices are optimal, it can be identified how the scanner conforms to this system. In fact, for the most thorough evaluation of the BRT scanner, it could have been tested against all the reference systems that have been studied.

In the current validation procedure, no sensitivity analysis is conducted. By analyzing how the output of scanner changes by certain changes of the input variables, the sensitivity can be tested.

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Glossary

- **System component**. Six system components are identified: *infrastructure*, *stations*, *vehicles*, *fare collection*, *ITS: Intelligent Transport Systems (passenger information, signal priority)* and *distinctive identity*. To be classified as a BRT system, at least these system components should be implemented above average standards.
- **Design variable**. Decisions made in a BRT system that determine the performance of the system. Each design variable can be assigned to one of the system components.
- **Purchase Power Parity (PPP)**. “An economic theory that estimates the amount of adjustment needed on the exchange rate between countries in order for the exchange to be equivalent to each currency's purchasing power” (Investopedia, n.d.).
- **Travel Time Ratio (TTR)**. Ratio indicating the difference between the door to door travel time by public transport and the travel time by car. How lower this ratio how higher the competitiveness of public transport.
- **Visual Basic for Applications (VBA)**. Excel’s supported programming language.
- **Fixed signal priority**. “Whether the corridor has fixed traffic signal phase timings that give priority to buses.”(BRTdata, 2014)
- **Dynamic signal priority.** “Whether the corridor has dynamic traffic signal phase timings that give priority to buses” (BRTdata, 2014)
- **Station pair.** Two stations located near each other, serving each a particular direction.

Acronym list

BRT	Bus Rapid Transit
CNG	Compressed Natural Gas
GOVI	Grenzeloze Openbaar Vervoer Informatie
HOV	Hoogwaardig Openbaar Vervoer
ITS	Intelligent Transportation Systems
LOS	Level Of Service
LPG	Liquefied Petroleum Gas
OD-Matrix	Origin-Destination Matrix
PPP	Purchase Power Parity
SCBA	Societal Cost Benefit Analysis
TOD	Transport Oriented Development
TTR	Travel Time Ratio

1 Introduction

This chapter discusses the purpose and content of this report. Section 1.1 introduces the concept of Bus Rapid Transit (BRT). Section 1.2 describes why it is necessary to perform an evaluation of the applicability of different BRT configurations; also the research objective is defined. Section 1.3 describes the societal and scientific relevance of this study. Section 1.4 describes the research approach. Finally, Section 1.5 presents the contents of this report.

1.1 Background

The world population is growing and related to that also the population of many cities. This often results in a congested road network together with urban expansions. This, in combination with an increasing environmental awareness, results in a growing demand for high quality urban public transport solutions (Trigg, 2012). Urban public transportation services are generally created either via rail or road. Where road is associated with busses, rail can appear in the form of metro, tram, light rail or even heavy rail.

Compared to bus systems, rail systems are, in general, associated with higher capacities and speeds and therefore seen as the mode providing the higher level of service (Deng & Nelson, 2011). This assumption ignores the fact that there are many different configurations of bus systems. Bus systems sharing their infrastructure with car users, represent a different level of service than bus systems using dedicated infrastructure. Similarly bus systems using for instance large, easy accessible vehicles instead of small, more difficult accessible vehicles are clearly an improvement to the quality of the bus service. These high quality bus systems can reach even service levels on the basis on which they are able to compete with rail systems.

These high quality bus systems are generally indicated as Bus Rapid Transit (BRT). These BRT systems are rapidly gaining popularity all over the world (BRTdata, 2014). Figure 1-1 indicates the development of the number of BRT systems over the years up to 2013. According to the same source this number is already increased to 190 (May 2015).

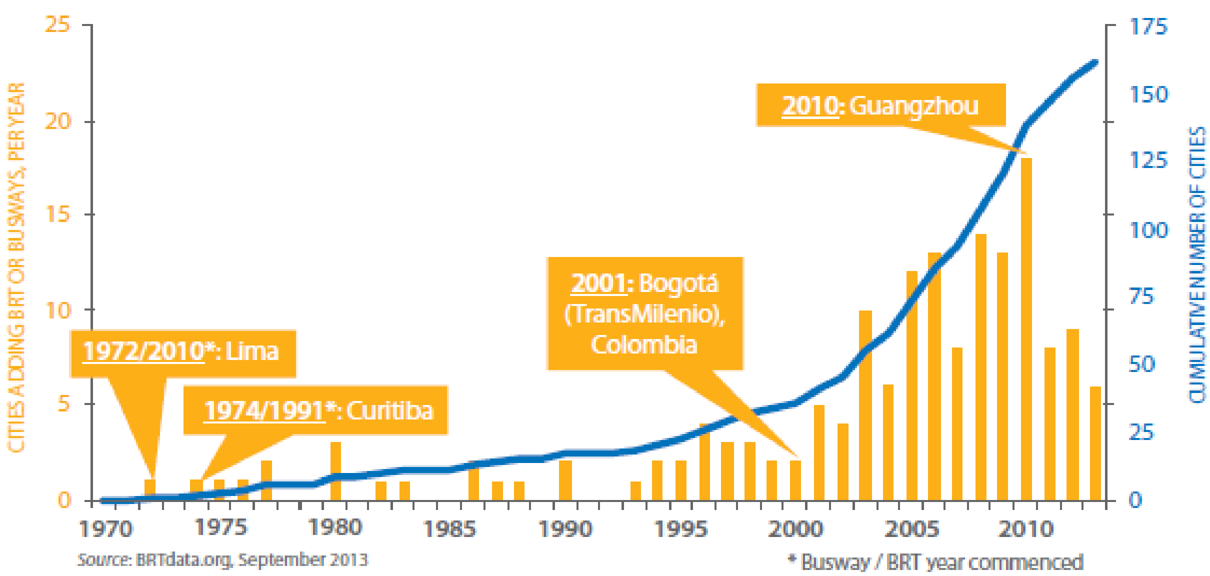


Figure 1-1: Overview of number of BRT systems worldwide. Figure reprinted from (BRTdata, 2014)

In recent years new systems appeared mostly in Asia, North and South America and Europe. In the Netherlands, Amsterdam/Haarlem, Eindhoven and Utrecht are among the cities with one or more BRT services. In most of these cases, the cost-effectiveness and greater operating flexibility of these systems, compared to rail transit systems, were the main reasons for implementing a BRT system (Levinson, 2003a).

By implementing BRT, the quality of the service is improved compared to a conventional bus service. This is proved by the fact that BRT systems are even seen as viable alternatives to rail transit systems. In general six system components are identified where improvements are made for BRT as compared to conventional bus services (the origin of these six system components is described in Section 2.1):

- Infrastructure
- Stations
- Vehicles
- Fare collection
- Intelligent transport systems (among other route information and signal priority)
- Identity/brand of the service

By making improvements to these aspects, this can result in reduced travel and waiting times, increased service reliability and improved user experience (Federal Transit Administration, 2009). In summary, BRT services provide a higher level of service than conventional urban bus services.

1.2 Problem statement

This section consecutively presents the differences in the configuration of BRT systems, followed by the problem definition, research objective and research questions.

1.2.1 Differences in the configuration of BRT systems

Indicating systems as BRT may give the impression that BRT is associated with a standardized implementation of system components. This is far from being the case; it appeared that the configuration of these systems is really different. For each of the six system components a wide range of design variables can be identified. The different implementation of these design variables results in a large range of system appearances, from ‘light versions’ (partially dedicated bus lanes, some priority at intersections, fare collection in the bus, conventional buses) to ‘heavy versions’ (complete free path, fare collection at the bus stop, buses with additional and extra wide doors). Figure 1-2 indicates this difference. Both systems are seen as BRT systems, but their implementation is clearly very different.

Figure 1-2: Impression of the BRT approach in Bogota (left) and Utrecht (right). Figures reprinted from (World Recources Institute, n.d.) and (Fjellstrom, 2010)

The choices for the implementation of these design variables impact the appearance. And, with that, also strongly the quality of the service is impacted. These choices primarily impact the perceived quality of the system by the customer, and with that its ridership. Secondary these choices impact the results of the system regarding environmental quality, spatial planning and economic vitality. The costs of the system, both for implementation, maintenance and exploitation, can limit the spectrum of choices.

From the variety of appearances it can be concluded that there are apparently several possible solutions that fit the principles that were formulated when setting up a BRT system. This raises the question what these goals were, why subsequently the respective choices regarding the design variables were made, and what the results of these choices were. Currently a lot of information is known about the possible choices (Federal Transit Administration, 2009; ITDP, 2007; Levinson, 2003b; Wright, 2003), but what still lacks is insight about when to make which choice.

1.2.2 Problem definition

This research is conducted on behalf of Movares, a leading engineering consultancy company covering the fields of infrastructure, public transport, mobility, power, waterways and urban development. Movares has observed that the popularity of BRT is increasing. With that, its difference in appearances naturally also is increasing. However, the knowledge about the applicability of these different forms seems to be lagging behind. Movares aims to be a leading company regarding the development of high quality bus services in the Netherlands. It is expected that, just like worldwide the demand for high quality bus services in the Netherlands will continue to grow. This can partly be devoted to the high costs of light rail projects, in combination with the lack of available funds caused by the current economic situation. Furthermore, the demographic characteristics of the Netherlands encourage the use of bus systems. With many relatively small cities (where a tram connection is often not cost-effective) and many people who daily are using bicycles who form a potential group of new bus users, this leaves room for the implementation of high quality bus services. Movares therefore is interested in additional insight in the relation between different appearances of these systems and their applicability in different situations. By conducting research on this topic, a better insight in opportunities, risks, costs and benefits of the possible design choices can acquired and the decision making process can be enriched. An associated higher goal is to enrich the insight in the applicability of different BRT configurations, compared to various other public transport applications, in different situations.

1.2.3 Research objective

In this research the drivers behind, and results of, design choices in BRT systems worldwide are researched. The final goal is to obtain insight in the applicability of different BRT configurations. These insights will be translated into a BRT design model presenting the appropriate design decisions adapted to the local conditions. To make the model easy and attractive to work with, the model will be implemented in a software tool, the BRT design scanner. This scanner will be able to indicate the appropriate BRT configuration for new systems. Also, the scanner can be used to evaluate the configuration of existing systems. In this research, an example of the last case is presented to reflect on the quality and generate suggestions for improvement of the scanner.

1.2.4 Research questions

Below the main research questions and corresponding sub questions are presented.

Main research question: How to decide on the applicable configuration of a BRT system?

In the approach of this research, this main research question is answered by means of answering the following sub questions:

- What is state of the art of the research into the configuration of BRT systems?
  - How can BRT be defined, and which components can be distinguished in a BRT system?
  - What are possibilities to capture the variety in BRT systems?
  - What is in the literature already available to assess the applicable BRT configuration?

- What are the impacts of design decisions on the performances in existing BRT systems?
  - What are the design variables on which BRT systems can be differentiated from each other?
  - How to assess the performance of a BRT system, and which performance indicators correspond to this?
  - What is an appropriate stet of reference systems to research the relation between the design variables and the performances?
  - When relating the design variables to the performance indicators, which patterns can be identified?
  - When relating the design variables to the performance indicators, which outliers, which require additional research, can be identified?
  - How can these identified outliers be explained?

- How can the acquired insights about the result of design decisions on the performance be captured in a BRT design model?
  - Which design variables have to be implemented in the BRT design model?
  - Which design decisions can be recognised for these design variables, and what influences this decision?

- How can the BRT design model be implemented in a software tool, the BRT design scanner?
  - What are the requirements of the BRT design scanner?

   - How can the input variables be made operational?

- What is the applicability and quality of the BRT design scanner and its underlying model, based on a case study of the BRT service through Leidsche Rijn?
   - What is, based on an analysis of the advised and realized configuration, the quality of the suggestions provided by the scanner?
   - What is, based on an SCBA analysis of a few suggested measures, the quality of the suggestions provided by the scanner?
   - What improvements to the BRT design scanner are identified which can enhance the predictive quality of the scanner?

1.3 Societal and scientific relevance

Societal relevance: Transport is a basic need of people. In the Netherlands, millions of people use public transport daily to fulfil their travel needs. Providing services with a higher quality (e.g.: higher speeds, reliability and comfort) will impact a lot of people. With the level of congestion in the Netherlands, providing high quality sustainable transport solutions is very important. It is thought that BRT is a solution to create these sustainable high quality transport service. Additional insight in the applicability of different BRT configurations is therefore desirable.

Scientific relevance: As already been presented earlier in this chapter, BRT experiences a worldwide explosive growth in applications. These systems however have all different configurations. Currently a lot of information is known about the possibilities to differentiate this configuration. However there is a lot less insight in the drivers behind and results of these design choices. Acquiring insight in the strengths and weaknesses of different BRT configurations in different situations can help to improve the knowledge of the possibilities of BRT (both within the bus-mode as compared to rail solutions).

1.4 Research approach

The research as presented in this report is based on three steps: literature study (1), specification of BRT design model and implementation in BRT design scanner (2), evaluation of BRT design scanner based on case study (3). Figure 1-3 below visualizes this approach. For each of the blocks the corresponding research questions are added.

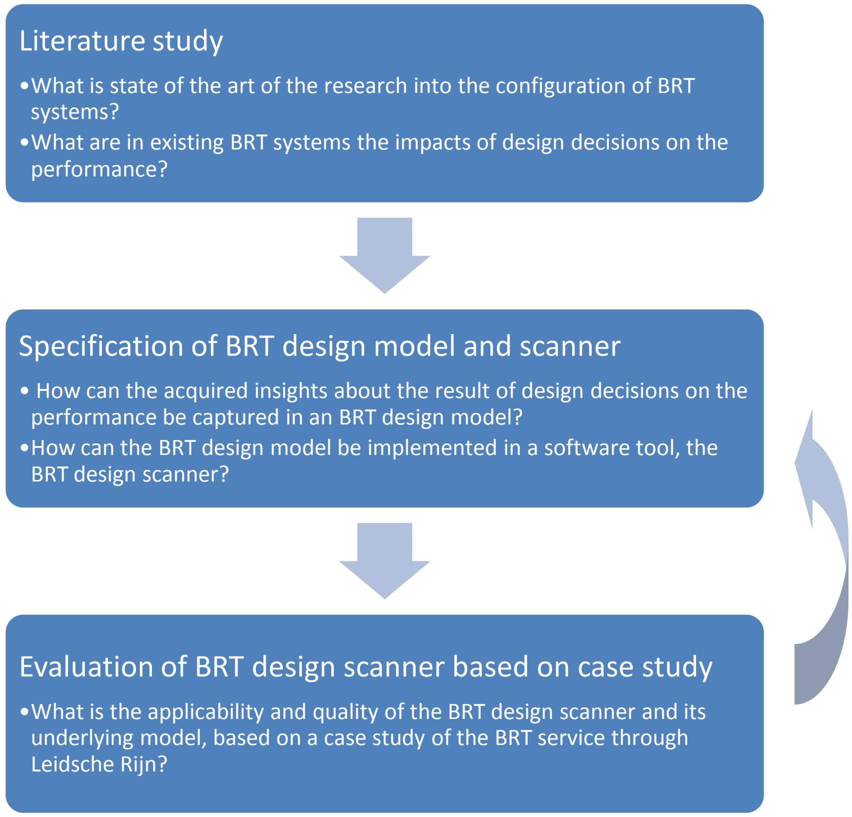


Figure 1-3 Overview of research approach

Between the last two blocks a reciprocal relationship can be identified. The case study will result in improvements to the BRT design scanner. Some of these identified improvements will be immediately incorporated in the scanner, and some of these will be identified and noted for potential future development of the scanner.

1.5 Report contents

The structure of this report is summarized by Figure 1-4 below.

Chapter 2: Determining the BRT configuration: state of art

- Defintion of a BRT system (2.1)
- Decomposition of a BRT system (2.2)
- Specification of research approach (2.3)
- Positioning of the research (2.4)

Chapter 3: Studying BRT in practice

- Selection of design variables (3.1)
- Selection of performance indicators (3.2)
- Set of reference systems (3.3)
- Researching the set of reference systems (3.4)
- Relating the design variables to the performance indicators (3.5)
- Relating the performance indicators to each other (3.6)
- Discussion of outliers (3.7)

Chapter 4: Formulation of a BRT design model

- Usability of the BRT design model in the design procedure (4.1)
- Model formulation approach (4.2)
- Design variables left out of consideration (4.3)
- Design variables that do not depend on local conditions (4.4)
- Design variables that depend on local conditions (4.5)

Chapter 5: Formulation of the BRT design scanner

- Requirements of the BRT design scanner (5.1)
- Construction of the BRT design scanner (5.2)

Chapter 6: Case study based reflection on the BRT design scanner

- Introduction of case study area (6.1)
- Evaluation method (6.2)
- Input and resulting output of the BRT design scanner (6.3)
- Reflection on differences between the advised and realized configuration (6.4)
- Evaluation of advices by means of a Societal Cost Benefit Analysis (6.5)
- Imrovements to enahance the predictive quality of the BRT design scanner (6.6)

Chapter 7: Conclusions

- Determining the BRT configuration: state of the art (7.1)
- Relation beteen the configuration and the performance of BRT systems (7.2)
- Formulation of the BRT design model and scanner (7.3)
- Quality of BRT design scanner and underlying model (7.4)
- Main research question (7.5)

Chapter 8: Discussion and reccomendations

- Discussion of applicability of BRT design scanner (8.1)
- Discussion of research methodologies (8.2)

Figure 1-4: Overview of the report contents

2 Determining the BRT configuration: state of the art

This chapter presents the state of art regarding the determination of applicable BRT configurations. In Section 2.1 analyzes different definitions of BRT. Section 2.2 presents the decomposition of a BRT system into system elements and design variables. Section 2.3 presents the specific research approach to come to a BRT design model is presented. Section 2.4 presents the differences between the BRT design model as formulated in this research and already existing models.

2.1 Definition of a BRT system

In Chapter 1, "Introduction" it was pointed out that the number of BRT systems worldwide is rising fast but their configurations show considerable variation. Apparently there are a lot of degrees of freedom when setting up that system. This then raises the question: what the definition of a BRT system is? Below, a few different definitions of BRT are presented:

- **Federal Transit Organisation (Federal Transit Administration, 2009)**
  BRT is a permanently *integrated system* of facilities, services, and amenities that collectively improve the *speed, reliability,* and identity of bus transit. In many respects, BRT is rubber-tired light rail transit (LRT), but with greater operating *flexibility* and potentially *lower capital and operating costs.*
- **BRT-Standard (ITDP, 2014)**
  Bus Rapid Transit (BRT) is a high-quality bus-based transit system that delivers *fast, comfortable, and cost-effective services* at metro-level *capacities*. It does this through the provision of dedicated lanes, with busways and iconic stations typically aligned to the center of the road, off-board fare collection, and *fast* and frequent operations.
- **BRT planning guide (ITDP, 2007)**
  Bus Rapid Transit (BRT) is a high-quality bus based transit system that delivers fast*, comfortable and cost effective urban mobility* through the provision of right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at *a fraction of the cost.*
- **EMBARQ (Carrigan, King, Velasquez, Raifman, & Duduta, 2013)**
  Bus rapid transit (BRT) is a *high-quality, efficient* mass transport mode, providing *capacity and speed* comparable with urban rail (light and heavy rail).
- **Sustainable transport: A sourcebook for policy makers in developing countries (Wright, 2003)**
  In general, BRT is high-quality, customer-orientated transit that delivers *fast, comfortable and cost-effective* urban mobility.
- **National BRT Institute (The National BRT Institute, n.d.)**
  BRT is an innovative, *high capacity, lower cost* public transit solution that can significantly improve urban mobility. This permanent, *integrated system* uses buses or specialized vehicles on roadways or dedicated lanes to quickly and efficiently transport passengers to their destinations, while offering the *flexibility* to meet transit demand. BRT systems can easily be customized to community needs and incorporate state-of-the-art, low-cost technologies that result in more passengers and less congestion.

All the definitions presented above are all slightly different, but the characteristics mentioned are well aligned. The definition that is used during this research is:

- BRT is a bus-based public transport service that performs well in terms of speed, reliability, comfort and capacity and additionally is associated with high flexibility and relatively low costs.

2.2 Decomposition of a BRT system

To create such a system that performs well in terms of speed, reliability, comfort and capacity, compared to conventional bus systems, the qualities of a few system components need to be upgraded. ((ITDP, 2007; Jarzab, Lightbody, & Maeda, 2002; Kittleson & Associates Inc., 2007; Levinson, 2003b)) all present a slightly different list of system components on which this should be done. In this research it is assumed that to be classified as a BRT system, at least the following system components should be implemented above average standards:

- Infrastructure
- Stations
- Vehicles
- Fare collection
- ITS: Intelligent Transportation Systems (passenger information, signal priority)
- Distinctive identity

For each of these six system components different design variables can be identified. In literature, more than 100 different design variables are used to define characteristics of a BRT system. Each of these design variables are related to one of the six system components. Figure 2-1 presents an example of the subdivision of system components in design variables. The large number of different design variables implies that an endless amount of 'different' BRT systems can be created.

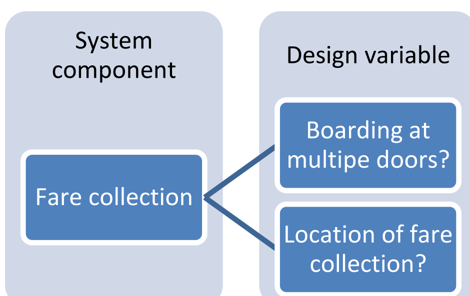


Figure 2-1: Overview of relation between system components and design variables

All the decisions on these design variables, determine the realized quality of the system. However, as was stated by (Kittleson & Associates Inc., 2007), certain design variables will outweigh each other in terms of importance.

To capture these differences in configurations, and quality, different categorisation approaches are available in the literature. These categorization methods present the most important design variables of BRT, with various levels of implementation. (CERTU, 2010; ITDP, 2007, 2014) all present categorization methods which identify a spectrum of BRT solutions. The more advanced these implementations are, the higher the BRT system scores within the spectrum of BRT solutions. In Figure 2-2 the categorization method used in (ITDP, 2007) is presented as example.

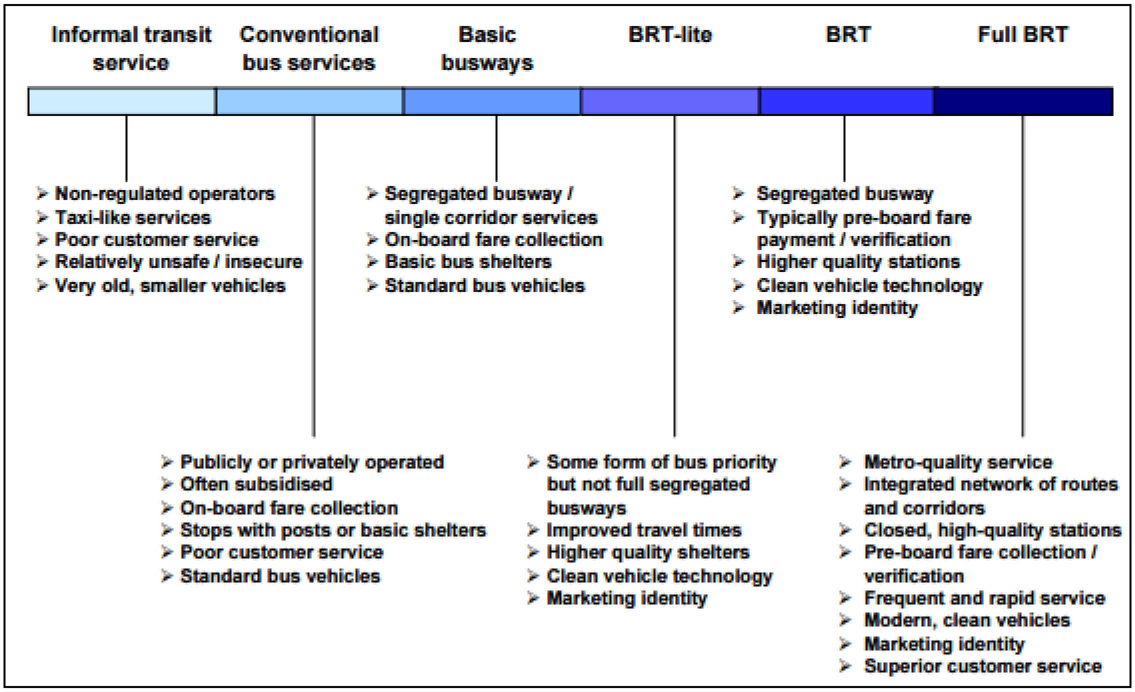


Figure 2-2: Example of a categorization approach as presented by (ITDP, 2007)

2.3 Specification of research approach

As presented in Chapter 1, “Introduction”, the goal of this research is to advice in which situation which type of BRT configuration is appropriate. In the previous section, a set of standard BRT configurations is identified. From this perspective, it is a logical step to assess the applicability of a these standard configurations in different situations. However, using a few of these categorization methods to categorize existing systems worldwide has resulted in problems. Systems often exhibit characteristics of both light versions and advanced versions (see Appendix A for two examples of systems where this is the case).

Because the difficulty to fit a system in a specific category, advising when to implement one of the standard BRT solutions is insufficient. This probably will result in a system that is under- or overdesigned on certain design variables.

Of course, advising a more advanced form of BRT will presumably result in a system associated with a higher quality. But, by doing so, the cost effectiveness of measures is neglected (creating for instance a grade separated intersection when, looking at the amount of crossing traffic, a regular intersection with signal priority may be sufficient). This importance of designing a system to best accommodate the local travel demand and urban context was one of the main recommendations in the study executed by (Carrigan et al., 2013). Also in (Levinson, Zimmerman, & Clinger, 2002) it is advocated that, “BRT system development should be the outgrowth of a planning and project development process that stresses problem solving and addresses demonstrated needs, rather than advocating a particular solution.”

In practice there are apparently reasons to deviate from these standard configurations. This fact makes it interesting to research how the implementation of each specific design variable separately can be matched with the local conditions.

This approach is used, instead of investigating the applicability of the standard BRT configurations within the local conditions. Figure 2-3 indicates both the non chosen approach (red) and the chosen approach (green).

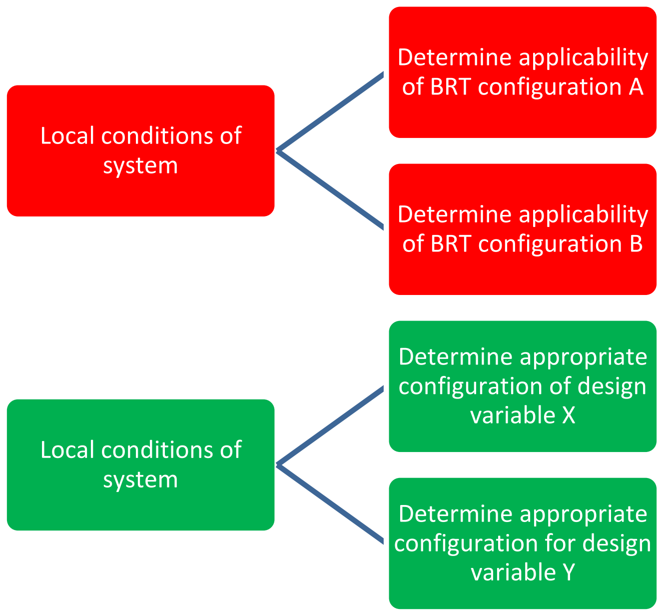


Figure 2-3: Overview of non chosen approach (red) and the chosen approach (green)

2.4 Positioning of the research

Literature is researched to scan for the availability of similar models that advice over the design decisions in BRT systems. Below, existing approaches are presented together with their advantages and disadvantages. The goal of this section, is to elaborate on how the approach of this research, improves upon what is already available.

- **(Federal Transit Administration, 2009; ITDP, 2007; Kittleson & Associates Inc., 2007)** are three extensive reports presenting a description of the characteristics and possibilities that are associated to BRT. Practices worldwide are presented to indicate the spectrum of solutions, and the potential results BRT systems can achieve.

  These reports are not intended to prescribe solutions for specific situations. The possible design decisions when setting up a BRT system, together with their pro's and con's are presented in detail. A description in which situation which approach is suitable, that is the goal in this research is not included.

- **BRT Standard**: "The BRT Standard is an evaluation tool for world-class bus rapid transit systems (BRT) based on international best practices."(ITDP, 2014). The BRT standard assesses a score to a BRT system based on which it will be labeled as: non-BRT, basic-BRT, bronze-standard, silverstandard or gold-standard. The scores are the result of point additions and point deductions based on the configuration of the system. The higher the score the more the system resembles the ideal BRT system.

This methodology is appropriate to identify the level of sophistication of the system. However, no insight is gained whether or not it matches the local conditions. In this research based on the local conditions, the appropriate configuration is advised.

- **SmartBRT** is a plug-in for Paramics, a traffic micro simulation software package. (Van der Werf, 2005) describes the tool as: "SmartBRT is designed for modelling and simulating hypothetical transit systems, especially those making use of Bus Rapid Transit (BRT) technologies and policies. SmartBRT can be used to evaluate new technologies and policies that haven't been fully explored in deployed systems."

  This tool is able to provide insight in design decisions at an operational level. Microscopic simulations about different configurations of signal priority, the effect of different load/unload policies or simulations regarding the required bus capacity are examples of researches that are supported. This research is intended to advice about the main design decisions on a more strategic level.

- **Framework of bus rapid transit development and deployment planning**. In (Miller, Yin, Balvanyos, & Ceder, 2004), the approach is described as: "This report has developed a deployment planning framework for BRT enabling transit agencies to determine an optimal configuration of BRT elements given budgetary, institutional and other types of constraints."

  In this framework, based on an available budget, potential cost effective combinations of design elements are selected. This approach exhibits similarities with the approach in this research, there are however certain important differences:

  - The implementation of design elements is only associated with yes/no, no different types of intersections or infrastructures are identified for instance. In the model, as constructed in this research, this is done.
  - The cost effectiveness of design elements is only based on the travel time gains/costs-ratio that is associated to them. However, a lot more aspects determine the desirable configuration, for instance the reliability of the service and the impact on car traffic. In the model, as constructed in this research, these factors are included.
  - The budget limits the set of suggested solutions. In the model, as constructed in this research, the most fitting or in other cases most cost-efficient configuration for each of the design variables is analyzed separately. An indication of the costs is additionally presented.

2.5 Conclusion

This chapter has elaborated on the state of art of defining the appropriate BRT configuration. From a diversity of definitions, BRT has been identified as a bus-based public transport service that performs well in terms of speed, reliability, comfort and capacity and beside that is associated with a high flexibility and relatively low costs. It has also been identified that this performance is generally reached by making improvements to the system components:

- Infrastructure
- Stations
- Vehicles
- Fare collection
- ITS: Intelligent Transportation Systems (passenger information, signal priority)
- Distinctive identity

From researching the appearance of BRT systems all over the world, it was concluded that a great variety of different design variables are associated to these system elements. It also appeared that the configuration of these design variables differs greatly.

The goal of this research is to identify the applicable BRT configuration in different situations. These large differences in the implementation of design variables make it however difficult to identify standard configurations of BRT systems. This has resulted in an approach where the implementation of each specific design variable will be separately matched with the local conditions. This approach is used instead of investigating the applicability of the standard types of BRT configurations within the local conditions.

From an investigation of four available models that advice about the appropriate BRT configuration; none is identified to use the same approach as this research.

In the next chapter, case studies are used to raise questions why the respective choices regarding the design variables were made, and what the results of these choices were. This will form the input for the establishment of the BRT design model (formulated in Chapter 4).

3 Studying BRT in practice

In the previous chapter, the goal of this research was identified to determine, based on the local conditions, the appropriate BRT configuration. This is done by determining the appropriate configuration for a set of design variables individually. To acquire these insights, the characteristics (by design variables), and performances (by performance indicators) for a set of existing BRT systems are examined. By subsequently researching the relation between these (between performance indicators mutually and between performance indicators and design variables), by identifying outliers and patterns, insights are gathered about the impact of a design variable on the performance of the system.

Figure 3-1 presents an overview of the structure of this chapter.

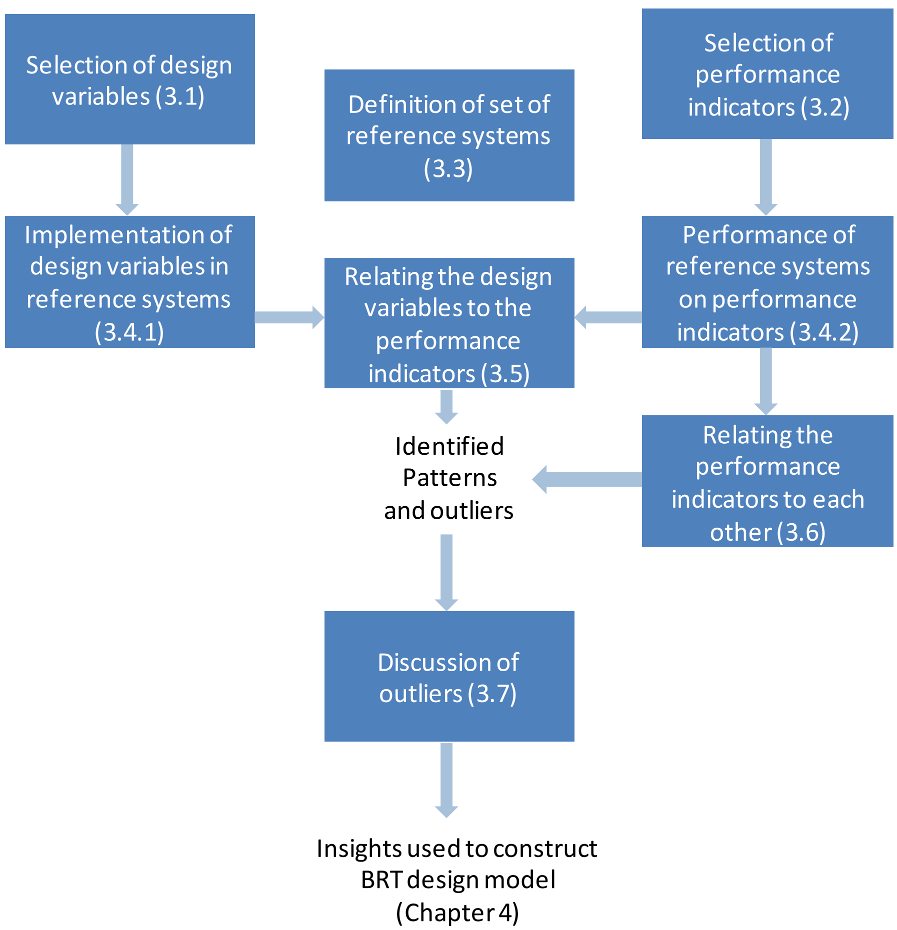


Figure 3-1: Overview of contents of Chapter 3

It should be noticed that the Sections 3.5 and 3.6 are intended to only present the results and identify the outliers. In Section 0 these findings are subsequently interpreted. This is particular approach is chosen because:

- For the interpretation of the diagrams, mostly multiple diagrams should be consulted.
- The interpretations are herewith presented all together.

3.1 Selection of design variables

In this section the selection of design variables is presented. These design variables are selected on a number of criteria. Firstly, it is important that the implementation of these design variables is traceable in the reference systems. Secondly, it is important that these design variables are significant determinants of the quality of the bus service. As said, in literature more than 100 different design variables are used to define the characteristics of BRT systems. Among other (BRTdata, 2014) and (World BRT, 2014) present a large number of design variables together with their appliance in BRT systems around the world. In this research, the selection for 19 of these design variables is made. This selection is based on:

- Availability of data about the implementation in the set of reference systems.
- Presence of design variables, related to each of the six system components (see Section 2.2)
- Presence of the design variables, used in the different categorization methods (see Section 2.2)
- Expected relation between the implementation of the design variable, and the primary performance of the system (based on (Kittleson & Associates Inc., 2007))

The 19 design variables that are researched are presented in**Fout! Verwijzingsbron niet gevonden.** below. Additionally the related design decisions (operationalisations of the design variables) are presented.

Table 3-1: Design variables taken into consideration for this research

Design variable	Design decision
Sliding doors at stations	Yes/no
Station access level/elevated	Level/elevated
Station access open/closed	Open/closed
Enhanced stations (seating, weather protection, ecstatic)	Yes/no
Pre board fare collection	Yes/no
Platform level boarding	Yes/no
Location of infrastructure	Median/curbside
Level of segregation	Mixed traffic operation/Segregated, intersections with other traffic/grade separated on intersections
Signal priority	No priority/fixed priority/dynamic priority/total segregation
Percentage of stations with passing lanes	%
Vehicle type	Standard/articulated/bi-articulated
Number of doors	Number
Fuel type	Diesel/CNG/LPG/hybrid
Real time travel time information on next bus	Yes/no
Distinctive system	Stations/ busses/marketing identity
Operational mode	Direct service/trunk-only/trunk-feeder
Platform height	Meter
Guided system	Yes/no
Skip stop services	Yes/no

Additional to these design variables, a few context variables are defined. These context variables are useful to interpret the observations in the reference systems. Table 3-2 below presents the investigated context variables.

Table 3-2: Context variables taken into consideration for this research

Context variable	Operationalization
Year system commenced	Year
Inhabitants of urban area	Number
Network length	Kilometre
Stop spacing	Meter
Investigated corridors	Name

3.2 Selection of performance indicators

The performance of a BRT system can be assessed by identifying performance indicators. For the respective systems, the design variables as presented in the previous section determine the configuration, and the affiliated quality of the service. Before the performance indicators used to evaluate the configuration are defined, first insight is required in the goals that together determine this configuration.

3.2.1 Interests determining the configuration

The realization of a BRT system (and other public transport systems) is the result of the interests of a lot of different stakeholders. To indicate this, below the interests of three important groups of stakeholders are assessed. These are: users, society, and public transport authority (see Figure 3-2).

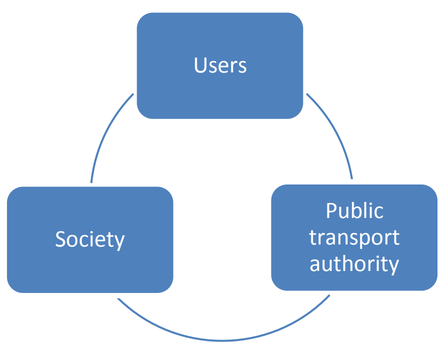


Figure 3-2: Main groups of stakeholders

Users. The users are the people that are using the BRT service, and are thus directly impacted by its performance. (Peek & Van Hagen, 2002) constructed a Maslow pyramid indicating the aspects impacting the customer satisfaction in public transport. This pyramid, indicated in Figure 3-3, differentiates between satisfiers and dissatisfiers. The satisfiers are added values; to guarantee a certain level of quality; the dissatisfiers however need to be always present. According to this analysis, a public transport service needs to be related to a pleasant experience, should be clear, comfortable and fast, but most importantly, reliable and safe. This hierarchy is partly supported by (Baltes, 2003), a research specifically focussed on BRT. The statistical analysis of specific service elements, executed in this research, presents the frequency of the service, comfort, speed and reliability as aspects customers place high value on.

The results of the design decisions on these customer satisfaction aspects are identified as the *primary performance*. Note that these aspects indicate the customer satisfaction, directly resulting from the physical design. The height of the fare will also have a certain effect, however, this effect is not considered in this research.

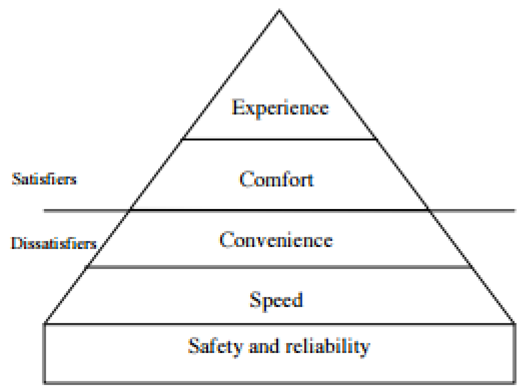


Figure 3-3: Maslow pyramid, formulated by (Peek & Van Hagen, 2002) , indicating the aspects impacting the customer satisfaction in public transport. Figure reprinted from (Van Oort, 2011)

Society. The stakeholder group 'society' is associated to people in the environment, which are either negatively or positively impacted by the existence of the system. Pollution (noise, air or visual pollution), either increasing or decreasing, can be the result of the implementation of the bus system. Generally, there is also an impact on the flows of car traffic (and other slow vehicles). This can be the case when vehicles are crossing the bus system, or are travelling in the same direction. This effect is mainly dependent on the level of segregation of the infrastructure and the implementation of signal priority on the bus corridor. Also effects related to Transport Oriented Development (TOD), or changes in the property prices can possibly be identified. The effects of the design decisions on all these types of aspects related to the environmental quality, spatial planning and economic vitality are identified as the *secondary performance*.

Public transport authority. The public transport authority is the public organ that is responsible for the establishment of the bus service. It is the client for which the bus service is established. Generally, the goal for these clients is the realization of a cost-effective system that corresponds to the formulated goals. The effect of the design decisions on the level of cost-effectiveness is identified as the *tertiary performance*.

The interests of these three groups of stakeholders will together result in the eventual configuration. The users of the system would benefit from a large priority to reach the primary goals: speed, reliability, etc. The society/the environment will benefit from a large priority to reach the secondary goals of the system. The public transport authority will benefit from a large priority to create a cost-effective system. The relative weighing of these aspects will determine the eventual configuration of the BRT system.

3.2.2 Assessing the quality of the configuration

In case the BRT configuration is aligned to the urban context and policy goals, the performance will presumably be better than when this is not the case. 'Performance' is however a term that can be interpreted differently. Miller et al. (2004) distinguishes two types of performances, the performance on the service quality and output, and the performance on the service consumption.

The service quality and output is related to measurements like average speed, achieved reliability. By relating the service quality and output, to the associated BRT configuration, the cost-efficiency is considered. The service consumption is related to measurements indicating the usage of the system. When relating the service consumption to the BRT configuration, the cost-effectiveness is considered. By subsequently relating the service quality and output to the service consumption, the service-effectiveness is considered.

Figure 3-4 summarizes both the different interests resulting in the BRT configuration, and the subsequent relation between this configuration and the two identified types of performance (the lower half of the figure is adapted from (Miller et al., 2004)).

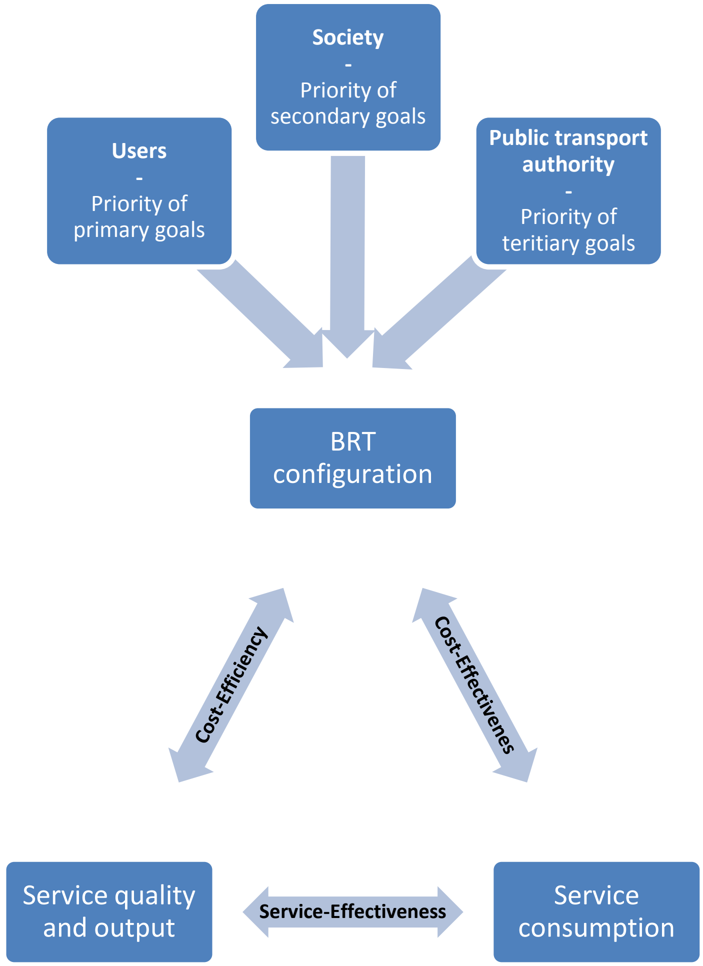


Figure 3-4: Overview of establishment of the BRT configuration together with the assessment of the subsequent performance. Lower half of the figure is adapted from (Miller et al., 2004))

In Section 3.1, the design variables, which will be used to identify the BRT configuration, were presented. However, to be able to research the relation between the BRT configuration and the performance, additionally, data is needed indicating the service quality and output, the service consumption and the costs.

Service quality and output. There are many indicators available that give an indication of the service quality and output. These indicators can be related to the primary- and secondary goals of the system. For instance, indicators related to the primary goals of the system can be:

- Speed: operational speed, maximum speed.
- Reliability: standard deviation of travel time, punctuality, regularity, reliability buffer time and average additional travel time.
- Comfort: probability of having a seat and level of crowding in the vehicle.

Examples of indicators related to the secondary goals of the system can be CO_2 emissions, and the development of property prices around the corridor.

Service consumption. The indicators, for the level of service consumption are related to the ridership of the system. The most common ones are passengers per day and passengers per hour per direction.

Costs of the system. Indicators for the costs of a system are for instance infrastructure costs, equipment costs, operational costs. It should be noted that these indicators do neither indicate the service quality and output, nor the service consumption. They are directly related to the BRT configuration, and are used to determine the cost efficiency and the cost effectiveness of the systems. Therefore, in this research, they are nevertheless understood as a performance indicator.

In the literature, generally little information is available about the performance of systems on these mentioned performance indicators. In case indicators are available, their availability mostly differs among the systems. Since, for the case study, the systems need to be mutually comparable, the same performance indicator needs to be available for most of the reference systems. The number of performance indicators that fit this criterion is small. Eventually, for each of the systems, generally the following performance indicators could be found:

Service quality and output

- **Operational speed**: average realized speed over the identified trajectory.

Service consumption

- **Passengers per hour per direction**: the number of people passing the busiest station of the service during a period of one hour.
- **Passengers per day**: total number of passengers using the bus service per day.

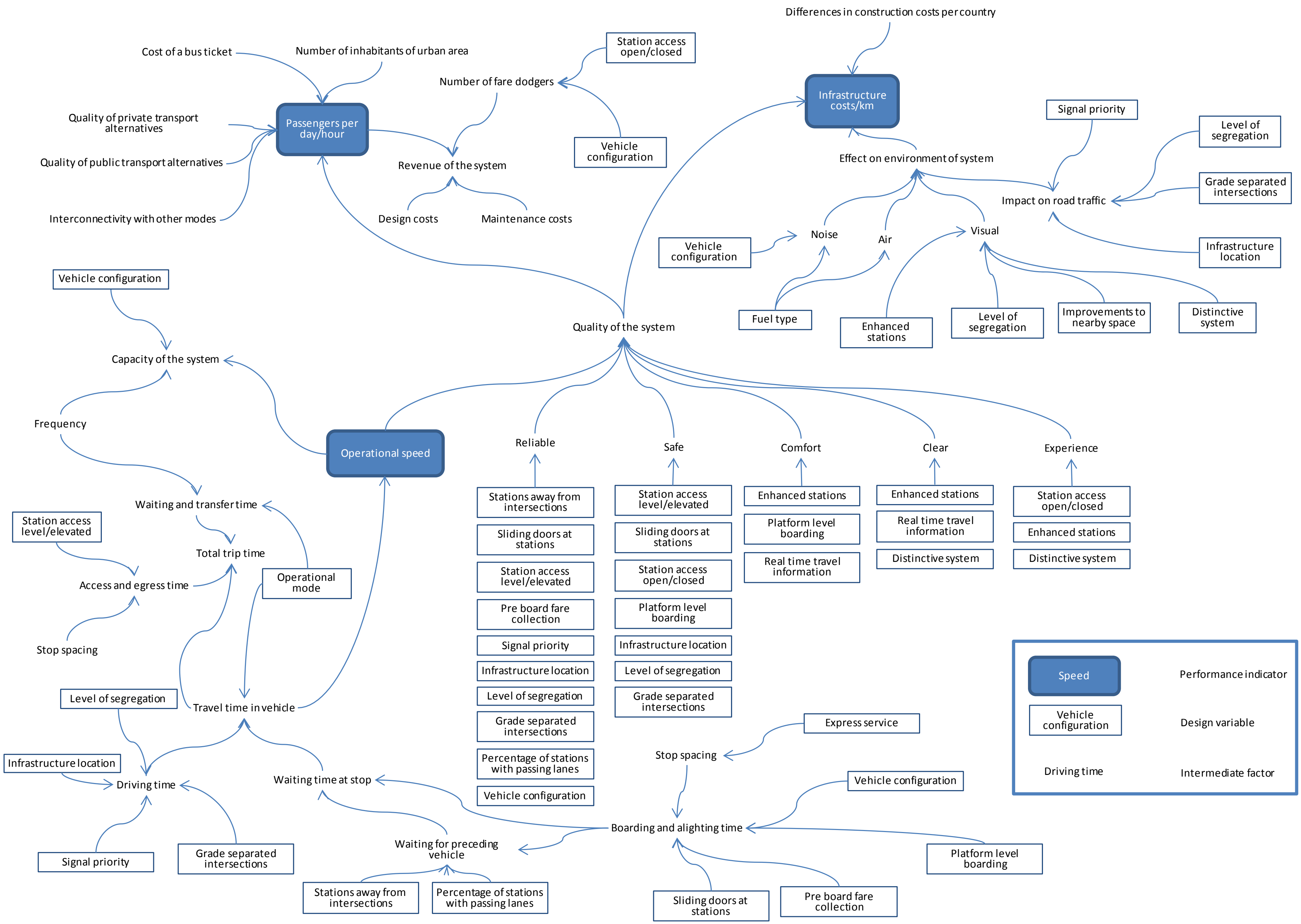
Costs

- **Infrastructure costs**: costs of realizing the bus infrastructure per kilometre.

However, as depicted, the operational speed is only one of the possible indicators indicating the service quality and output. Also other aspects presented in the Maslow pyramid (Figure 3-3) play a role. As said, no performance indicators could be identified related to these service quality and output indicators. However, it is still insightful to get an idea of these factors. Therefore, based on the implementation of different design variables, an approximation of the level of reliability and comfort is created. These two approximations are presented in Appendix B.

To conclude this paragraph, in the diagram on the next page, the design variables and the performance indicators that are investigated for each of the reference systems, are related to each other. The goal of the diagram is to indicate how the design variables determine the few performance indicators. By displaying these relations it is clear that the context a BRT system is designed is complex. Also it is noticeable that the most of the design variables impact the 'dissatisfiers' (speed, reliability and safety).

Note that, to create a legible diagram, some of the same design variables appear on multiple locations in the diagram.



Differences in construction costs per country
Station access open/closed
Cost of a bus ticket
Number of inhabitants of urban area
Number of fare dodgers
Infrastructure costs/km
Signal priority
Level of segregation
Quality of private transport alternatives
Passengers per day/hour
Vehicle configuration
Revenue of the system
Effect on environment of system
Grade separated intersections
Quality of public transport alternatives
Impact on road traffic
Interconnectivity with other modes
Design costs
Maintenance costs
Noise
Air
Visual
Vehicle configuration
Infrastructure location
Vehicle configuration
Fuel type
Enhanced stations
Level of segregation
Improvements to nearby space
Distinctive system
Quality of the system
Capacity of the system
Frequency
Operational speed
Reliable
Safe
Comfort
Clear
Experience
Waiting and transfer time
Stations away from intersections
Station access level/elevated
Enhanced stations
Enhanced stations
Station access open/closed
Station access level/elevated
Sliding doors at stations
Sliding doors at stations
Platform level boarding
Real time travel information
Enhanced stations
Total trip time
Distinctive system
Distinctive system
Operational mode
Station access level/elevated
Station access open/closed
Real time travel information
Access and egress time
Pre board fare collection
Platform level boarding
Stop spacing
Signal priority
Infrastructure location
Infrastructure location
Level of segregation
Speed
Performance indicator
Level of segregation
Level of segregation
Travel time in vehicle
Grade separated intersections
Grade separated intersections
Vehicle configuration
Design variable
Express service
Infrastructure location
Percentage of stations with passing lanes
Stop spacing
Driving time
Intermediate factor
Driving time
Waiting time at stop
Vehicle configuration
Vehicle configuration
Boarding and alighting time
Waiting for preceding vehicle
Signal priority
Grade separated intersections
Platform level boarding
Stations away from intersections
Percentage of stations with passing lanes
Sliding doors at stations
Pre board fare collection

3.3 Set of reference systems

For the investigation of the relation between the design variables and performance indicators, a set of reference systems is defined. (BRTdata, 2014) defines around 190 bus systems worldwide as BRT. From this set 20 systems are selected. This is done based on the following criteria:

- Information available in literature about the implementation of the design variables and the values of the performance indicators.
- Impression of level of sophistication of the BRT system. The goal is to include the whole spectrum of BRT configurations; from BRT-light configurations to full-BRT configurations (see Figure 2-2).
- The geographical location. The goal is to incorporating systems in the dataset from all over the world. With a slight preference for the European practice.

Figure 3-5 presents the set of reference systems resulting from this approach.

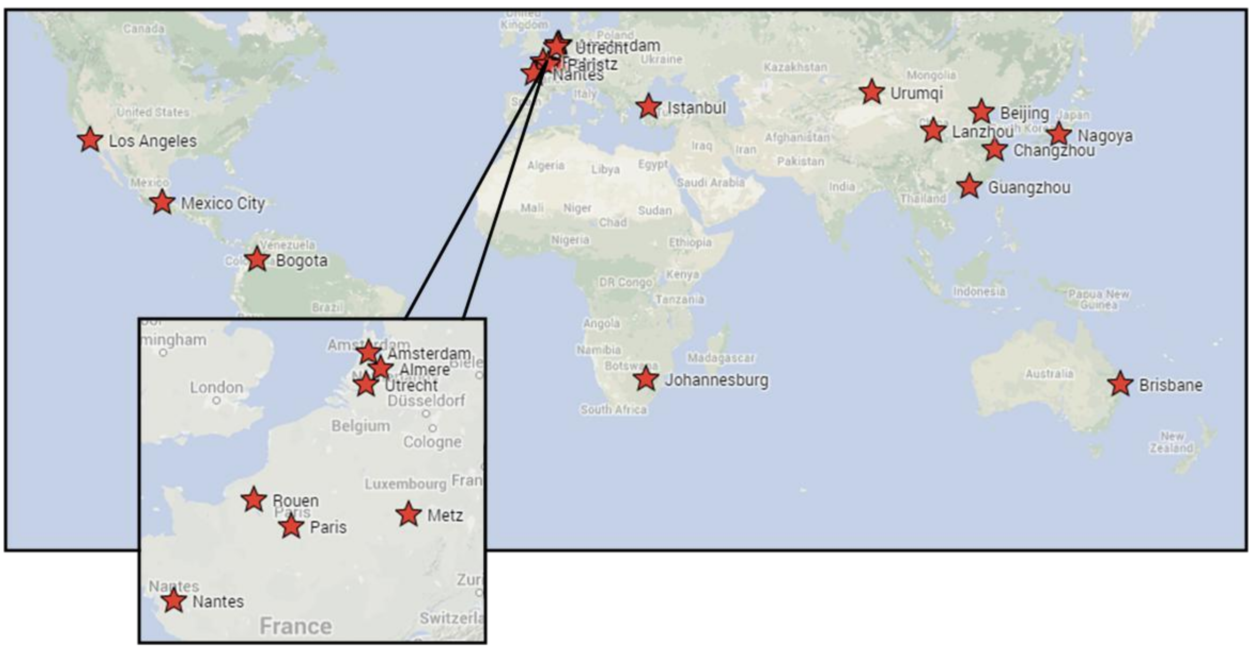


Figure 3-5: Set of resulting reference systems

It can be noted that there are many French and Chinese systems present in the set of reference systems. This is due the fact that in these countries many BRT systems are created of which the characteristics and performances are well documented. In Appendix B.I it is documented which corridors in these cities are considered.

3.4 Researching the set of reference systems

This section presents the implementation of the design variables and the values for the chosen performance indicators in the set of reference systems.

3.4.1 Implementation of design variables in reference systems

Appendix B.I presents the implementation of the design variables in the reference systems. It can be concluded that the implementation differs a lot between these systems. The data is used for the analyses conducted in Section 3.5 and for the discussion of the outliers in Section 0.

3.4.2 Performance on performance indicators

This section presents the values for the four performance indicators, researched in the set of reference systems. In Appendix B.II a tabular overview is presented, to be able to clearly identify the outliers, this section contains bar charts. In some cases values were not acquired, when this is the case, these are blanks in the diagrams.

Operational speed

Figure 3-6 presents the operational speeds. With 11,5 km/h, Urumqi performs the worst, where, with 55 km/h, Brisbane performs the best.

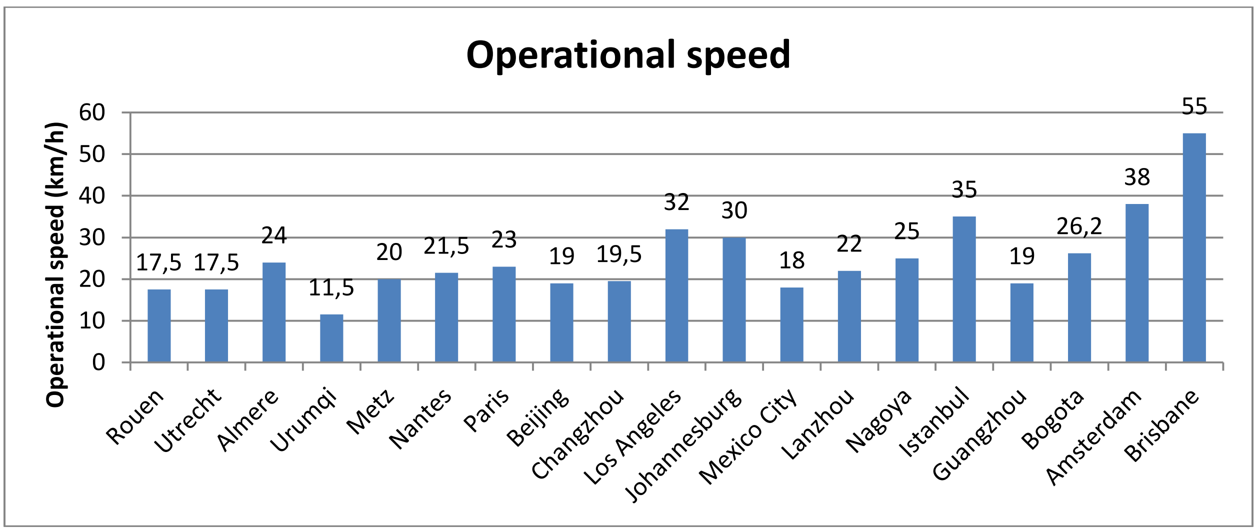


Figure 3-6: Operational speed in set of reference systems

Passengers per day

Figure 3-7 presents the passengers per day. It is clear that, in general, the non-European systems are associated with multiples of the ridership of European systems (excluding Istanbul).

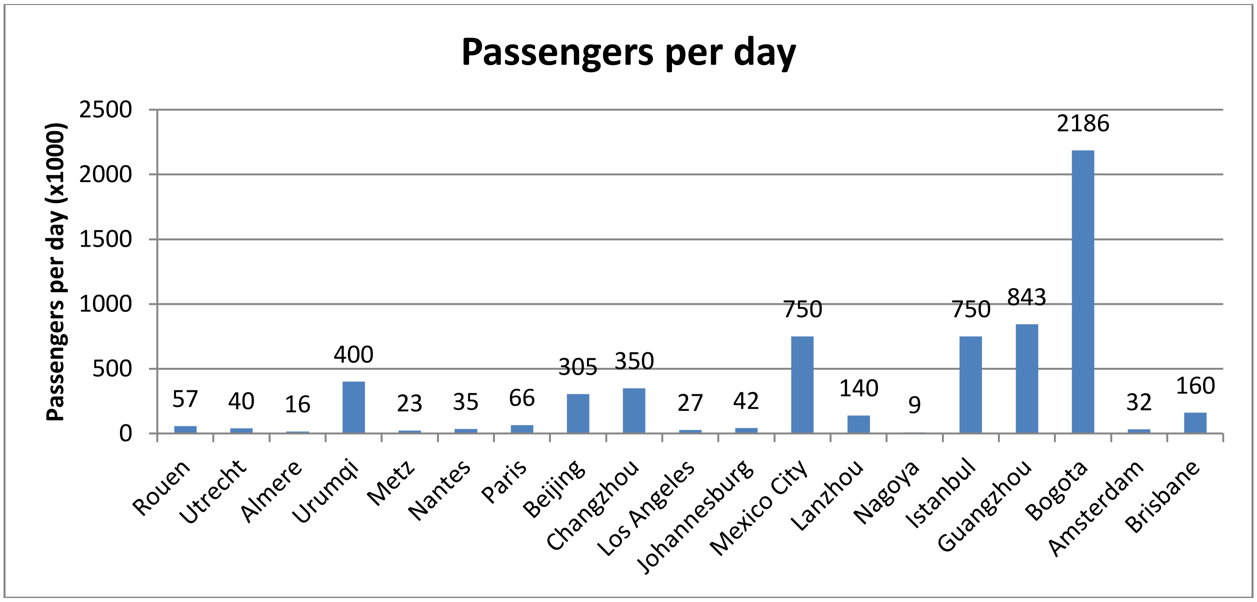


Figure 3-7: Passengers per day in set of reference systems

Passengers per hour per direction during the peak period

Figure 3-8 presents the number of passengers, passing the busiest station of the network during a period of one hour. It is clear that, like the passengers per day, the systems mutually differ a lot. It is also noticeable that these two indicators, both related to ridership, mutually also differ quite a lot. The relative performance of Brisbane on both indicators is an example of this.

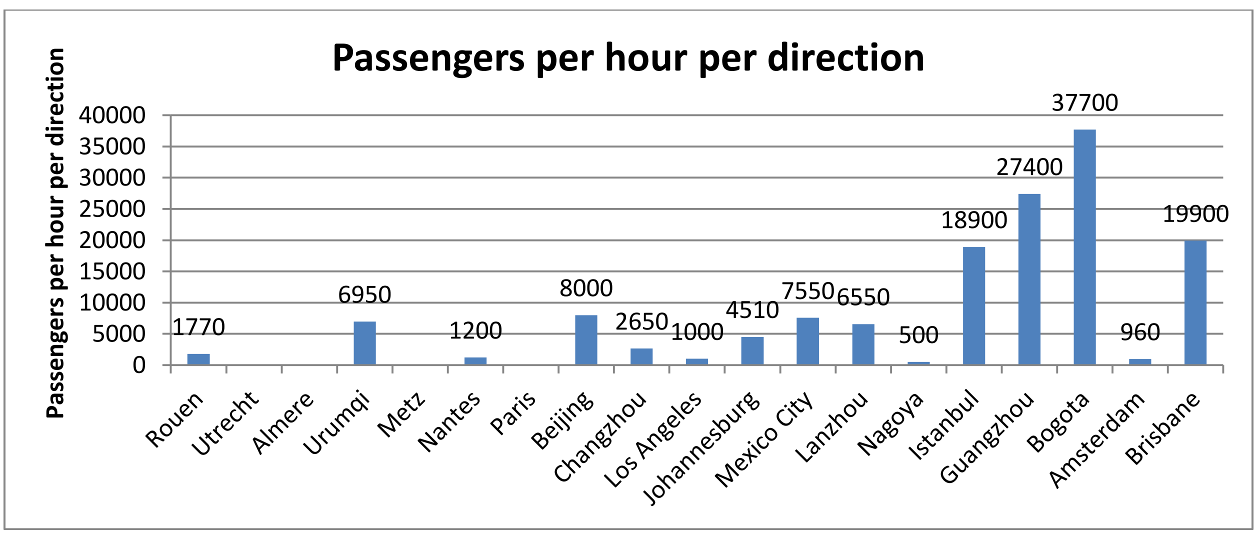


Figure 3-8: Passengers per hour per direction in set of reference systems

Infrastructure costs

Figure 3-9 presents the infrastructure cost per km. Clearly, these costs per kilometre demonstrate large differences between the systems. The infrastructure costs, as found in the literature, were displayed in different currencies, spent in different years, and originating from different areas over the world. To make these costs mutually comparable, these three effects were corrected for by normalizing to Euros. In Appendix C the normalization of these infrastructure costs is elaborated on.

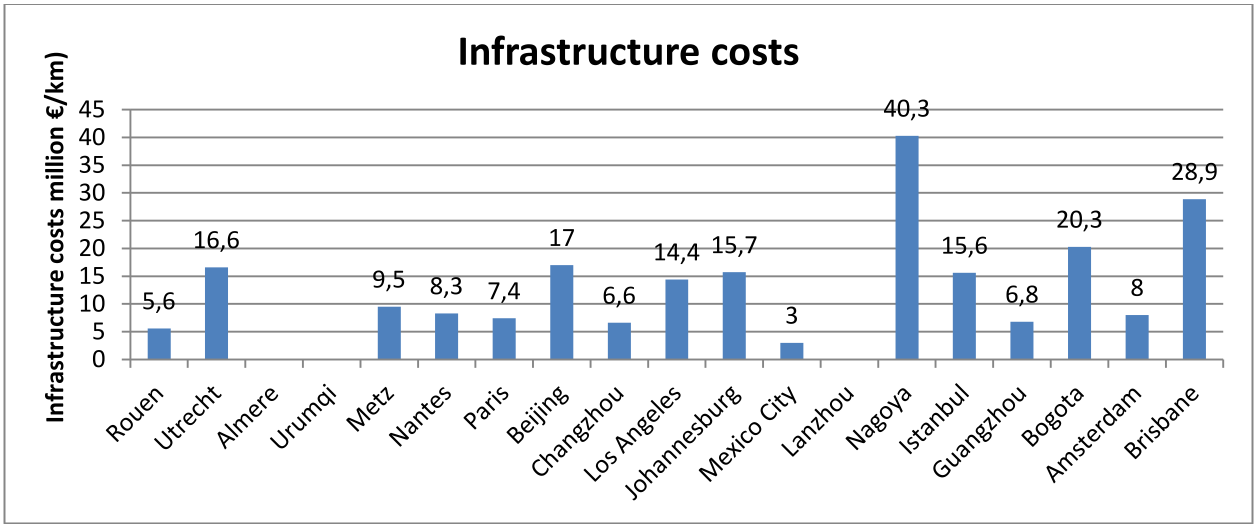


Figure 3-9: Infrastructure costs of set of reference systems

In Chapter 1, "Introduction", the image was outlined that there are large differences in the configuration, and performance of BRT systems. The findings in this section, regarding the implementation of the design variables, and the performance on the performance indicators, clearly support these statements.

3.5 Relating the design variables to the performance indicators

The performance on the performance indicators on one side, and the implementation of the design variables on the other side, can be related to each other. By doing this, insights can be acquired about the potential positive and negative relations between the BRT configuration and its performance.

A possible way to relate the performance indicators to design variables is by using mathematically based correlation algorithms. An example of such an approach is presented in (Hensher & Li, 2012). In this research, a random effects regression model is used to identify, based on a large set of reference systems, factors (e.g. fare height, frequency) that have a statistically significant impact on daily passenger-trip numbers. Because of the relative small amount of records and accompanied data, in this research, it is chosen instead to manually plot the dependent variables (performance indicators) and independent variables (design variables) against each other. By visually analyzing these graphics, patterns and outliers can be identified. These patterns and outliers subsequently form input for additional research, of which the eventual findings will be among other used for the formulation of the BRT design model in Chapter 0.

Considering the number of plots that are created, in this section three of these plots are displayed, other plots are displayed in Appendix E.[1].

[1] Within the available time, it is tried to plot the variables against each other, which potentially are related to each other.

Figure 3-10 presents the relation between the operational speed (dependent variable) and the stop spacing (independent variable). Like expected, a strong correlation can be identified between the operational speed and the stop spacing. However still some remarkable things can be identified:

- The operational speed of Brisbane is exceptionally high; on the other hand the operational speed of Urumqi is really low.
- Although the stop spacing of Los Angeles, Brisbane and Amsterdam are nearly the same, there are significant differences in the operational speed of these systems.
- Four Chinese systems (Urumqi, Beijing, Guangzhou and Changzhou) operate with relatively low speeds.

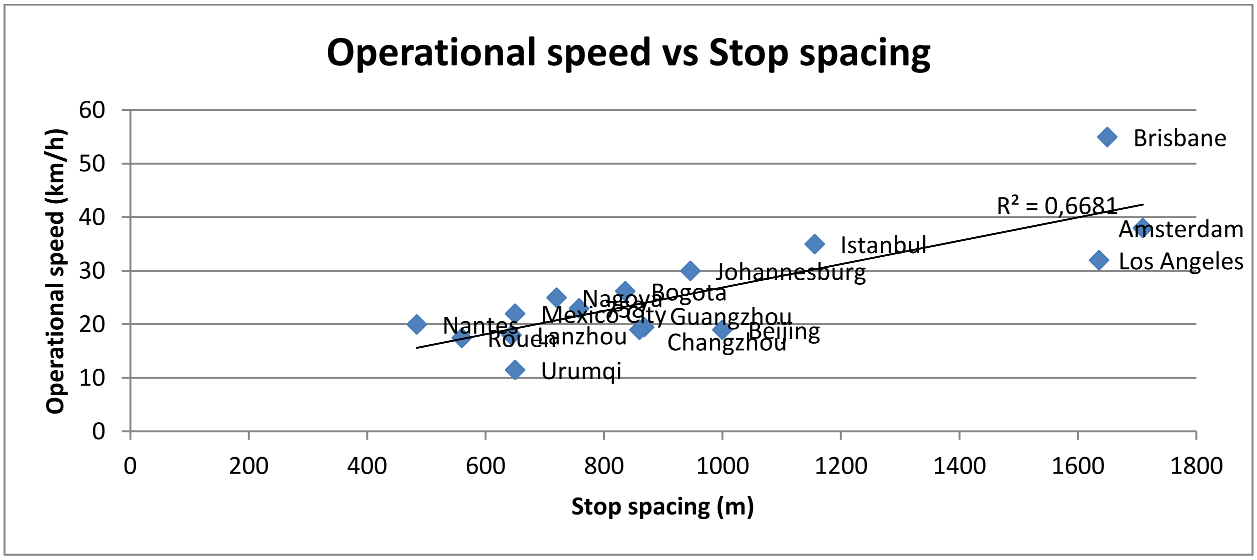


Figure 3-10: Relation between the operational speed and the stop spacing

Figure 3-11 presents the relation between the operational speed (dependent variable) and the type of signal priority (independent variable).

In the set of reference systems, four different levels of signal priority are distinguished: no signal priority (1), fixed signal priority (2), dynamic signal priority (3), and grade separated intersections (4). As expected, there is a strong relation between the operational speed and the type of signal priority. It is remarkable that the service in Johannesburg, without any type of signal priority, functions with a relatively high speed. Also the low speed of Nagoya is notable.

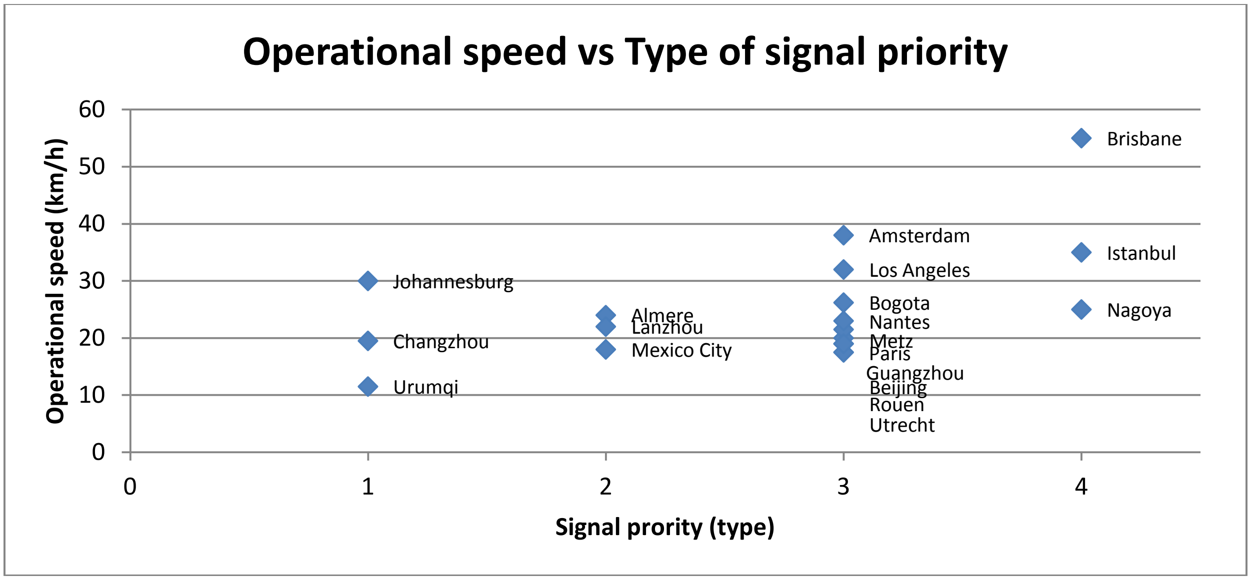


Figure 3-11: Relation between the operational speed and type of signal priority

Figure 3-12 presents the relation between the passengers per day (dependent variable) and the network length (independent variable). The presented values give an indication of how heavy the available infrastructure is used. It is clear there are major differences between the systems. Guangzhou is associated with by far the highest network usage. The few other outliers are also all systems outside Europe (notwithstanding Istanbul).

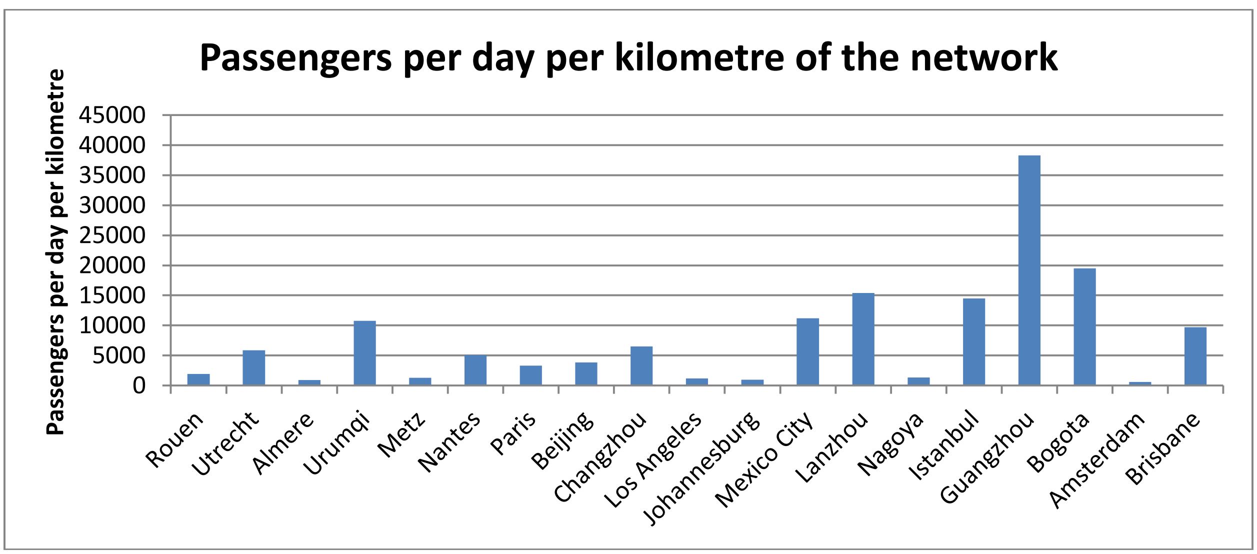


Figure 3-12: Passengers per day per kilometre of the network for the set of reference systems

3.6 Relating the performance indicators to each other

By relating the performance indicators to each other, insights can be acquired about the relative performance of the BRT systems compared to each other. As was presented in Section 3.2.2, this can be done by comparing the systems mutually on their cost-efficiency, cost-effectiveness, and service-effectiveness.

3.6.1 Cost-efficiency

Based on the available data, the cost efficiency of the systems can be analyzed by relating the operational speed to the infrastructure costs. Figure 3-13 presents the results of this regression analysis. As expected, there is a quite significant relation between the costs of the infrastructure and the operational speeds. However some things are remarkable:

- Brisbane performs extraordinary. Although the costs of the infrastructure are high, the resulting performance in terms of speed is really good.
- Nagoya is associated with very high infrastructure costs; the performance in terms of speed is however not aligned to this.
- A cluster of systems, associated with infrastructure costs ranging from 5 to 10 million euro and an operational speed of around 20 km/h can be identified. However, the system of Amsterdam has comparable costs but performs much better than this cluster.

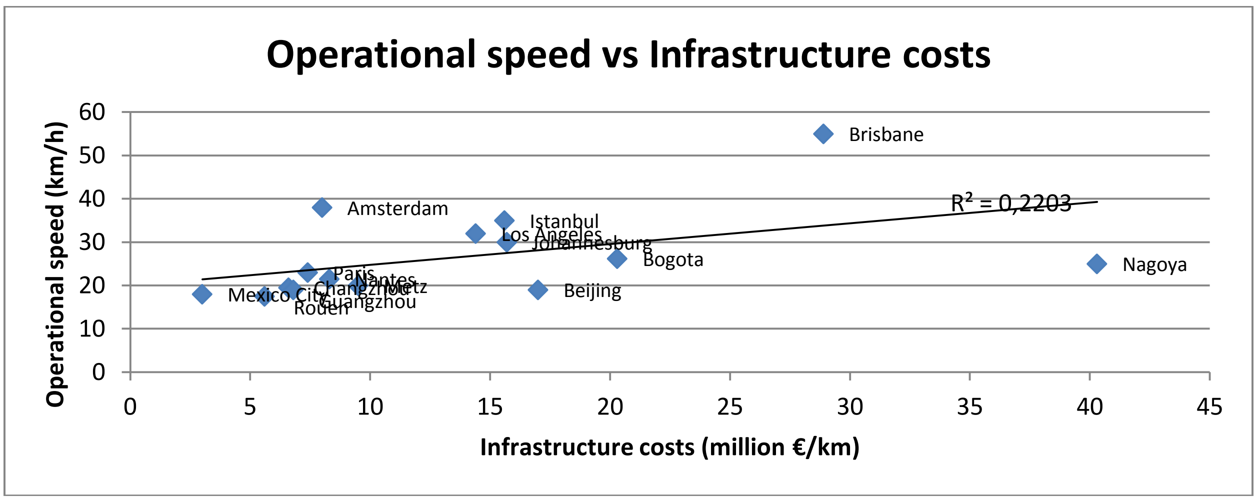


Figure 3-13: Relation between the operational speed and the infrastructure costs

3.6.2 Cost-effectiveness

The cost effectiveness of the systems can be analyzed by relating the two ridership indicators (passengers per day and passengers per hour per direction) to the infrastructure costs.

Figure 3-14 displays the relation between the passengers per hour per direction and the infrastructure costs. In contrast to the case of passengers per day, the size of the analyzed network does not influence the value of this indicator. Based on this diagram, some remarkable findings are:

- Nagoya performs badly; on the other hand, Bogota performs really well.
- Guangzhou serves a lot of passengers during the peak hour, while it is associated with relatively low infrastructure costs. The systems of Brisbane, Istanbul, Beijing, Johannesburg and Los Angeles are all associated with higher infrastructure costs, but all transport fewer passengers.
- European systems (with the exception of Istanbul) and Changzhou, compared to systems on other continents, have low passenger volumes in combination with low costs. These European systems form, together with Changzhou, a cluster in this diagram.

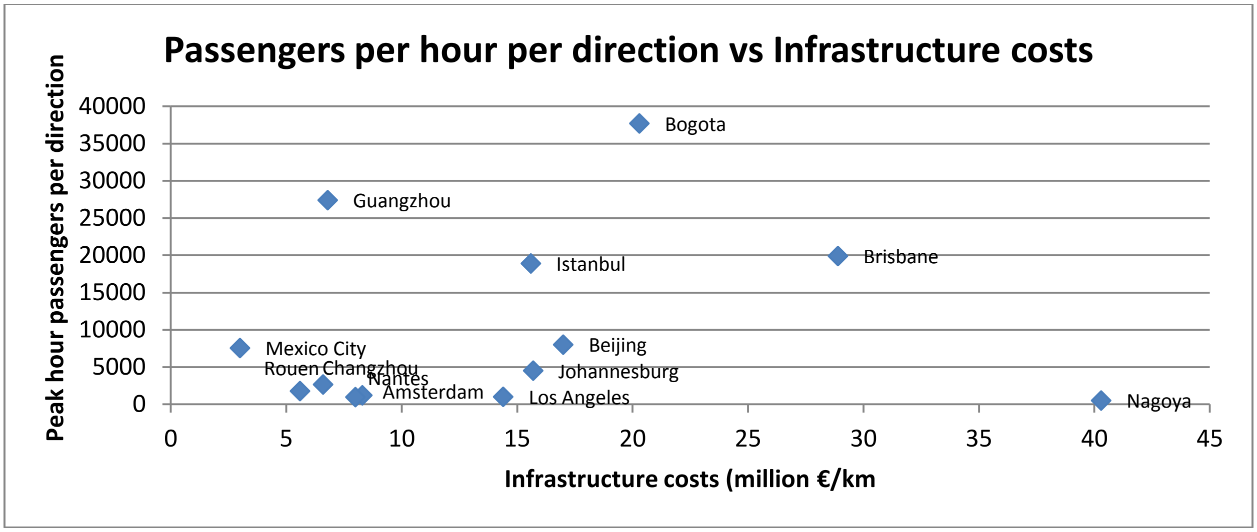


Figure 3-14: Relation between the passengers per hour per direction and the infrastructure costs

Figure 3-15 presents the relation between the passengers per day and the infrastructure costs. In this value, the size of the network (the network lengths for each of the identified systems can be found in Appendix B.I) does have a large influence. Some remarkable findings:

- Nagoya, and to a lesser extent, Brisbane, perform badly; On the other hand, Bogota performs really well.
- European systems (with the exception of Istanbul), compared to systems on other continents, have low passenger volumes in combination with low costs. These European systems form, together with Changzhou, a cluster in this diagram.

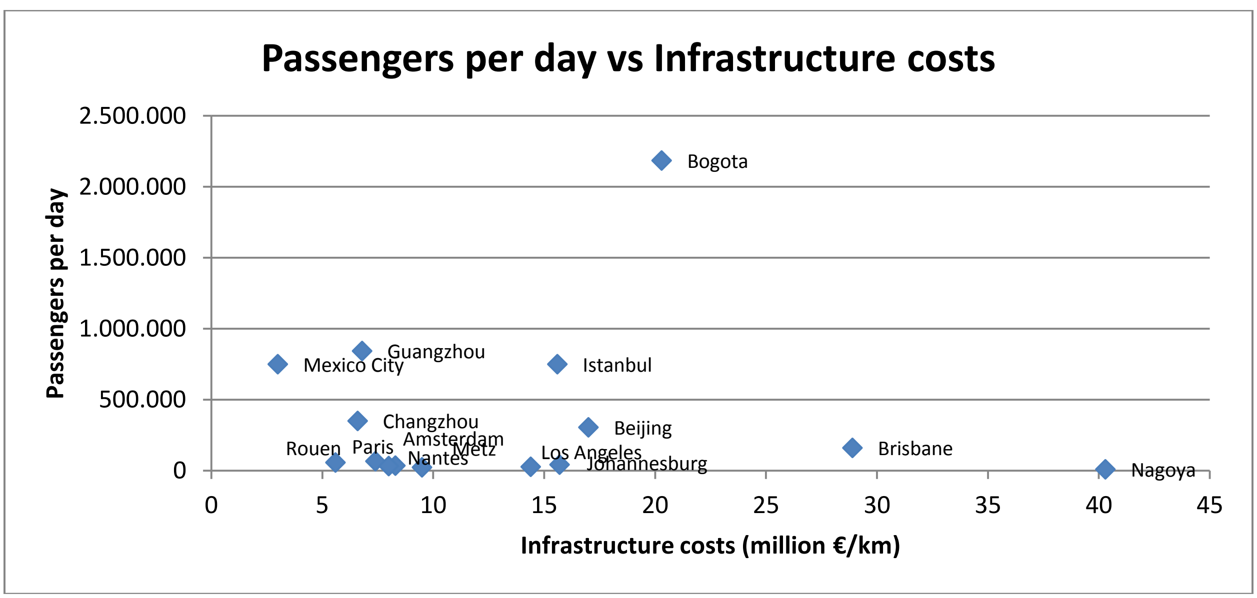


Figure 3-15: Relation between the passengers per day and the infrastructure costs

3.6.3 Service-effectiveness

Based on the available data, the service-effectiveness of the systems can be analyzed by relating the operational speed to the service consumption (passengers per day and passengers per hour per direction). Figure 3-16 provides, with the passengers per hour per direction used as indicator for the service consumption, this overview. No remarkable findings can be extracted from the study of this diagram. The same is the case when relating the operational speed to the passengers per day.

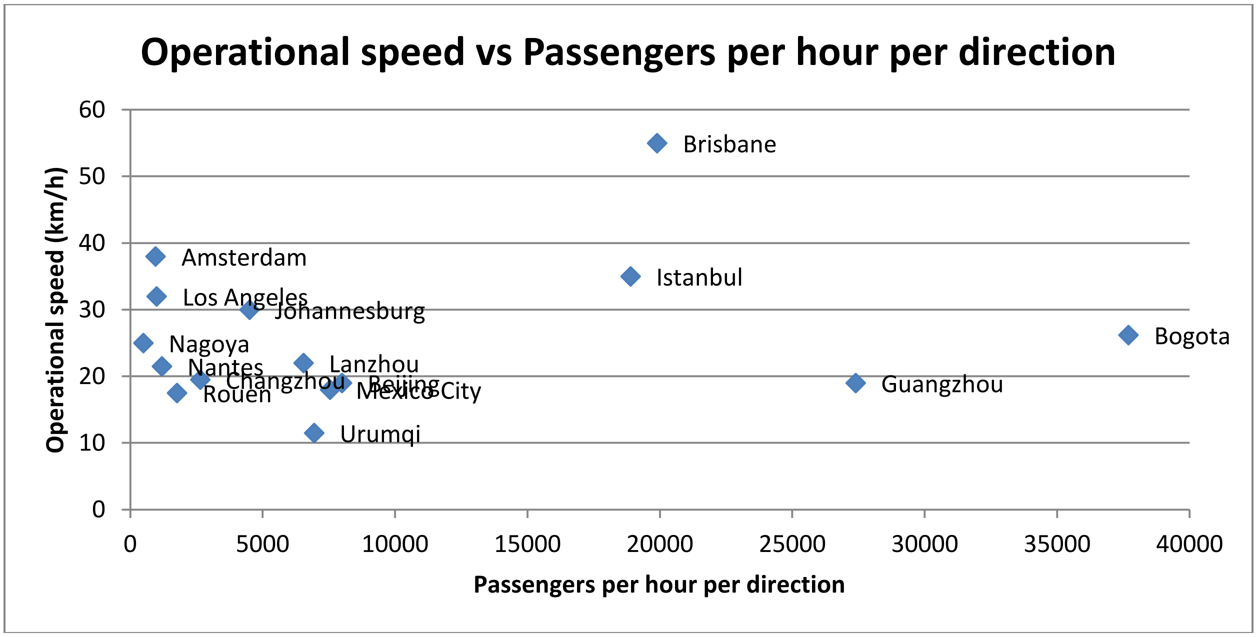


Figure 3-16: Relation between operational speed and passenger per hour per direction

3.7 Discussion of outliers

This section discusses the outliers as identified in the Sections 3.4, 3.5 and 3.6. This section uses the terms 'satisfiers' and 'dissatisfiers'. Please consult Section 3.2.1 for an explanation of these terms.

High speed and ridership in Brisbane. Figure 3-6, Figure 3-9, Figure E-9 and Figure E-10 show that Brisbane can be associated with high infrastructure costs but performs very well in terms of speed, and also attracts lot of passengers.

Considering the strong relation between the operational speed and the stop spacing, as can be observed in Figure 3-10, the high speed can be partly attributed to the large stop spacing (1650m). However, as can be also observed in Figure 3-10, the system of Brisbane performs better than Amsterdam (38km/h) and Los Angeles (32 km/h), which are systems with comparable stop spacings. This difference can probably be explained by the existence of express services. The system of Brisbane consists, in contrast to Amsterdam and Los Angeles, of many different express services. Additionally, the existence of passing lanes on all stations guarantees the efficient operation of these express services.

The type of infrastructure is another aspect that may be identified to contribute to the high operational speed. Firstly, the infrastructure is completely segregated; this prevents interference with other traffic. Secondly, as described by (Walker, 2009), the infrastructure is largely built on an area that has been reserved for freeway expansion. This ensures that barely any curves are present on the trajectory, and therefore contributes to a fast operation.

In Figure E-9 and Figure E-10 it can be observed that also the ridership of the system is very high. According to (Lucas, 2009) the ridership increased 180% between 2001 and 2009. It can be expected that this is mainly the result of the conformance to the 'dissatisfiers': speed and reliability. However, the configuration of the stations indicates that also significant effort has been made to conform to the 'satisfiers'. According to (Hoffman, 2008), the stations are designed as 'rapid transit stations' and not as just bus stops and they were valued as a critical to the systems success (see Figure 4-11 for an example of two of these stations).

So, it seems that the performance of Brisbane can be explained by an approach where significant effort has been made to conform to both the dissatisfiers as the satisfiers. This eventually resulted in an integrated system with a high speed and ridership.

High ridership in Bogota. As can be seen in Figure 3-7, with 2,185 million passengers per day, the number of users in Bogota is immense. This is not only the case when looking at absolute values, but also compared to the number of inhabitants of the urban area (Figure E-7), and compared to the network length (Figure E-9). Two main drivers of this ridership are identified.

On the one hand, in the urban area consisting of around 8 million inhabitants, no rail based public transport systems are present; bus transport is the only public transport modality. The large BRT network (112 km) covers the whole urban area, additionally many feeder bus services are connected to the BRT services.

On the other hand, by off board fare collection, dedicated infrastructure, express services in combination with passing lanes, considering the immense number of users, the realized quality in terms of speed and reliability is still good. Several sources, among other (Cain, Darido, Baltes, Rodriguez, & Barrios, 2006), (Hidalgo & Graftieaux, 2007) and (ITDP, 2007) indicate that the role of strong political leadership by the former Mayor of Bogota was crucial in the development of the system. (Cain et al., 2006) described his vision as: "He envisioned the new bus system as being the centrepiece of an overarching mobility strategy that would encourage non-motorized travel, discourage private vehicle use, and facilitate urban renewal through the redevelopment of the city's public space."

So, it seems that in the case of Bogota, strong commitment was necessary available to create a system of such proportions that is able to serve, with a respectable level of speed and reliability, an immense number of users.

Relatively low operational speed in Urumqi, Guangzhou, Beijing, Changzhou and Los Angeles. Figure 3-10 presents the relation between the stop spacing and the operational speed. In this figure, Urumqi, Guangzhou, Beijing, Changzhou and Los Angeles are identified as systems that perform below average. From (eBeijing, n.d.; Eckerson Jr, 2009; Liu, Zhang, & Wang, 2012) it appeared that exactly in these systems a proper intersection treatment was not present or insufficiently programmed to provide priority to bus vehicles. It is interesting to observe that in these systems, as can be identified in Table B-1 and Table B-2, most other design variables have an 'advanced' implementation. For instance, all systems are associated with a distinctive identity, make use of off board fare collection and consist of enhanced stations. In the case of Beijing, Urumqi and Changzhou even closed stations with sliding doors are constructed.

So, it can be concluded that in these systems the design variables impacting the 'satisfiers' are given sufficient priority. However the design variable (signal priority), mainly impacting the more important 'dissatisfiers', less priority is given.

The high infrastructure costs combined with the low ridership in Nagoya. From Figure 3-7, Figure 3-8 and Figure 3-9 it is observed that the system of Nagoya is associated with low riderships and very high infrastructure costs.

The infrastructure costs of the system are the result of the construction of a completely dedicated and elevated infrastructure. This results in a reliable system of which the relatively low speed (25 km/h) is aligned to the relatively short stop spacing (720 m, see Figure 3-10).

The low ridership seems to be the result of the short corridor (only 6,7 km) and the relatively small importance of the OD-relation. Nagoya consists of a suburban railway and subway system that serve the most important OD-relations. Busses serve the OD-combinations associated with lower travel demands.

Considering the small OD relation the decision for an elevated infrastructure is remarkable. According to (Takeshita, Kato, Hayashi, & Shimizu, 2008), the considered corridor was identified to be the best selection for new BRT corridor. However, the road width in the built-up area appeared to be too narrow to develop a BRT system on ground level. Therefore, the Guideway Bus System, running on an elevated track in the built-up area, was preferred instead.

So, the development of the system of Nagoya can be viewed from the perspective of political commitment. Notwithstanding, the minimal number of users, to guarantee competitive levels of reliability and speed, a very costly elevated infrastructure has been created.

Relatively high speed in Johannesburg. Observing Figure 3-10 and Figure 3-11, it could be concluded that considering the fact that no signal priority is present, the speed of the system of Johannesburg is high. It is expected that the absence of signal priority has a significant negative effect on the realized speed. Although literature was consulted to identify why this is not the case in Johannesburg, no answers were obtained. Additional research into the drivers of this high operational speed is desirable.

Relatively low occupation of European systems. In Figure E-10 and Figure E-9 it was observed that compared to the systems worldwide, the occupancy of the European systems is limited. Two explanations are identified that for most of the identified systems are true. Firstly, as can be identified in Table B-3, the numbers of inhabitants of the urban areas the systems are located in are much smaller. Secondly, the presence of rail systems (heavy rail, metro, light rail, tram) serving generally the most important OD-relations impacts the occupancy of the BRT systems.

Low speed but high ridership in Urumqi. As was indicated above, the absence of signal priority in the system of Urumqi results in a low speed. However, as could be observed in Figure 3-7, the ridership is still very high. From literature research, no clear evidence could be identified. However, two hypotheses could be formulated. Firstly, it is possible that a lot of passengers are dependent on using the BRT service. The BRT system is in fact the only urban public transport system present in Urumqi, no metro, light rail or tram systems are present. Secondly, the identified speed of 11,5 km per hour is associated to the peak period, in non-peak periods much higher speeds are reached. Additional research into the drivers of this high ridership is desirable.

High ridership in Guangzhou. As could be observed in Figure 3-7 and Figure 3-8, the system of Guangzhou is associated with a very high ridership. The BRT corridor of 22 km is located straight through the city centre of a city with more than 11 million inhabitants. To accommodate this demand, the system is designed to serve as many people as possible. This is done by the implementation of express services, combined with extremely long stations equipped with passing lanes (with station lengths up to 285 m, multiple busses can be served simultaneously).

Rouen, a system that only consists of 66% segregated infrastructure still performs well. As could be observed in Figure E-2, the system of Rouen only consists of 66% segregated infrastructure. However, Figure 3-10 shows that the system still performs in conformance to the stop spacing (560 m). The system is formed by three lines that share a section of dedicated infrastructure in the city centre. On this trajectory through the old city centre, cars are prohibited. Outside the city centre, vehicles operate more mixed with other traffic. Apparently, this configuration is sufficient to guarantee the speed and reliability of the service. It should be noted that the approach, of dedicating the city centre to public transport only, is frequently used in France. In the system of Metz, also one of the reference systems, the same principle is used.

3.8 Conclusion

This chapter first outlined how the quality of a BRT system can be assessed. In this assessment, the performance indicators *infrastructure costs*, *operational speed*, *passengers per hour per direction*, and *passengers per day* are used. Also a set of 24 design/context variables is determined. Subsequently the characteristics (by design variables), and performances (by performance indicators) of reference systems are examined. By subsequently researching the relation between these two, insights are gathered about how these systems perform, and outliers are researched.

The main lesson that could be extracted from this research is the importance of commitment. In this context, commitment is explained as the willingness to create a system that first of all conforms to the primary goals of the system: the 'dissatisfiers' and the 'satisfiers'. The importance of the secondary and tertiary goals seem to be important but these are not assessed in this study. The importance of commitment for the design of a system was also highlighted by (Roos, 2014) (see the interview in Appendix O).

In the systems of Bogota, Brisbane, Rouen, this commitment was clearly present. In the case of Bogota and Brisbane this is highlighted by the fact that the design decisions are made, such that the all customer satisfaction aspects (dissatisfiers as well as the satisfiers) are met. To achieve this, in Bogota and Brisbane 'heavy' configurations were necessary. In Rouen even mixed traffic operations were possible on some sections. However, in all situations very successful systems are created that are very successful in terms of ridership and operational speeds.

It systems where this commitment appeared to be less strong, it seems that unbalanced systems are designed. The systems of Urumqi, Changzhou and Los Angeles are examples of such systems. For all of these systems the design decisions are made in such a way that a very 'heavy' appearance is created. However in all cases, the intersection treatment is not sufficient. This results in a poor performance in terms of speed and reliability, the main determinants of the level of customer satisfaction.

Also the case of Nagoya indicates that commitment can lead to the creation of a system that performs well on the 'dissatisfiers' and the 'satisfiers'. However, in the case of Nagoya, the attracted ridership was small. This indicates that to generate also a large ridership, the system should be considered within its local context.

So, each element should be cost-effectively configured to such a level that the primary performance is reached. This level is however dependent on the local conditions. These founding's confirmed that the approach, to separately match the implementation of each specific design variable with the local conditions, as presented in Chapter 2 is appropriate. A model in which the design decisions are accustomed to the local conditions is presented in the next chapter.

4 Formulation of a BRT design model

This chapter presents the formulation of a model to assess the applicable configuration of a BRT system. In the previous section, a research of reference systems is presented. The results of this analysis are used to formulate the BRT design model in this chapter.

For the formulation of this model, considering the limited time available for this research, the set of design variables is first constrained to the most important ones. The remaining design variables are subsequently divided into two categories. The first category contains design variables of which the optimal configuration is relatively insensitive to the local conditions. For these, a configuration is advised that is the same in all situations. The second category contains design variables of which the optimal configuration is relatively insensitive to the local conditions. For these, the configuration is based on the values of input variables which capture the local conditions.

The structure of this chapter is as follows. Section 4.1 presents the usability of the BRT design model in the design procedure. Section 4.2 presents the methodology used to formulate the model. Subsequently, in Section 4.3, the design variables are presented that for the remainder of this research are left out of consideration. The Sections 4.4 and 4.5 present the design variables of which the implementation is respectively independent of or dependent on the local conditions. Finally, Section 4.6 presents the conclusion of this chapter.

4.1 Usability of the BRT design model in the design procedure

As presented in Chapter 1, “Introduction”, there is worldwide a growing demand for high quality urban public transport solutions. The constructed model explores the possibilities of using high quality bus services to accommodate the wish for a high quality urban public transport solution. The model allows to explore in the exploratory stage of a (potential) project, adjusted to the local conditions, the applicable configuration of a bus service. These local conditions are specified for one particular corridor, of which the user already has an idea of the number of desired stops.

The formulated model presents an advised configuration of a set of design variables. These are design variables that mainly determine the primary quality of the bus service. Additionally, to enlarge the understanding, the alternatives for and implications of the suggested configurations are presented. Practically, this is useful for municipalities and other public bodies as well as other stakeholders who are interested in getting an impression of the design space of BRT configurations.

The model is intended to guide the discussion about the possible configuration on main features. The phase that is associated with this can be called the project preparation phase. This high level approach implies that the model can form input for a variety of subsequent studies in later stages of the design procedure, such as the operational and physical design. Figure 4-1 indicates the applicability of the model within this design procedure.

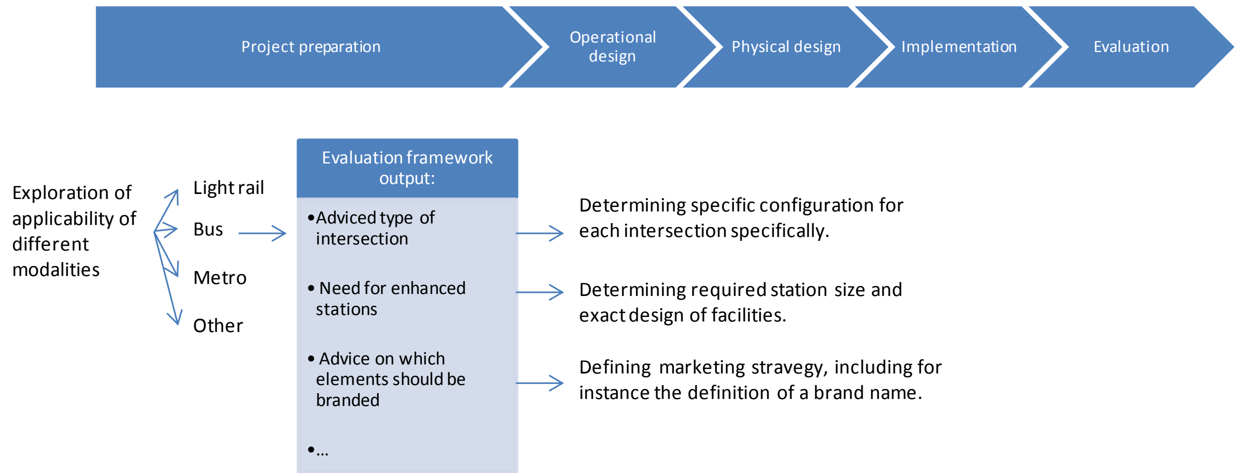


Figure 4-1: Applicability of the model in the total design procedure of a BRT system

As described above, the model is intended to be used during the project preparation phase. However, the model can also be used to review the configuration of an already existing bus service.

4.2 Model formulation approach

The design variables used in the model are originating from Chapter 3 "Studying BRT in practice". In this chapter, a set of 19 design variables is used to analyze the performances of the identified reference systems. Since not all of these 19 design variables could be directed translated into the model, some of these design variables are split, and some are taken together and are formulated as one design variable. This process has led to the 20 design variables that are further considered in the remaining of this chapter.

Considering the limited time available for this research, this set of 20 design variables is still a set that is too large to implement in the model. Therefore, this set is constrained to the most important ones. Section 4.3 presents 8 design variables that are left out as such, together with the reasoning why they are left out.

The 12 remaining design variables are divided into two categories. Design variables of which the optimal configuration is identified to be relatively insensitive to the local conditions (4 variables, presented in Section 4.4), and design variables of which the optimal configuration is identified to be sensitive to the local conditions (8 variables, presented in Section 4.5).

The research approach of this chapter is summarized in Figure 4-2.

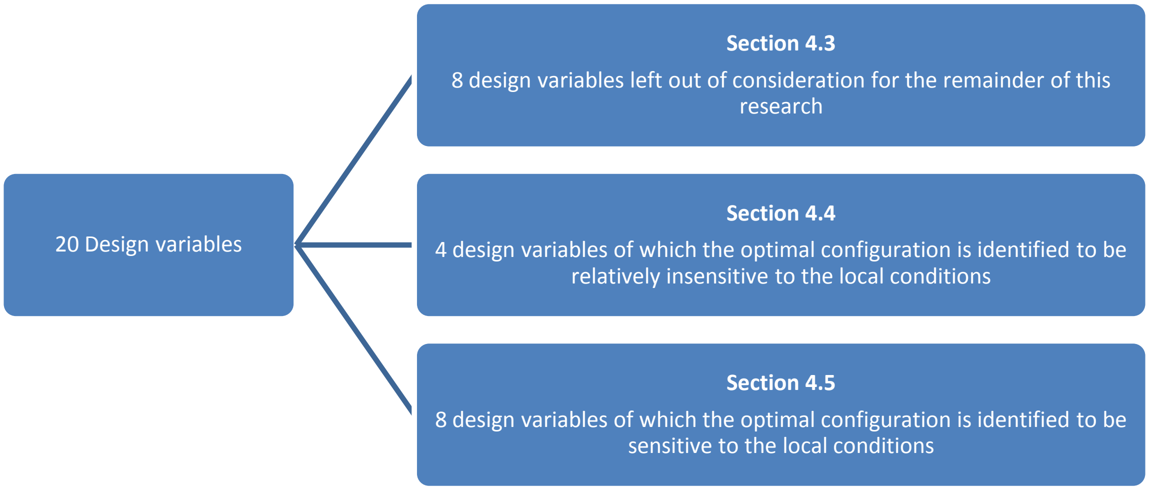


Figure 4-2: Research approach of Chapter 4

4.3 Design variables left out of consideration

Because of various reasons (among other: effect on primary performance of system, applicability for Dutch context, limited time available for this research), a set of eight design variables in total are left out of consideration. This section presents and evaluates these design variables.

4.3.1 Fuel type

The fuel types of the vehicles in the set of reference systems include CNG, LPG, diesel and hybrid versions. The decision for one of these fuel types depends mainly on the level of environmental awareness that should be displayed. New techniques are emerging quickly, in Hamburg for instance, hybrid busses, charged within 6 minutes at poles at the end of a line, is recently experimented with (OV-magazine, 2014a). Compared to a conventional diesel bus, the costs of all these new types of busses are generally higher (Kennisplatform Verkeer en Vervoer, 2005). However, the operational costs are not always lower. When deciding on the fuel technique, the initiator should have a clear idea of his budget, the environmental awareness that should be displayed, and the actual possibilities regarding fuel techniques. For simplicity, it is assumed in this research that there is only a minimal relation between the primary performance of the system (speed, reliability,..), and the chosen fuel type. For this reason this consideration is not implemented in the BRT design model.

4.3.2 Vehicle length

The variety in busses, used in the reference systems, is large. Looking at the vehicle length, some systems mainly operate standard busses (e.g. Brisbane), others mainly bi-articulated (e.g. Metz). From analysing the efficiency of articulated and bi-articulated busses, it will be concluded below that longer busses are barely more efficient than standard busses. Table 4-1 presents this analysis. It should be noticed that in this analysis the staff costs are not considered. Despite this, the analysis is still assumed to provide a sufficient insight in the efficiency of the different vehicle lengths. In the left columns (input), for three different vehicle lengths, the characteristics of a diesel bus are presented (key figures originating from (Kennisplatform Verkeer en Vervoer, 2005)). In the right columns (output), the efficiency of these three vehicle lengths is assessed. Form the minor differences between the output values, it can be concluded that, in case each vehicle is fully loaded, longer vehicles are not per by definition more cost-effective. It should be noted that the labour costs of the driver are not taken into consideration. Since the advised vehicle length is purely based on the travel demand in combination with the frequency, and aligned in a later stage of the design, this design variable is not considered in this research.

Table 4-1: Assessment of cost efficiency of three different bus vehicle lengths

Input				Output			
Length (m)	Capacity (pers)	Costs of diesel bus (€ x1000)	Cost of bus kilometre (€/km)	Costs bus/ capacity (x1000)	Costs bus/ bus length (x1000)	Cost of bus kilometre/ capacity	Cost of bus kilometre/ bus length
12	80	190	0,5	**2,38**	**15,8**	**0,0063**	**24**
18,75	130	280	0,75	**2,15**	**14,9**	**0,0058**	**25**
25	200	430	1	**2,15**	**17,2**	**0,0050**	**25**

4.3.3 Number of doors

The larger the number of doors in the vehicle, the more people are able to board and alight the vehicle in the same time unit. Therefore, the larger the travel demands per vehicle, the more doors are desirable. Also, the organization of the fare collection process determines the spread of passengers over the available doors, and with that the need for doors. Generally, the number of doors is strongly related to the length of the vehicle. 12 m vehicles have mostly two doors, 18,75 m vehicles have mostly three doors, and 25 m vehicles have mostly four doors. With the relatively low travel demands in the Netherlands, compared to the international practice, the number of doors commonly implemented in Dutch bus vehicles is in this research is assumed to be sufficient.

4.3.4 Type of guidance

Two types of guidance can be indentified: guidance on the infrastructure, or guidance only at stations. The first type of guidance is implemented in Nagoya; here the vehicle is mechanically guided over the whole trajectory. However, in the European Union, because of legal restrictions, this type does not exist. The second type of guidance is also used incidentally. In for instance Rouen, to navigate closely to the curb, and with that reduce the gap between the curb and the vehicle, optical guidance at stations is used. It is expected these techniques have benefits but, because of time constraints, they are not further considered in this research.

4.3.5 Platform height

The height of a platform can be either regular (In the approximate range of 30 – 35 cm), or high (In the approximate range of 90 – 100 cm). The decision for the height of a platform is directly related to the type of vehicles used. Besides differentiating in fuel type, vehicle length, or the number of doors, also the decision can be made between high- and low floor vehicles. In case of very high volumes, high floor vehicles can provide additional capacity. These types of vehicles are mostly used in the highly saturated systems of South America. For the Netherlands, for simplicity, it is recognised that the travel demands are relatively that low, that these high floor vehicles, and thus also these high platforms, provide no significant advantages. Because of this, the platform height is not further considered in this research.

4.3.6 Sliding doors in stations

In case of high platforms, sliding doors in stations are commonly implemented to safely facilitate the boarding procedure. Since these high platforms are not considered in this research, also the implementation of sliding doors is not considered.

4.3.7 Closed stations

By implementing closed stations it is possible to prevent fare evasion. In case of a closed station, the station platform can only be entered when the user possesses a valid bus ticket. On locations where closed stations are implemented, these always go along with high platforms/high floor busses. A reason for this is that high station platforms make physically closing the station easier. In case of regular platforms, physically closing the station is much more difficult. Since no high platforms are considered in this research, closed stations are also left out of consideration.

4.3.8 Grade separated entrance of stations

In case stations are located centrally (one station serving both directions), implementing grade separated entrances of the stations becomes optional. A grade separated entry of the station can provide a safe entry, without impacting the traffic flow. Since centrally located stations are not considered in this research, also grade separated entrances are not considered.

4.4 Design variables that do not depend on local conditions

This section presents four design variables of which the optimal configuration is identified to be relatively insensitive to the local conditions. For each of these design variables the recommendations are also summarized in Section 4.6.

4.4.1 Fare collection

When striving for a fast and reliable bus service, short dwell times are important. The different components of dwell procedure are visualized in Figure 4-3

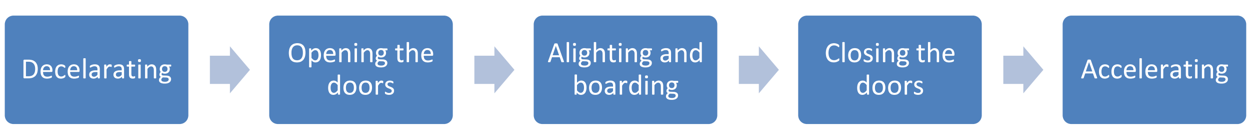


Figure 4-3: Overview of processes that are part of the dwell procedure

As is presented by (Transportation Research Board of the National Academies, 2013) the fare collection procedure is one of the determinants of the dwell time. Fare collection can take place on the station or inside the vehicle. Fare collection inside the vehicle can be achieved by using a chip card, or by buying a ticket from the bus driver. In case the fare collection takes place inside the vehicle, the fare collection process is part of the 'alighting and boarding' procedure (see Figure 4-3).

It is important that the fare collection takes places as quick and reliable as possible. The best way to achieve this is by collecting the fare before entering the vehicle. As was researched by (Hensher & Li, 2012), pre-board fare collection can relevantly increase the quality of BRT, given that it can reduce travel times and the variability of travel times.

In the Netherlands, nearly all people use a chip card to pay inside the vehicle, however paying to the driver is also still possible. This results in two recommendations to modify the fare collection procedure:

- Discourage the possibility to buy a ticket from the bus driver. Since it significantly slows down the boarding process, and decreases its reliability, this is undesirable. However, the frequency this option is used, determines the effectiveness of the measure. When this possibility is barely used it should be eliminated altogether to improve the overall service level.
- Pay on the station by chip card. When entering the vehicle, one should check-in at a special device, and after alighting one should check-out again. This process of checking-in in the vehicle is fast but not optimal yet. To reduce the boarding time per passenger, an improvement could be to check-in on beforehand on the stop. The higher the number of boarding's on a station, the more lucrative this improvement becomes. This method of payment is already common for the train services in the Netherlands and also for the light rail service connecting Nieuwegein and Utrecht. For bus services this method of payment is up until now not common in the Netherlands. *It is recommended to locate the fare collection location at the station* but since this is a new concept, it should be made sure this is clear for the customers.

When referring to Figure 4-3, currently in the Netherlands, the fare collection process influences the time needed for the 'alighting and boarding' procedure. By these two recommendations, the fare collection process has been decoupled from this procedure.

It should be noticed that these measures have two major implications:

- Since it can't be verified that people boarding the vehicle have checked in, fare evasion likely becomes a bigger problem. Outside the Netherlands, closed stations are implemented as solution. However, as was concluded in Section 4.3.7, these types of stations are not considered in this research.
- Since people are used to check in the bus (which is the case in all busses in the Netherlands), the clarity of the system will be reduced. Especially shortly after implementation, this will be likely the case.

4.4.2 Enhanced stations

For (potential) customers, stations are the first introduction to a bus system. In Section 3.2.1, it was described that, among other, customers value the comfort and the experience of the system. The design of the station heavily impacts these two customer satisfaction aspects. Two facilities are commonly implemented to provide a more pleasant waiting experience: seating facilities, and shelter against bad weather conditions. It should be noted that the implementation of these aspects can differ heavily. In this research, it is not investigated which station configuration/appearance is optimal. It is however concluded that in BRT systems, *designing stations with a significant level of quality is seen as critical to the success of a system*. Research of (Bodok, de la Haye, & Ebbink, 2010; Kennisplatform Verkeer en Vervoer, 2006) substantiate this claim. Brisbane is an example of a system where significant attention is paid to the quality of the stations. As was indicated in Section 0 the stations were valued as a critical to the systems success. (TransLink, 2012) describes the design philosophy behind Brisbane's BRT stations. In Figure 4-11, presented in Section 4.5.5, two examples of Brisbane's bus stations are shown.

4.4.3 Station level boarding

When striving to a fast and reliable bus service, as mentioned earlier, short dwell times are important. The boarding process is a significant determinant of the dwell time. As was supported by research of (Levine & Torng, 1994), by implementing station level boarding, passengers are able to alight and board the vehicle faster. To minimize the dwell time*, level boarding is therefore seen as a requirement*. Also, by implementing station level boarding, the accessibility of vehicles for disabled people is improved. In the set of reference systems, station level boarding is implemented in all systems (see Appendix B.I).

4.4.4 Dynamic travel time information

Analysis from (Balcombe et al., 2004) indicates the importance of the providence of travel time information to customers. Previously, it was only possible to provide static travel time information on bus stops. With the current availability of bus-following techniques, dynamic travel time information is becoming the new norm. Both on stations and in vehicles, information can be displayed about the expected arrival time of a bus at a certain stop. (Dziekan & Kottenhoff, 2007) indicated that providing dynamic travel time information can significantly reduce the perceived waiting time of a trip. In the set of reference systems, dynamic travel time information is also common. Istanbul and Bogota are two of the few exceptions. In Istanbul, during the peak period, every 15 to 30 seconds a vehicle is arriving. In Bogota the frequencies are comparable. In these situations, with such high frequencies, the providence of dynamic travel time information on the stop can be less necessary. Since in the Dutch situation these frequencies will never be reached, when designing a BRT system, *the providence of dynamic travel time information is identified to be always required*. For a presentation of the state of the art of dynamic travel time information systems (Schweiger, 2003) can be consulted. It should be noticed that this state of the art is originating from 12 years ago.

4.5 Design variables that depend on local conditions

This section presents eight design variables of which the optimal configuration is identified to be sensitive to the local conditions. In the BRT design model these local conditions are captured by a set of input variables. The input variables are broken down into input variables related to the policy context and input variables related to the system characteristics. The implementation in the model of the several input variables, related to the policy context, is motivated by expert judgment (Genot, 2015a; Roos, 2014; Van Oort, 2015). According to these experts, during discussions with government bodies, it often becomes clear that not only the clear, observable characteristics of the area are important. In reality, the real willingness to create a high quality service is mostly decisive when determining the configuration. Below, the input variables are presented.

Input variables – Policy context

- Investment period
- Presence of other successful high quality public transport service nearby
- The required level of speed-competitiveness of the system compared to other modalities

- The required level of reliability-competitiveness of the system compared to other modalities

Input variables – System characteristics

- Expected travel demand
- Length of trajectory
- Frequency
- Number of stations
- Predominant level of service (LOS) on trajectory
- Distribution of the demand over the trajectory
- Amount of crossing traffic

Sections 4.5.1 to 4.5.8 present these eight design variables. For each of these design variables:

- Considerations that influence the applicable configuration are presented.
- Identified output values together with the input variables that influence these output values are presented.
- It is referred to the relevant section of Appendix F, in which the relation between the input and output variables is described.

4.5.1 Type of infrastructure

When striving for a fast and reliable bus service, free flow conditions are necessary. In case of a very limited flow of cars in the same direction, mixed traffic operations are still possible. In case the volume of traffic increases, more advanced forms of bus infrastructure become necessary since otherwise the level of service (LOS) would decrease. Additional to the level of service, also limitations resulting from the spatial configuration, infrastructure costs and the policy context determine the appropriate type of infrastructure.

In the set of reference systems, different types of infrastructure can be identified. As was presented in Section 0, in the system of Rouen, different types of infrastructure are successfully implemented in the same system. However, since most systems are located in large urban areas with high traffic volumes, mostly dedicated lanes are present. Implementing dedicated lanes are here identified to be the only viable option to maintain a competitive level of speed and reliability. Figure 4-4 presents an example of the implementation of a dedicated lane in the BRT system of Istanbul. In case of a traffic flow with this level of service, a dedicated lane seems to be the only viable option.

Figure 4-4: Dedicated lane in the system of Istanbul. Figure reprinted from (Talaraza, 2012)

So, the traffic flow on the trajectory heavily determines the suitable infrastructure type for each competitive LOS requirement.

Implementation in model

The model suggests one of four types of infrastructure (see Figure 4-5 for an overview of these types); this outcome depends on the *predominant LOS on trajectory*, the *speed-competitiveness* and the *reliability-competitiveness*. Appendix F.I describes the relevant section of the model.

Type 1: Mixed with other traffic | **Type 2: Bottleneck solution** | **Type 3: Dedicated lane, at-grade intersections** | **Type 4: Dedicated lane, grade separated intersections**

Figure 4-5: Identified types of infrastructure. Figure of type 2 reprinted from (Meer Merwede, 2013)

4.5.2 Type of intersection

The choice for the type of intersection is a process of balancing different interests. The more people that use the bus service, the bigger the travel time losses for bus users are at non prioritized intersections. On the other hand, the more car users are impacted by a bus claiming priority on an intersection, the bigger the travel time losses for car users. Additional to that, the spatial configuration, the infrastructure costs of each type of intersection and the policy context determine the preferred type.

In Section 3.2.1, the importance that customers attach to the speed and reliability of a bus service is presented. Well functioning intersection treatment (in case intersections are present) is vital to guarantee the speed and reliability of a bus service.

The impact of intersection priority on the operational speed is clearly indicated in the set of reference systems. Figure 3-10, presented in Section 3.5, shows the relation between the stop spacing and the operational speed. As was presented in Section 0, it appeared that exactly in these systems a proper intersection treatment was not present or insufficiently programmed to provide priority to bus vehicles. Figure 4-6 indicates this really well, a four-phase intersection in Urumqi is displayed, where, because of the absence of signal priority, a large queue of BRT busses builds up.

So, in case a competitive level of quality (speed, reliability) needs to be reached, the crossing traffic flows on the intersections heavily determines the suitable type of intersection.

Figure 4-6: An intersection in Urumqi where a large queue of BRT busses builds up. Figure reprinted from (Fjellstrom, 2011b)

Implementation in model

The model suggests one of four types of intersections (see Figure 4-7 for an overview of these types); this outcome depend on the *expected travel demand*, the *frequency*, the *amount of crossing traffic,* the *speed- competitiveness* and the *reliability-competitiveness*. Appendix F.II describes the relevant section of the model.

Type 1: Mixed with other traffic	Type 2: Priority on bus compartment	Type 3: Priority on bus lane	Type 4: Grade separated intersection

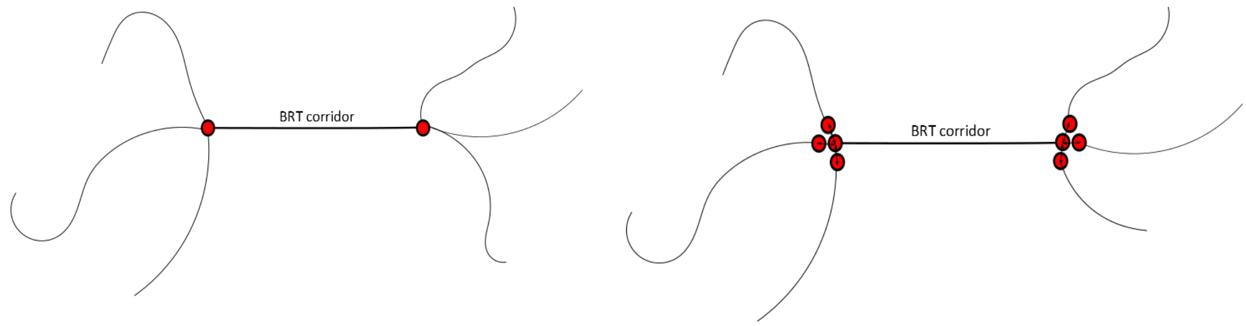
Figure 4-7: Identified types of intersections. Figures reprinted from type2:(Photonews, 2013), type 4: (Fjellstrom, 2011a)

4.5.3 Open or closed system

The densest regions ask for high capacity vehicles, while in remote residential area's smaller vehicles are generally sufficient. Passengers however favour a trip without a transfer, since this transfer costs time and convenience. This statement is intuitively true but also supported by scientific research. (Van der Waard, 1988) and (Wardman, 2004) present the perceived relative weights of access time, waiting time, and egress time, compared to in-vehicle time. Each of these travel time components is associated with a higher weight compared to the in-vehicle time. On the other hand, providing a direct connection between every pair of origins and destinations is impossible. Balancing between these two is the challenge.

Following from this, two ways of usage of a BRT corridor can be distinguished. A BRT corridor is the identified trajectory between A and B, equipped with the typical BRT characteristics (infrastructure, intersection treatment,...). In case vehicles are only serving the trajectory A-B, the services are indicated as trunk-only or trunk-feeder services. In case vehicles are entering the corridor at A and are leaving the corridor at B, the service is indicated as direct service. Figure 4-8 below visualizes the design of these two types of systems. These are called:

- **Open system** (with as operational mode direct service). In these systems the BRT corridor is entered without the need of a transfer.
- **Closed system** (with as operational mode, trunk only or trunk feeder). In this type of system, vehicles only travel on the BRT corridor.



Open system **Closed system**

Figure 4-8: Visualisation of the two identified system types

Researching the reference systems, it was found that both open (e.g. Guangzhou, Brisbane), as closed (e.g. Bogota, Istanbul) systems were used. Also hybrid versions exist (e.g. Johannesburg, Amsterdam). The optimal configuration is dependent on the characteristics of the considered area. Below, four important aspects are presented that greatly influence the decision for either an open or closed system.

- Distribution of travel demand. The location where passengers are living, combined with the decision for the type of system, define the respective travel time in vehicle, and the waiting and transfer time for each trip. One should strive to minimize this value. When knowing the origins and destinations of bus travellers, it is possible approximate the effectiveness of both types. In Beijing, an open system was converted to a closed system. The results were longer travel times because of the need for an extra transfer (Hook, 2008). This example emphasizes the need for a good alignment of the type of system and the distribution of the travel demand.
- Length of trajectory. The longer the BRT corridor, the longer the trip time, the smaller the relative impact is of a transfer is in the weighted travel time. This reasoning assumes all else being equal (cetris paribus).
- Operational costs of vehicles. When choosing for an open system, vehicles cannot be optimally attuned to the travel demand. The densest regions ask for high capacity vehicles, while in remote residential area's smaller vehicles are generally sufficient. Differentiating and attuning vehicle sizes to the demand is easier to do when operating in a closed system.
- Feasibility. Articulated or bi-articulated BRT vehicles can have problems to manoeuvre in narrow streets outside BRT corridors. When a maximum capacity on the BRT corridor needs to be realized, a closed corridor can be the only option.

Two additional implications of an eventual decision to implement a closed system are presented below:

- In case a closed system is operated, it is important to pay extra attention to the connection of the high frequent service (section on the BRT corridor) to the low frequent service (section outside the BRT corridor). The other way around (from low frequency to high frequency) the connection is naturally better organised.
- (CERTU, 2010) also noted that in case of a closed system: “Pedestrian routes between lines should be as short as possible, clearly indicated and safe”;

Implementation in model

The model suggests whether an open or closed system is likely the best option; this outcome depends on the *distribution of the demand over the corridor*, the *length of the trajectory* and the *expected travel demand*. Appendix F.III describes the relevant section of the model.

4.5.4 Express service

An express service is a frequently used form of a skip-stop service. Express services skip stops over a trajectory (mostly stops associated with a low demand), to increase the speed and reliability of the service. Express services operate in combination with local services, which serve every stop (Figure 4-9 indicates a possible configuration of a local and express service). Guangzhou and Bogota are examples of BRT systems that operate express services. According to (Wright, 2011) the implementation of express services is becoming the norm in BRT systems.

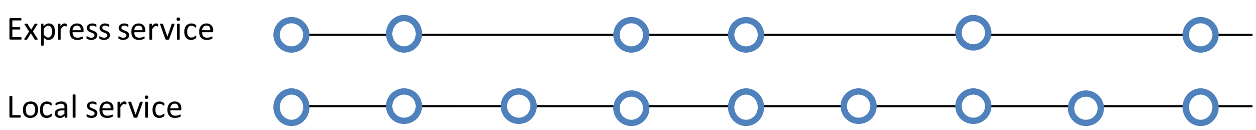


Figure 4-9: Possible configuration of an express service

By implementing express services, capacity can be increased and travel times for a share of the users can be reduced. The applicability of an express service is dependent on the travel demand and the associated distribution over the stops. These factors will determine the ratio of the travel time profits for people in the vehicle, and travel time losses for people who want to use a skipped stop (because of an increased waiting time, transfer time, access time and egress time).

Express services are most effective in case there is a significant spread of the travel demand over the line. In case of such a spread, this implies that there are stops where the demand is relatively low. These stops are attractive to skip. Often this is the case when the bus service is a radial line through the city centre (were besides serving the dense centre, also a more remote area is served), or when two dense areas are connected with each other (the remote area between the two dense centres).

In case a stop is skipped that was used previously, a user has the possibility to:

1. Walk further to the next stop
2. Wait or leave early to take a local line, because:
    - Walking further is not preferred
    - The desired destination is also skipped.

If users decide to walk further to the next stop, the impact on the access and egress time is much smaller In case of a short stop spacing. Therefore, also the stop spacing impacts the attractiveness of an express service.

Below, a few implications of implementing an express service are presented:

- Clearness of the system. In Section 3.2.1 it was described that the clearness of the public transport system is one of the determinants of the level of customer satisfaction. Implementing express lines can negatively impact this level of clearness. By implementing many express services, for example as seen on the BRT map in Figure 4-10, the BRT system of Bogota became very unclear. (Hook, 2008) reported that this resulted in people taking a local service because they cannot figure out easily which express services could be taken. When setting up a BRT system, acquiring additional capacity and improving travel times must be balanced with retaining the clearness of the system.
- Alignment of express and local services. In case an express service is implemented, alignment of express and local services is vital to provide efficient access to local stops.
- Equity. In case an express service is implemented, some stops have to deal with a lower frequency than other stops. From a viewpoint of equity this will be important to be aware of.
- Passing lanes. To accommodate that express services can pass local services, passing lanes at stops may be necessary. Section 4.5.8 elaborates on the possible need of passing lanes.

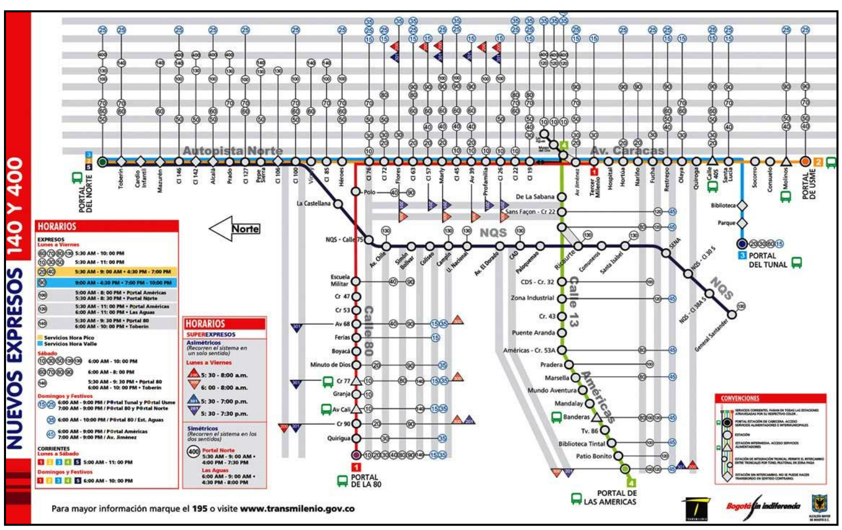


Figure 4-10: BRT map of Bogota's BRT system

Implementation in model

The model suggests if the implementation of an express service is potentially attractive or not; this outcome depends on the *distribution of the demand over the corridor* and the stop spacing (based on the *number of stations* and the *length of the trajectory*). Appendix F.IV presents the relevant section of the model.

4.5.5 Branding of elements

Like most commercial products, as was researched by (Beale & Bonsall, 2007), also the perception of the quality of a bus service can be influenced by marketing. By creating a unique brand and identity, that is effectively used, the perception of the quality of the system can be affected.

(Hess & Bitterman, 2008) describe the terms branding and identity, in relation to a BRT system, as follows:

- **Brand.** "A brand is the sum of all experiences, images and perceptions people have about a product, service, or company. A brand includes logos, icons, colours, fonts, product names, personality, values, heritage, reputation, functional attributes (e.g., employee/customer service, product offering, pricing, service delivery) and emotional attributes (e.g., flexible, dependable, trustworthy".
- **Branding.** "Branding is the conscious application of similar communication and identity elements to a particular product, service, or entity that is intended to identify functional attributes, differentiate, and form a personal emotional bond."
- **Identity**. "An identity is the mechanism used to broadcast "being" or existence to the public. In advertising, identity typically refers to the logos, icons, and product names that visually communicate the service/product brand to potential customers."

(Carrigan, Arpi, & Weber, 2011; Transport Canada, 2008) both present recommendations on how to brand a system. It appeared that these different recommendations are all strongly related to each other. According to (Hess & Bitterman, 2008), consensus seems to be that the following aspects are essential:

1. "Create a separate brand identity by using a colour palette, one that clearly delineates the service as a signature, offering different from that of the parent transit agency. This identity should be incorporated into everything related to the service: bus, station, maps, signage, etc.. "
2. "Focus on the positive and unique features of the service". For instance:
    - Modern
    - Efficient
    - Rapid
    - Reliable
    - Convenient
    - Comfortable
    - Safe
3. "Know your market, who will use it, why and when do they use it and what do they expect from the service. These insights determine on which of the features named above it's useful to focus on."

So, according to this research, a brand and identity should be implemented to all aspects of the system (bullet point 1). Because of the chosen operational mode, in some systems this is however impossible. In a closed system, both the stations and the vehicles can be branded. In case of an open system, the vehicles are also used outside the BRT corridor. Since in these systems mostly no special BRT vehicles are used, the branding of these vehicles is difficult.

Brisbane is an example of such an open system where regular transit vehicles make use of the BRT corridor. As is described by (Hoffman, 2008), here a so called infrastructure strategy is chosen. By developing a network of dedicated infrastructure with grade separated intersections, a range of evolving transit services can be developed. The infrastructure, and in particular the stations, are the focus of the branding, and image effort. As was indicated in Section 0, the design of the stations was valued as critical to the systems success. Figure 4-11 provides an example of two of these stations.

So, from the case of Brisbane, it can be concluded that in case branding of the vehicles is impossible, it is advised to focus the branding effort on the stations.

Figure 4-11: Example of the configuration of Brisbane's BRT stations. Reprinted from (Fjellstrom, 2014) and (Fjellstrom, 2009)

Implementation in model

The model suggests if only the stations should be branded, or that also the vehicles should be branded; this outcome depends on the output variable *open or closed system*. Appendix F.V describes the relevant section of the model.

4.5.6 How to position the system in the market

Bus systems appear in a broad spectrum of qualities. However, as was also pointed out by (Hensher, 2007), bus services are generally assumed to be a low quality mode of public transport. In case the system is a high quality bus service, instead of a conventional bus service, it is important that this is acknowledged by its potential users. Looking at potential ways to achieve this, two ways a system can be positioned in the market are identified. This can be either done by differentiating the service from existing bus services or by connecting the system to existing high quality public transport services (light rail, metro or other BRT services).

When differentiating the service, the service is presented to be totally different from the already existing bus service(s). An example is Mexico City; when introducing the BRT system, the new travel times were compared to the existing microbus service (see Figure 4-12) in a marketing campaign.

When connecting the service, the service is presented as an extension of an already existing high quality public transport service. This can be a light rail service, metro service, or other BRT service. Nantes and

Los Angeles presented their systems this way. In Los Angeles the bus service is strongly connected to the metro service. It is called ‘Metroliner’, the same identity is used and is only as bus service displayed on the metro map (see Figure 4-13). In Nantes the same principle is used. Here the high quality bus service is strongly connected to the light rail system. Here, the bus service is as only bus service displayed on the light rail map (see Figure 4-13).

So, based on these cases, common practices seem to indicated that the environment of the system determines if connecting or differentiating the BRT service from existing services is the best option.

Figure 4-12: Example of differentiating the BRT service in Mexico. Figure reprinted from (Urbanomics, 2012)

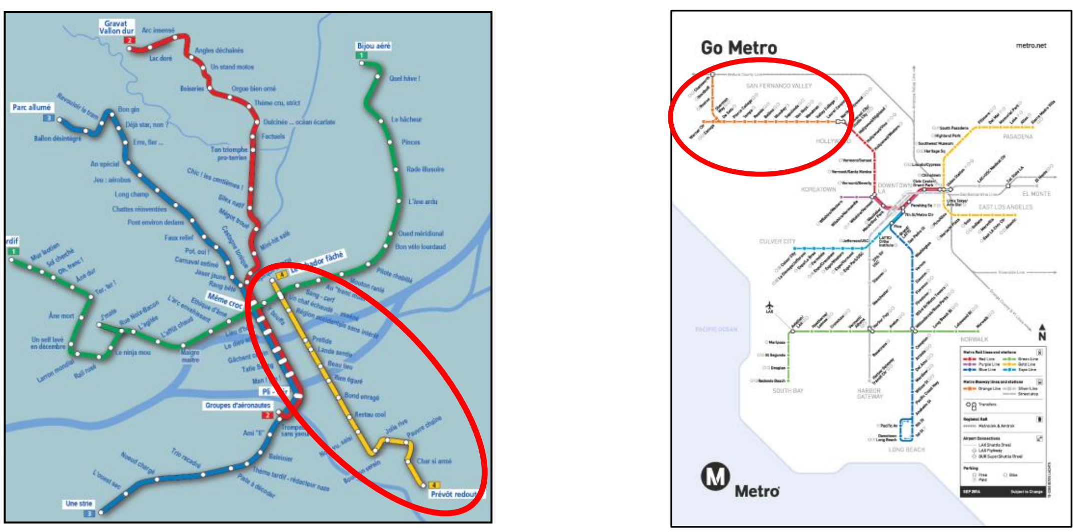


Figure 4-13: Example of connecting the BRT service in Nantes (left) and Los Angeles (right). Figures reprinted from (Rail for the Valley, 2014) and (LA Metro, 2014)

Implementation in model

The model suggests if connecting or differentiating the system from existing public transport services is likely the best option; this outcome depends on *other successful high quality public transport systems*. In Appendix F.VI presents the relevant section of the model.

4.5.7 Access and egress transport by bicycle

For the determination of the success of a public transport connection, the quality of the access en egress part of a trip is vital. The faster the modality, the longer someone is willing to travel to the access point of a system (Daniels & Mulley, 2013). A conventional bus line is associated with a low speed, typically serves a small area. Within this area, walking is the dominant modality (Van der Blij, Verger, & Slebos, 2010). In case of an increased operational speed (e.g. because of a greater stop spacing), people are willing to travel a longer distance to a stop (Van der Blij et al., 2010). For these longer trips, using the bicycle as access and egress modality becomes more attractive. To capture the potential of this user group, the usage of the bicycle as access- and egress mode should be stimulated. One way to do this is by providing high quality bicycle infrastructure to connect the bus stations. A more common way to do this is to provide sufficient and high quality bicycle parking facilities.

The BRT system of Amsterdam ('Zuidtangent') is a successful example of integration of the bicycle transport and bus transport. With a high operational speed (38 km/h) and large stop spacing (1800 m), the bicycle is a popular mode of transport for access and egress purposes. According to (Roos, 2014), involved in the design process of the system, there was emphasis on large, covered parking facilities for bicycles (see Appendix O for full interview).

So, based on the investigated literature and the experiences in the BRT system of Amsterdam, it can be concluded that, the higher the speed of the BRT system, the more important sufficient and high quality bicycle parking facilities become.

Implementation in model

The model evaluates the importance of bicycle parking facilities as likely being not particularly important, important or necessary; this outcome depends on the stop spacing (computed based on the *number of stations* and the *length of trajectory*). Appendix F.VII presents the relevant section of the model

4.5.8 Passing opportunity

In case an express service is implemented on a corridor, a problem may occur when two vehicles need to pass each other at a station. The need for vehicles to pass each other is dependent on the frequency, the difference in speeds, the design of the timetable and the length of the trajectory. When passing is desirable, but physically impossible, this almost certainly will impact the effectiveness of the express service.

In case passing is desirable there are two possibilities, the use of passing lanes on stations, or using the opposite lane for passing. In several of the researched reference systems, passing lanes are implemented (see Appendix B.I for this overview). Figure 4-14 displays an example of a passing lane in the system of Brisbane. The advantage of using the opposite lane for passing is that no additional infrastructure is required. However, because the busses need to travel over the opposite lane, the level of safety is reduced. This level of safety and the availability of passing opportunities decrease with an increasing frequency.

The decision whether opposing lane passing is possible, or passing lanes are needed is not considered in this research. The model as developed only estimates the likelihood of needing a passing opportunity.

Figure 4-14: Example of passing lane in the BRT system of Brisbane. Figure reprinted from (Fjellstrom, 2007)

Implementation in model

The model suggests if passing opportunities might be needed or that passing opportunities are not needed; this outcome depends on the output variable *express service*. Appendix F.VIII it presents the relevant section of the model.

4.6 Conclusion

In this chapter, because of various reasons (among other: lack of available data, time constraints, minimal effects on system performance, and applicability for Dutch context), the total set of 20 design variables is reduced to 12 design variables.

Of these 12 design variables, for 4 of these, the optimal configuration appeared to be relatively insensitive to the local conditions. For these design variables, notwithstanding the local conditions, the following is recommended:

- **Fare collection**: To reduce the dwell times, locating the fare collection process at to the stop is identified as an effective measure. For the Dutch situation, this implies that check in devices should be located on stops, and buying tickets from bus drivers should be discouraged.

- **Enhanced stations**: It is identified that it is preferable to enhance the quality of the stations, more than just providing the basic facilities shelter and seating. By (potential) customers, the stations should be identified as an access point of a high quality mode of public transport.

- **Station level boarding**: It is identified that to speed up the dwell procedure, providing station level boarding is a basic requirement.

- **Dynamic travel time information**: Considering the current state of art of vehicle following techniques, and the customer satisfaction it adds, dynamic travel time information is identified as a requirement.

The other 8 design variables, of which the optimal configuration appeared to be sensitive to the local conditions, are listed below.

- **Type of infrastructure**: Depending on the traffic flow on the trajectory and the priority to reach a high level of speed and reliability, the suitable infrastructure type can be assessed.

- **Type of intersection**: The type of intersection is identified to be crucial to the systems success. It is identified that in case the type of intersection is not adjusted to the local conditions, this can result in a service that performs badly in terms of speed and reliability. In many occasions this means that, to realize competitive levels of speed and reliability, full priority or grade separation on intersections is required.

- **Open or closed system**: To be able to define if either an open (operational mode is direct service) or closed system (operational model is trunk only or trunk feeder) is optimal, it is identified that it is essential to evaluate the origins and destinations of the users of the systems.

- **Express service**: Depending on the distribution of the travel demand and the stop spacing of the service, it is identified that express services sometimes can provide significant travel time profits. However, the reduction of the clearness of the system appears to be a disadvantage.

- **Branding of elements**: It is identified that the branding and identity is a vital aspect of a BRT system. The type of system (open or closed) appeared to be decisive when recommending the elements that should be branded.

- **Positioning of system in market**: As stated above, it is identified that the branding and identity is a vital aspect of a BRT system. It appeared that the presence of existing high quality public transport systems in the surrounding determine the optimal way the system is positioned in the market. Options are connecting it to, or differentiating from, these existing systems.

- **Access and egress transport by bicycle**: It has been identified that with larger stop spacings, the bicycle becomes a more attractive mode for access and egress transport. To capture this potential travel demand, as the stop spacing increases, high quality bicycle parking facilities become more necessary.

- **Passing opportunities**: It is identified that that in case expresses services are incorporated; the need for passing opportunities should be assessed.

The BRT design model evaluates the output values for these eight design variables. Their recommended implementation is related to input variables that capture the local conditions. It appeared to be important to include in the input variables, besides the system characteristics (e.g. expected travel demand, frequency), also the policy context (both policy context and system characteristics). In some cases, also output variables are identified to influence other output variables. Table 4-2 presents these relations. In this table, each ‘x’ indicates that the output variable is determined by the value of the associated input or output variable.

Table 4-2: Overview of determination of output variables of the BRT design model

		Input variables - system characteristics							Input variables - policy context				Output variables			
		Expected travel demand	**Length of trajectory**	**Frequency**	**Number of stations**	**Predominant LOS on trajectory**	**Distribution of demand over corridor**	**Amount of crossing traffic**	**Investment period**	**Other successful high quality pt systems**	**Competitiveness speed**	**Competitiveness reliability**	**Open or closed system**	**Express service**	**Type of infrastructure**	**Type of intersection**
Output variables in BRT design model	**Type of infrastructure**					x					x	x				
	Type of intersection	x		x				x	x		x	x				
	Open or closed system		x				x									
	Express service		x		x		x									
	Elements to brand												x			
	Position in market									x						
	Bicycle parking facilities		x		x											
	Passing lanes													x		
	Indication of speed		x		x											x
	Indication of reliability														x	x
	Indication of infrastructure costs				x										x	x

In the next chapter the model formulated in this chapter is implemented into a software tool.

5 Formulation of the BRT design scanner

This chapter describes the design of the BRT design scanner, a tool in which the model, as formulated in the previous chapter is implemented. The BRT design scanner is developed to make the BRT design model easy and attractive to work with. Section 5.1 presents the requirements of the scanner, Section 5.2 describes the construction of the scanner.

5.1 Requirements of the BRT design scanner

For the translation of the model into the BRT design scanner, a set of requirements is used. Below, these requirements are presented.

- **Should implement the model formulated in Chapter 4**. This is a trivial, but a very important requirement.
- **Adjusted to audience**. The BRT design scanner should be usable by municipalities and other public bodies as well as other stakeholders who are interested in the applicability of different BRT configurations.
- **Easy understandable and quickly usable**. Uses input variables of which the values are likely known for the audience (see above).
- **Provide results quickly**. Within a few minutes, the BRT design scanner should present an overview of the organization of the eight design variables.
- **Interactive quality**. When changing the input variables, the results on the output variables should become immediately visible.
- **Visually attractive**. The appearance of the BRT design scanner must encourage its usage.
- **Modular design**. The configuration of the BRT design scanner should be easily adjustable. There should be the possibility to add or change the input and output variables. Also, there should be the possibility to change the translation of the input variables into the output variables.

5.2 Construction of the BRT design scanner

The previous section presented the design requirements of the BRT design scanner. This section presents the translation of these requirements into the final tool.

The BRT design scanner is constructed in Microsoft Excel and is supported by a graphical interface, constructed with Excel's supported programming language: Visual Basic for Applications (VBA). The tool implements and automates the relations as presented in Appendix F. By this, an interactive tool is created that links the input variables to the output variables.

By filling in *textboxes* and making choices by clicking *option buttons* all input variables can be specified. By subsequently pressing the *(re)analyze-button* the applicable configuration is presented. For each of the input and output variables *info boxes* are created (which can be displayed by clicking on the *?-*button). For the input variables these *info boxes* contain information about the right interpretation of the input variables. For the output variables, these *info boxes* present the additional acquired knowledge (such as implications and considerations) originating from Chapter 4.

5.2.1 Input variables - policy context

Table 5-1 below presents the input variables related to the policy context.

Table 5-1: Input variables of the BRT design scanner related to the policy context

Input variable	Operationalization	Explanation
Investment period	Number of years	Here, the user has to define for which period of time the costs of different solutions have to be compared for.
Other successful high quality public transport service nearby?	Yes No	The user has to define if, in the surroundings of the investigated area, already a high quality public transport service is present. This can be either a light rail, metro or other BRT service.
Competitiveness for speed	Not particularly competitive Reasonably competitive Very competitive	Compared to other modalities, looking at the operational speed, how competitive should the bus system be?
Competitiveness for reliability	Not particularly competitive Reasonably competitive Very competitive	Compared to other modalities, looking at the level of reliability, how competitive should the bus system be?

5.2.2 Input variables – system characteristics

Table 5-2 below presents the input variables related to the system characteristics.

Table 5-2: Input variables of the BRT design scanner related to the system characteristics

Input variable	Operationalization	Explanation
Expected travel demand	Passengers/day (sum of both directions)	The user has to define the approximated travel demand on the investigated trajectory (sum of both directions). This value represents the total number of people in the vehicle, on the considered trajectory, during a whole day.
Length of trajectory	Km	The user has to define the approximated length of the investigated trajectory.
Frequency	Vehicles/hour (sum of both directions)	The user has to define the approximated frequency, the envisaged BRT service will operate with. This frequency is the sum of the frequencies in each direction.
Number of station pairs	Number of station pairs	The user has to define the approximated number of station pairs that will be created on the considered trajectory. A station pair is two stations located near each other, serving each a particular

		direction. To make the scanner also usable in case the user has yet no idea about this, a decision can be made for three levels of stop spacing: • 500 m (enclosing connection) • 800 m (partly supporting connection, partly enclosing connection) • 1200 m (supporting connection) The scanner links this stop spacing value subsequently to a number of station pairs.
Predominant level of service (LOS) on trajectory	LOS A LOS B LOS C LOS D LOS E LOS F	By entering the predominant LOS on the trajectory, it is tried to capture the type of traffic flow on the considered trajectory. Six service levels are identified, from A-Free flow to F-Breakdown flow. The user has to choose the level of service that represents best the situation on the considered trajectory during the peak period. Figure 5-1 graphically represents these six different levels of service.
Distribution of the demand over the trajectory	Distribution A Distribution B Distribution C	The distribution of the demand over the trajectory indicates the distribution of the people boarding and alighting over the considered trajectory. The user has to choose, from the three distributions presented in Figure 5-2, the distribution that represents best the real situation.
Amount of crossing traffic (peak period)	Number of intersections with travel demand: A/B/C/D/E/F (sum of both directions)	The user has to define the number of intersections, together with the amount of crossing traffic, that are crossed on the considered trajectory. Because of issues to implement arbitrary chosen arrival rates, six categories of crossing traffic flows and corresponding arrival rates (sum of both directions) are identified: **Category** — **Car vehicles per hour (sum of both directions)** A — <200 B — 200-500 C — 500-1000 D — 1000-1500 E — 1500-2000 F — >2000 Note that these values only concern car vehicles; slow traffic (pedestrians and cyclists) is not taken into consideration.

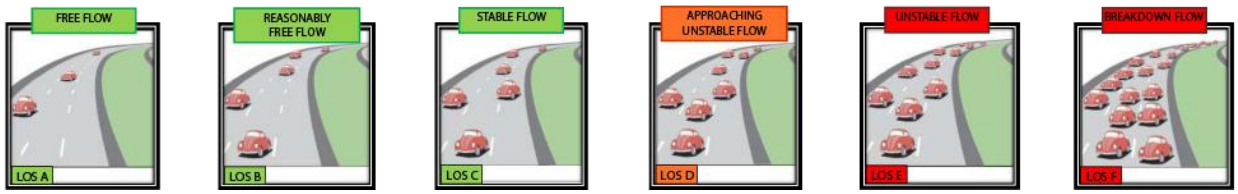
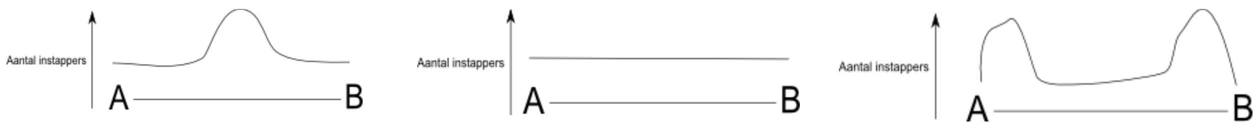


Figure 5-1: graphical representation of different levels of service. Figure reprinted from (Kgbdesign, n.d.)



Distribution A **Distribution B** **Distribution C**

Figure 5-2: Three different distributions of the travel demand over the trajectory.

5.2.3 Output variables

Table 5-3 below presents the output variables of the BRT design scanner. Additional to the values for the eight investigated output variables also three additional indicators are presented. These three indicators provide a rough estimation of the infrastructure costs, the level of reliability and the operational speed associated to the presented configuration. The calculation method of these three indicators is described in Appendix F.IX to F.XI.

Table 5-3: Output variables of the BRT design scanner

Output variable	Operationalization	Explanation
Type of infrastructure	Type 1: Mixed with other traffic Type 2: Bottleneck solution Type 3: Dedicated lane, at-grade intersections Type 4: Dedicated lane, grade separated intersections	Indication of which of the four infrastructure configurations, considering the system characteristics and policy context, is the most applicable.
Type of intersection	Type 1: Mixed with other traffic Type 2: Priority on bus compartment Type 3: Priority on bus lane Type 4: Grade separated intersection	Indication of which of the four intersection configurations, considering the system characteristics and policy context, is the most applicable.
Open or closed system	Probably open system Probably closed system	Indication if an open or closed system is the likely applicable configuration.
Express service	Probably express service Probably no express service	Indication if an express service is likely to be an efficient addition.
Branding of elements	Brand stations Brand stations and vehicles	Indication if only the stations should be branded or that also the vehicles should be branded.
How to position	Connect to existing service	Indication if the BRT service should either

the system in the market	Differentiate from existing service	be differentiated or connected to existing public transport services.
Access and egress transport by bicycle	Not particularly important Important Necessary	Indication of how important high quality bike parking facilities are for the considered system.
Passing opportunities	Passing opportunity might be needed Passing opportunity not needed	Indication if passing opportunities might be needed.
Indication of operational speed	Km/h	Indication of which operational speed is associated to the suggested configuration.
Indication of reliability	Limited reliability Predominantly reliable Very reliable	Indication of which level of reliability is associated to the suggested configuration.
Indication of infrastructure costs	Million €/km	Indication of infrastructure costs associated to the suggested configuration.

The three figures below present screenshots of the scanner. Figure 5-3 presents the input variables related to the system characteristics. Figure 5-4 presents the input variables related to the policy context and the output variables. Note that the lower 4 output variables in Figure 5-4 represent the design variables of which its optimal configuration is relatively independent of the local conditions (as presented in Section 4.4).

BRT
Design Scanner

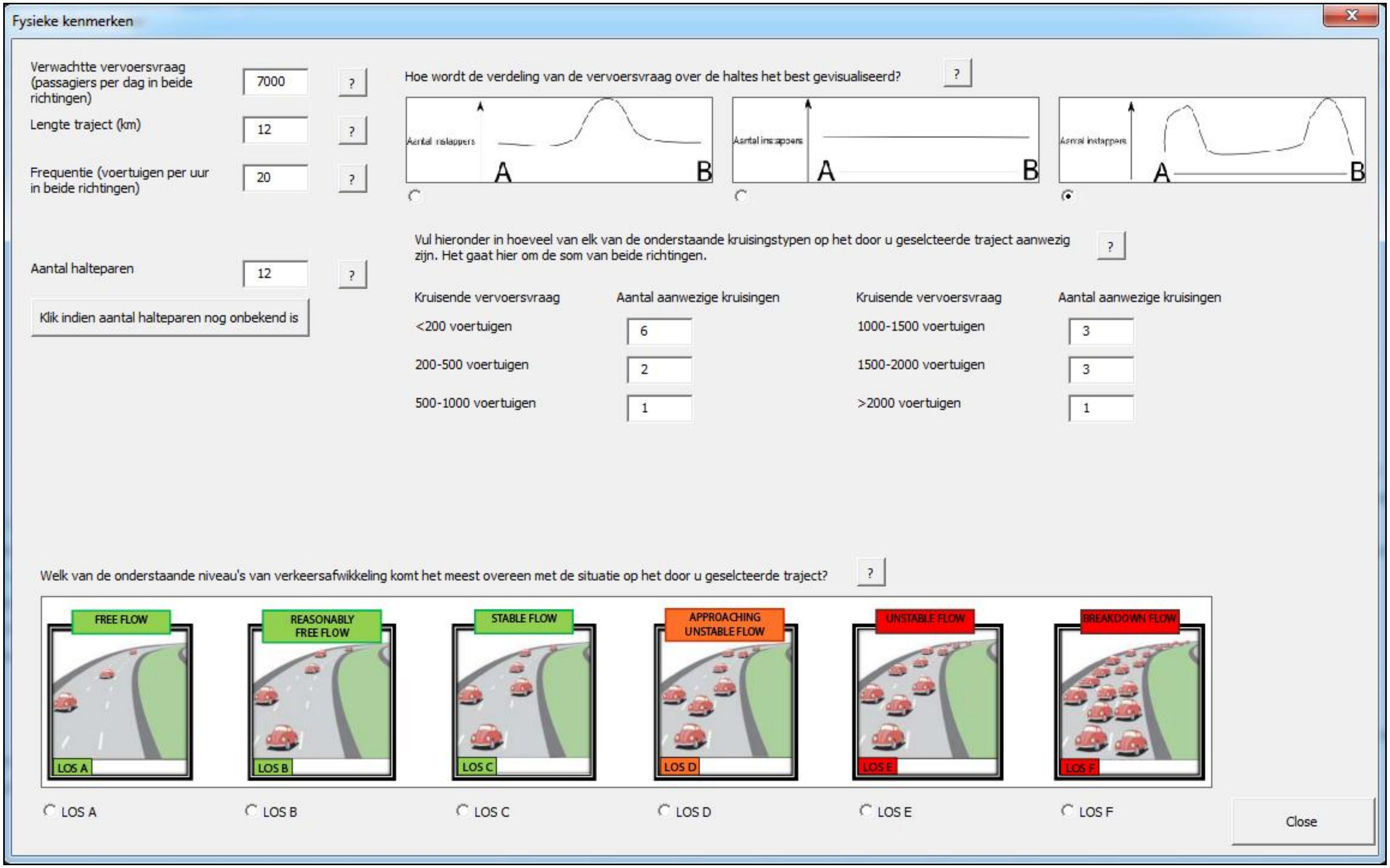


Figure 5-3: Input module of the BRT design scanner related to the system characteristics

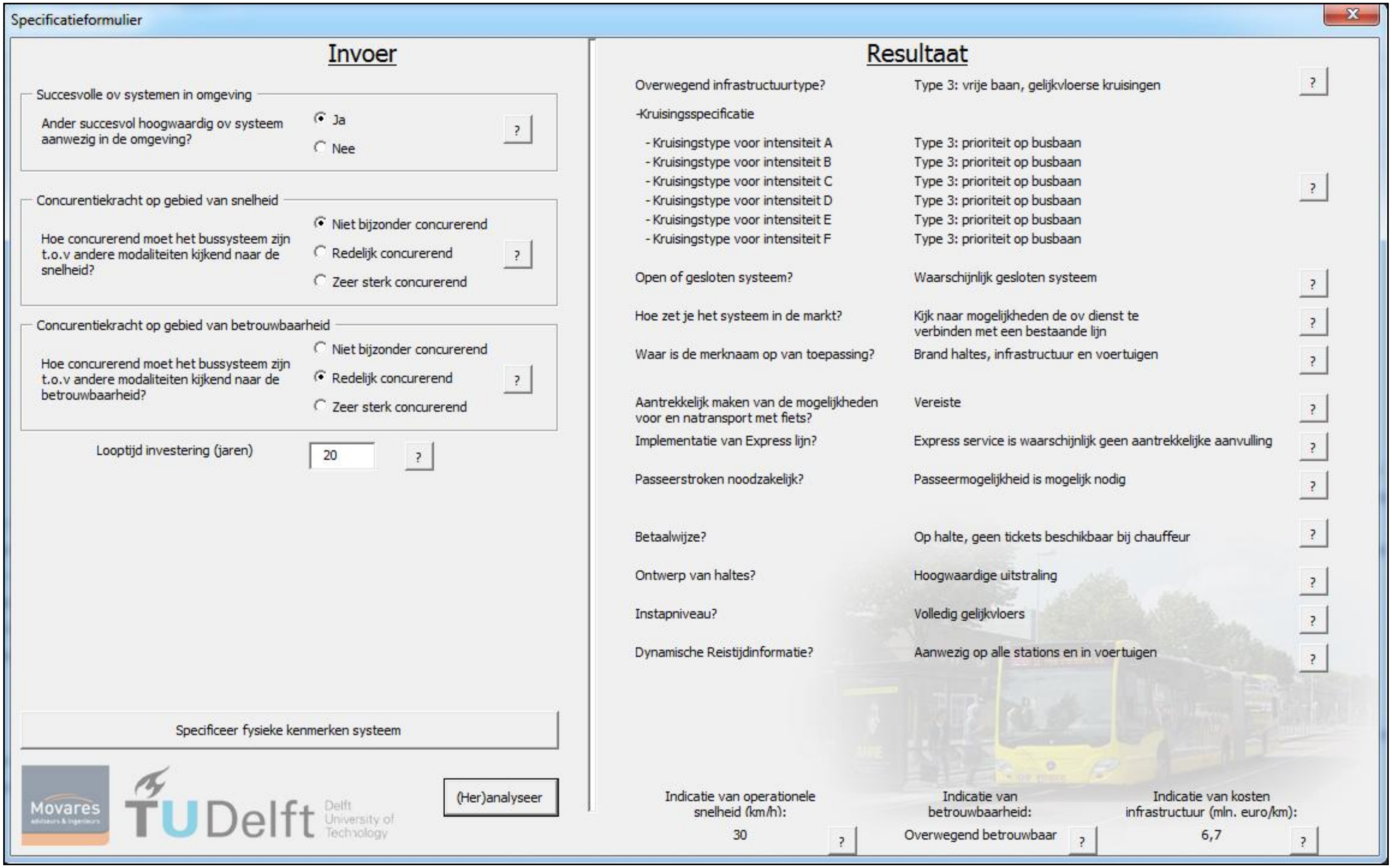


Figure 5-4: Input module related to the policy context (left) and the output module of the BRT design scanner (right)

5.3 Conclusion

This chapter presents the formulation of the BRT design scanner, a software tool intended to advice on the applicable configuration of a BRT service, considering the local conditions. By using this tool, in the exploratory stage of a (potential) project, within a few minutes, an advice is presented about the organization of a set of design variables that mainly determine the primary quality of the bus service. The model can also be used to assess the qualities of an existing BRT system

The BRT design scanner is constructed in Microsoft Excel and is supported by a graphical interface, constructed with Excel's supported programming language: Visual Basic for Applications (VBA). The scanner implements and automates the relations as presented in Appendix F. By this, an interactive tool is created that links the input variables to the output variables.

In the next chapter, the scanner is reviewed based on a case study. The goal of this case study is to reflect on the applicability, deficiencies and possible improvements of the tool.

6 Case study based reflection on the BRT design scanner

This chapter presents a review of the BRT design scanner based on a case study. By applying the BRT design scanner to this case study, the functioning of the scanner is reflected upon. When referring to the BRT design scanner, in this chapter it is referred to both the model as well as the implementation of the model in the scanner. In case one of these is discussed specifically, this will be indicated. The goal of this analysis is twofold:

- **Reflect on the quality of the advices provided by the scanner.** This is done by both reflecting on the differences between the advised and realized configuration, as well as by evaluating three of the advices by means of a Societal Cost Benefit Analysis (SCBA).
- **Gather suggestions for the improvement of the scanner.** By executing this case study, suggestions are gathered to improve both the predictive quality as well as the experience of working with the tool.

The case studied is the bus service between Station Vleuten, through Leidsche Rijn, to Utrecht Central Station.

In Section 6.1, the public transport network of Utrecht is briefly analysed and the particular decision for the study area of Leidsche Rijn is pointed out. In Section 6.2, the methodology for reflecting on the scanner is presented. In Section 6.3, the input and resulting output of the scanner are presented, followed by a reflection on the differences between the advised and realized configuration in Section 6.4. In Section 6.5, by means of an SCBA analysis, three of the advices are evaluated in detail. Subsequently, in Section 6.6 improvements to enhance the predictive quality of the tool are presented. Finally, in Section 6.7, the chapter is concluded.

6.1 Introduction of case study area

In this section the public transport network of Utrecht and Leidsche Rijn is briefly analysed, the study area is defined and the choice for the particular study area is explained.

6.1.1 Public transport in Utrecht and Leidsche Rijn

With around 330.000 inhabitants, Utrecht is the fourth largest city of the Netherlands (CBS, n.d.). Utrecht Central Station (CS) serves around 230.000 passengers daily, the most of all Dutch stations (Treinreiziger.nl, 2009). This mainly causes a significant demand of travellers from the outskirts of Utrecht to the central station/city centre. The most important outskirts (associated with the largest demand) are connected to Utrecht CS by means of a Hoogwaardig Openbaar Vervoer (HOV) service. HOV is a characterized by its own bus and tram lanes, high quality vehicles and dynamic travel time information. Leidsche Rijn, the study area, is one of the regions that are served by such a HOV service. Since HOV-bus is the Dutch term being used for BRT systems, this service will be further on indicated as BRT service. From Utrecht CS, Leidsche Rijn can be reached by bus via a trajectory via the northern part of the city (north radial) and via a trajectory via the southern part of the city (south radial). These corridors consist of mainly dedicated infrastructure and come together at De Meern Oost.

In Appendix G, further information is presented about the public transport services in Utrecht and Leidsche Rijn.

6.1.2 Definition of study area

The focus in this study is on the north radial, between Station Vleuten and Utrecht CS, covered by line 28. Currently the station area of Utrecht CS is being reconstructed. Since large road works are part of this project, the bus service in this area is temporary disrupted. Therefore, in Section 6.5, when evaluating the advices of the scanner by means of a SCBA, the trajectory between the stops Hasebroekstraat and Utrecht CS is left out of consideration. Figure 6-1 provides a map of the studied part of the trajectory of bus line 28.

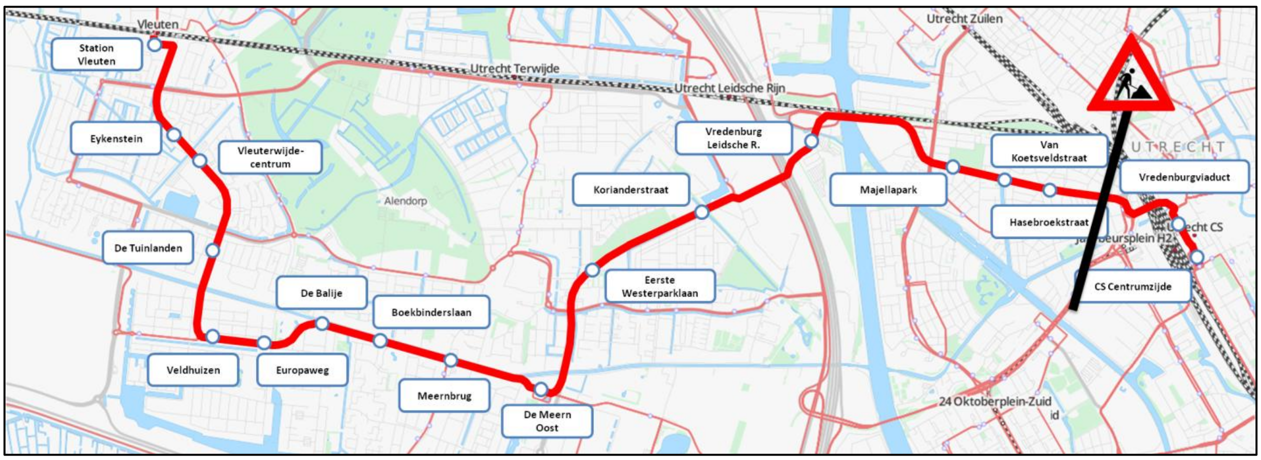


Figure 6-1: Trajectory of bus line 28

6.1.3 Why Leidsche Rijn?

There are three reasons why the specific case is appropriate to review the BRT design scanner.

Firstly, the bus service through Leidsche Rijn is labelled as BRT service. For the particular system, the goal was to create a fast, frequent and reliable bus service (see the considerations and starting points of the design in Appendix M). The BRT design scanner is exactly intended for this kind of systems.

Secondly, the importance of the service contrasts with the realized quality. The area of Leidsche Rijn is analyzed with the Mobiliteitsscan, a software tool developed by CROW (n.d.) enabling macroscopic static traffic simulations. This analysis emphasizes the importance of a fast and reliable connection to Utrecht CS (see Appendix x for this analysis and a further description of the characteristics of the Mobiliteitsscan). Within the municipality there is a perception that the realized quality does not correspond to the intended quality. In other words, there is an idea that the speed and reliability of the service can and should be improved. The fact that on one side the connection is important, but on the other side, the realized quality is not aligned, results in an interesting case study area.

Thirdly, via contacts at the municipality of Utrecht and Bestuurs Regio Utrecht (BRU) a lot of information was available. Also practically, the fact that the situation of Movares' office in Utrecht is located near the study area is further easing accessibility to detailed information.

6.2 Evaluation method

By applying the BRT design scanner to the bus service through Leidsche Rijn, the functioning of the BRT design scanner is reflected upon. This process has two products:

- Reflection on the quality of advices provided by the scanner.
- Suggestions for possible improvements to the scanner.

Reflection on the quality of advices provided by the scanner

This reflection is based on two analyses:

- Reflection on the differences between the advised and realized configuration of the bus service through Leidsche Rijn.
- Evaluation of three of the advised improvements to the bus service by means of a Societal Cost Benefit Analysis (SCBA).

Suggestions for possible improvements to the scanner

During the execution of this case study, suggestions are gathered to improve the predictive quality of the tool. The improvements are related to the:

- Interface of the BRT design scanner. Reflection on the way the complex reality is translated into the input variables of the scanner.
- Internals of the BRT design scanner. Reflection on the way the input variables are translated into the output variables.

In the overview below (Figure 6-2), the structure of this chapter is presented. Additionally, for the sections 6.4 to 6.6 the methods used to execute these analyses are presented.

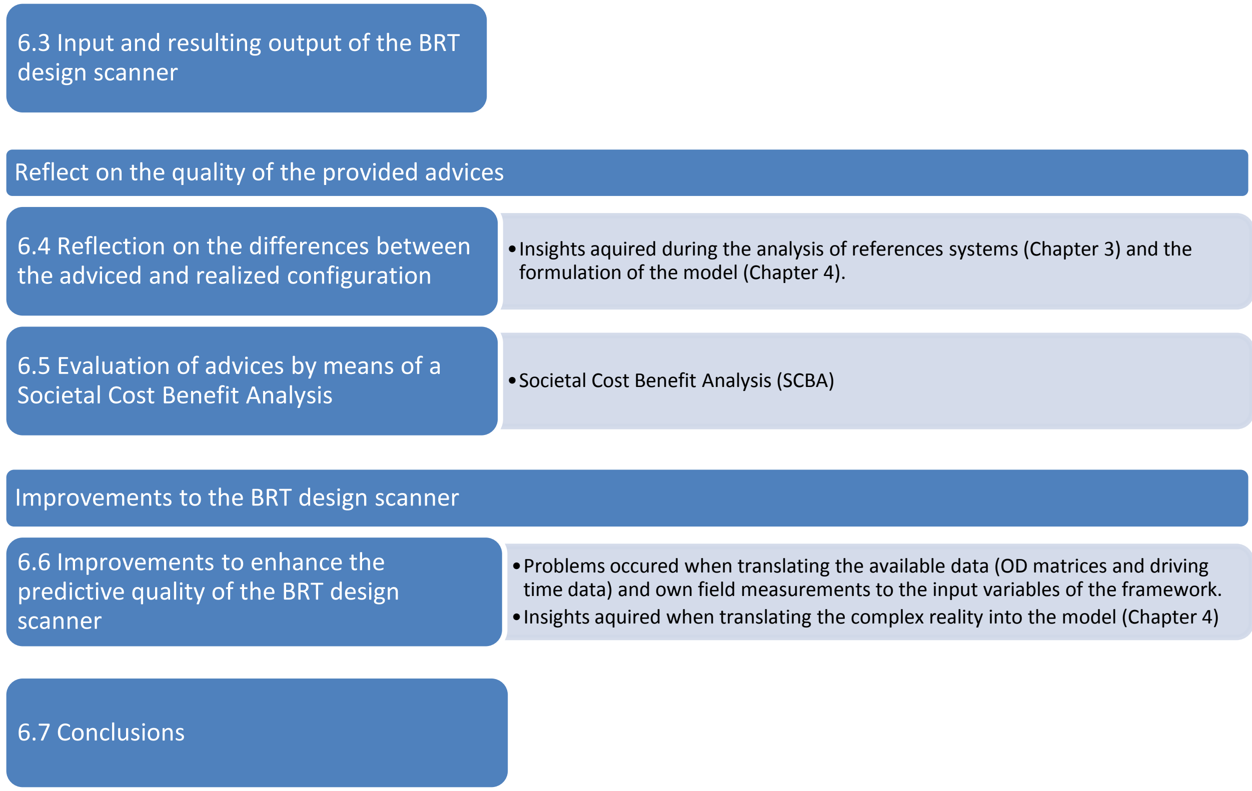


Figure 6-2: Overview of research approach of Chapter 6

6.3 Input and resulting output of the BRT design scanner

This section presents the input variables related to the bus service through Leidsche Rijn. Subsequently, the advised configuration is compared to the realized configuration and subsequent differences are evaluated.

6.3.1 Input variables

Below the input variables that are filled-in in the BRT design scanner to capture the characteristics of the bus service through Leidsche Rijn are presented. The answers on these questions regarding the policy context are originating from an email conversation with Rob Tiemersma, consultant mobility at the Municipality of Utrecht. The other input variables are resulting from different analyses (the origin of these input variables is presented in Appendix H).

Input variables – Policy context

• Investment period	20 years
• Other successful high quality public transport service nearby?	Yes
• Competitiveness of the system compared to other modalities looking at speed?	Reasonably competitive
• Competitiveness of the system compared to other modalities looking at reliability?	Very competitive

Input variables – System characteristics

• Expected travel demand	10.000 passengers per day
• Length of trajectory	10,8 km

- Frequency (sum of both directions) — 20 vehicles per hour
- Number of station pairs — 17 station pairs
- Predominant level of service (LOS) on trajectory (peak) — LOS D
- Distribution of the demand over the trajectory — Distribution C
- Amount of crossing traffic (peak, sum of both directions)
    - <200 — 8 intersections
    - 200-500 — 7 intersections
    - 500-1000 — 3 intersections
    - 1000-1500 — 2 intersections
    - 1500-2000 — 1 intersections
    - >2000 — 1 intersections

For the meaning of *LOS D* and *Distribution C*, please consult Section 5.2.2.

6.3.2 Evaluation and comparison of resulting output

This section reflects on the results of the output module for the case study. Table 6-1 below presents an overview of the 12 design variables, their advised implementation and their implementation in reality. The colour in each row indicates how well these two correspond (red = implementation totally different from advice, yellow = some difference in implementation, green = implementation as advised).

Table 6-1: Comparison of advised and realized implementation of design variables

Design variable	Advised	Reality	Correspondence
1) Dynamic travel time information	Implemented in vehicles and stations	Implemented in vehicles and stations	green
2) Station level boarding	Always implemented	Always implemented	green
3) Enhanced stations	High quality facilities	All basic facilities present	yellow
4) Type of infrastructure	Type 3: free lane	Type 3: free lane	green
5) Open or closed system	Closed	Closed	green
6) Position in market	Try to connect the service to existing high quality service	Not connected to existing high quality service	red
7) Branding of elements	Brand vehicles and stations	Only stations slightly branded	yellow
8) Passing opportunity	Possibly necessary	Not present	yellow
9) Access and egress transport by bicycle	Very important	Not particularly important	yellow
10) Express service	Implemented	Not implemented	red
11) Type of intersection	All of type 3: priority on bus lane	All of type 3: priority on bus lane, but not functioning well	red
12) Fare collection	Outside vehicle	In vehicle	red

6.4 Reflection on differences between the advised and realized configuration

As can be seen, for several design variables, the implementation in reality is different compared to the advised implementation. These differences can either indicate that the scanner is not formulated well or the configuration of the investigated bus service is not optimal. Below, for each of the design variables it is evaluated which is likely the case.

Enhanced stations.

The two identified necessary facilities are present on all stations: seating facilities and shelter against bad weather conditions. Although all stations posses these important basic facilities, these facilities are not associated with a high quality. The stations, aesthetically, do not represent an attractive entrance of a high quality public transport system. Examples worldwide, but also in the Netherlands at the Zuidtangent, prove that more enhanced stations are usual in BRT systems. It is therefore plausible that the model output is more correct than the current realization.

Position in market.

It is advised to connect the service to an existing high quality public transport service. In this case of Leidsche Rijn this could be the SUNIJ tram service to Nieuwegein. Presenting the considered BRT service, the other three BRT axes (see Appendix G) and the tram service as one high quality system is an option. Considering the successful practices in Nantes and Los Angeles, the suggestion to connect the service is plausible.

Branding of elements.

It is advised to incorporate a brand on the vehicles used on the considered service. Currently, no brand is incorporated; all busses in Utrecht have the same appearance. By branding the busses, it can be made clear that the service is to be associated with a higher level of quality. This measure limits however the possibilities to use the busses on other trajectories. The level to which this is a problem for the considered service determines the quality of this advice.

Passing opportunity.

The scanner suggests that passing opportunities might be needed, whereas in reality these are not present. The headways of busses are currently on most of the trajectory not shorter than 5 minutes (in case of a frequency of 12 vehicles per hour and assuming no deviations from this schedule). Only in case an express service skips most of their stops (in case of a dwell time of 30 seconds, this number is minimally 10), interference with local services will occur. So, the advice of the scanner is likely wrong. As is further on presented in Section 6.6, incorporating the frequency into this decision can improve the quality of the tool.

Access and egress transport by bicycle.

Bike parking facilities are present near all stations, their quality is however not as suggested by the scanner. At the time of the first survey (7th of May 2014) (see Appendix P) there was a regular shortage of places. Recently, on most stations, additional parking facilities were created. With the exception of De Meern Oost these parking facilities are not covered. To improve the attractiveness of using the bike as access or egress mode, increasing the number of covered bike parking facilities is advised. Especially when express services are implemented, providing high quality parking facilities becomes increasingly important.

Express service.

Express services are common in a lot of BRT systems worldwide. Considering the significant frequencies (2x12 vehicles per hour during the peak hour), the relatively low stop spacing (635 m) and the demand pattern (see Appendix N.II), the suggestion of implementing an express service seems plausible. Section 6.5.2 analyzes what this modification to the service can yield on a yearly basis.

Type of intersection.

The type of intersection advised, aligns with the realized intersection configuration. Based on field measurements and an analysis of the driving performance (Appendix N), it can be concluded that currently insufficient priority is acquired by busses. Considering the importance of well functioning priority treatment for the speed and reliability of the service, the statement that this should be updated is justified. Section 6.5.3 analyzes what this modification to the service can yield on a yearly basis.

Fare collection.

Checking in on the station is for bus services in the Netherlands currently unconventional. So, the fare collection location of the identified bus service cannot be identified as bad. However, the fact that checking in on the station is already common for train and some tram services in the Netherlands, just like off board fare collection is frequently implemented in BRT systems worldwide, makes it a plausible suggestion. Section 6.5.4 analyzes what this modification to the service can yield on a yearly basis.

So, based on the analysis in this section, the optimal configuration as outcome of the scanner seems to be justified.

6.5 Evaluation of advices by means of a Societal Cost Benefit Analysis

In this section, by means of a reduced Societal Cost Benefit Analysis, it is analysed what implementing a selection of the suggested measures in reality can yield. In Section 6.4 it was concluded that model outcomes that were different from the realization, suggested by the scanner, are plausible. However, by also getting an idea of the potential profits these measures can yield in reality, the insight in the usefulness of the measures suggested by the tool can be increased.

6.5.1 Methodology

In this section the yield of the implementation of three of the design variables is analyzed in detail. These are the design variables that impact the speed and reliability of the service and are implemented not as advised (non green in Table 6-1).

Following from the analysis in Section 3.2.2 (causal diagram), the design variables *enhanced stations*, *fare collection process*, *type of infrastructure*, *type of intersection*, *open or closed system* and *express service* impact the speed and reliability of the system. Since the *fare collection process*, the *type of intersection* and *express service* are not implemented as advised, these will be analyzed in more detail.

For these design variables it is computed what the suggested measures can yield. This evaluation is inspired by the methodology of a Societal Cost Benefit Analysis (SCBA). A SCBA is a systematic approach that calculates the costs and benefits of a project over a large period of time (Romijn & Renes, 2013). For this approach it is necessary to monetize all effects, a process that costs a lot of time and comes with a lot of uncertainty. Therefore, not all traditional SCBA effects are considered (for instance environmental effects are not considered in this study), and not all the effects that are considered are subsequently monetized. Considering the purpose of this case study, this simplification is justified. In this study the following effects are taken into consideration:

- Collective travel time in vehicle
- Collective travel time access and egress
- Operational costs
- Investment costs
- Reliability
- Nuisance for other traffic

The profits related to the two travel time components are computed in seconds and subsequently monetized. The operational costs are computed by multiplying the travel time profit by the cost of an operational hour (based on expert judgement a cost of €100/hour is assumed (Genot, 2015b)). The other three effects are only evaluated qualitatively. For these three effects it is determined if, compared to the current situation, there is a small deterioration, no effect, small improvement or great improvement.

In case the suggested measures are implemented the travel demands will be impacted. In the end of this section, a brief assessment of the potential increase of the demand is presented. Although this increased demand will subsequently impact the computed SCBA effects again, this feedback loop is not included in this research.

Because of the limited time available for this study, combined with the goal of this analysis, the effects are computed for one single bus trip only. Chosen is for one trip from Vleuten to Utrecht CS, during the morning peak (8:00 - 8:59). This is the time slot with the largest travel demand (see Table N-3 in Appendix N for an overview of the distribution of the travel demand over the day).

However, although the effects are computed for one trip only, it is interesting to approximate the results of the measures on a yearly basis. Based on the following assumptions, the profits and losses for a whole year are approximated:

- The travel time valuation of all persons is €9,25 per hour, a value that is based on research by (KiM, 2013).
- The computed effects for the direction Station Vleuten – Utrecht CS are the same for the direction Utrecht CS – Station Vleuten.
- The travel demand in March 2014 (on which the analysis is based) is representative for all other months.
- By computing the yearly profits based on 350 instead of 365 days, a sufficient correction is made for days with a lower than average demand (as a result of collective free days and holidays).
- The bus service frequency’s used to translate the one trip into the total trips per day are in accordance with the frequency’s presented in Table H-1 (Appendix H)

- Half of the number of busses operates as express service.
- Travel time profits or losses are linear with the number of users. Based on this assumption correction factors are computed for all hour blocks compared to a working day 8:00-8:59. So in case of a correction factor of 0,27 for Saturday 18:00-18:59, the profits of the measures for busses in this hour block are computed by multiplying the identified profits for a working day between 18:00-18:59 by 0,27. All correction factors, as presented in Table N-4 (Appendix N), are based on the distribution of the demand as presented in Figure N-14 (Appendix N).

Below the analyses are presented for the three investigated design variables.

6.5.2 Express service

6.5.2.1 Introduction

This section analyzes the costs and benefits of the implementation of an express service.

This analysis is based on the following assumptions:

- The demand is taken as a constant (the total number of origins and destinations in the OD-matrix).
- All people that want to use a skipped stop walk to the nearest stop. In case a stop is skipped that was used previously, a user has the possibility to:
  3. Walk further to the next stop
  4. Wait or leave early to take a local line, because:
     - Walking further is not preferred
     - The desired destination is also skipped. Given the OD-data, this situation is very unlikely.

  In this research, the effects are computed for the case that all users decide to walk further.

- The spatial characteristics (for instance a stop close to shopping centre) or the composition of the user group per stop (for instance a stop close to a retirement home) do not influence the decision to skip a stop.
- The vehicle will stop at each stop located on the line. Since the busiest time slot is analyzed, combined with executed field observations, this is a justifiable assumption.

Figure 6-3 indicates the distribution of the demand on the trajectory Station Vleuten CS – Station Vleuten (See Appendix N.II for a larger version of this image). It is clear that the majority of the trips are orientated towards Utrecht CS; this supports the idea that an express service might be effective.

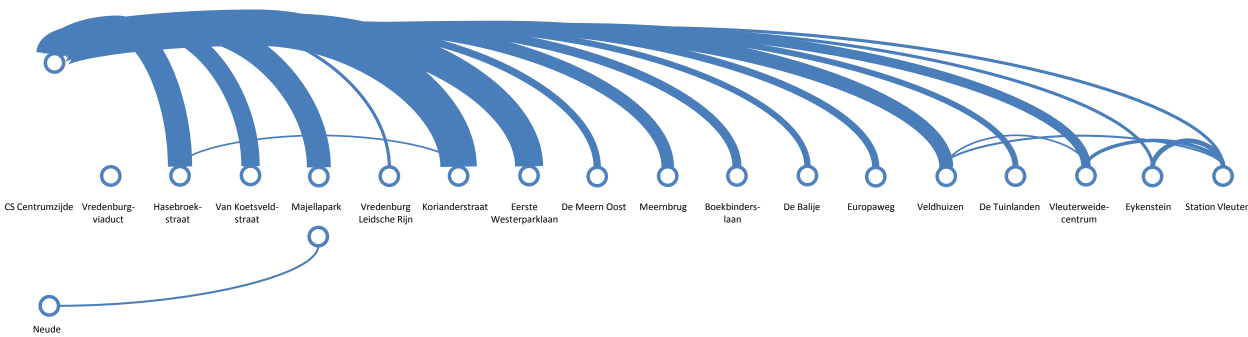


Figure 6-3: Representation of OD-relations on trajectory Utrecht CS (left) and Station Vleuten (right). The arc thickness is proportional to the travel demand on the OD-relation. Representation analogue to (van Waveren & Courtz, 2014)

Based on the available data, an express service can be computed that yields the largest collective travel time profits. From the available OD-matrices, the average number of people boarding and alighting is extracted. From this, also the average number of people in a vehicle over the line could be determined. Figure 6-4 graphically represents, per stop, the average number of people boarding, the number of people alighting and the number of people in the vehicle.

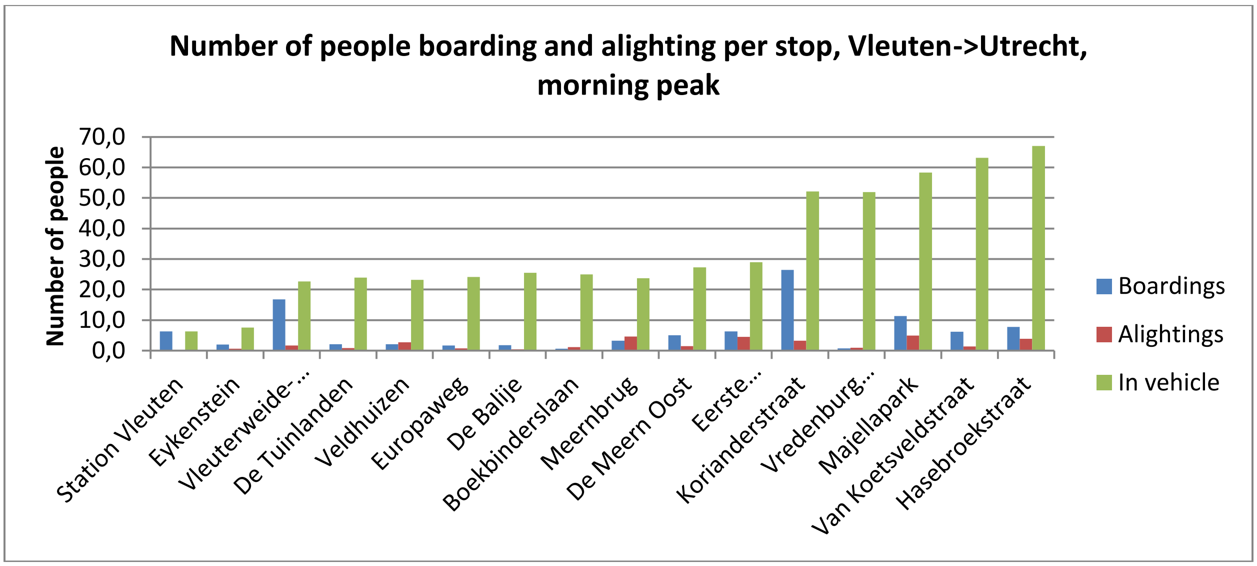


Figure 6-4: Number of people boarding and alighting per stop between Vleuten and Utrecht CS in the morning peak

Based on this data the costs and benefits of skipping a stop can be calculated. The method that is used for this, is adapted from (Roeske, 2014). The costs and benefits are expressed in seconds:

- The benefits are calculated by the number of passengers that are skipping a stop, multiplied by the average time saved from skipping a stop.
- The costs are calculated by the number of people wanting to use the skipped stop, multiplied by the average extra walking distance, divided by the walking speed.

In case the benefits are higher than the costs, the stop might be skipped. Since it is assumed that all people migrate to the nearest available stop, removing a stop impacts the costs and benefits of other stops. The greedy algorithm used in this method complies with this phenomenon. This algorithm deletes in each iteration the stop with the highest benefit cost (BC)-ratio. This process stops when all stops have a BC-ration smaller than one. In Appendix I.I, the algorithm that is used is described in more detail, combined with an elaboration on the application for bus line 28.

The application of this greedy algorithm results ultimately in the BC-ratio's presented in Table 6-2 below. In this table the initial BC ratios and the BC-ratios after the last iteration are presented. The higher the ratio, the more attractive the stop is to skip. According to this evaluation, skipping the four stops results in the highest total benefits.

Table 6-2: Result of the greedy algorithm used to determine which stops could be skipped

Station	BC-ratio initial situation	BC-ratio after 4th iteration
Eykenstein	0,47	0,47
Vleuterweide-Centrum	0,21	0,21
De Tuinlanden	0,84	0,84
Veldhuizen	0,69	0,34
Europaweg	1,71	**Skipped**
De Balije	1,84	0,49
Boekbinderslaan	2,16	**Skipped**
Meernbrug	0,38	0,25
Busstation De Meern oost	0,38	0,38
Eerste Westerparklaan	0,20	0,20
Korianderstraat	0,13	0,10
Vredenburg Leidsche Rijn	2,08	**Skipped**
Majellapark	0,41	0,19
Van Koetsveldstraat	1,68	**Skipped**
Hasebroekstraat	1,04	0,50

Figure 6-5 graphically represents the resulting configuration of the express and local bus service.

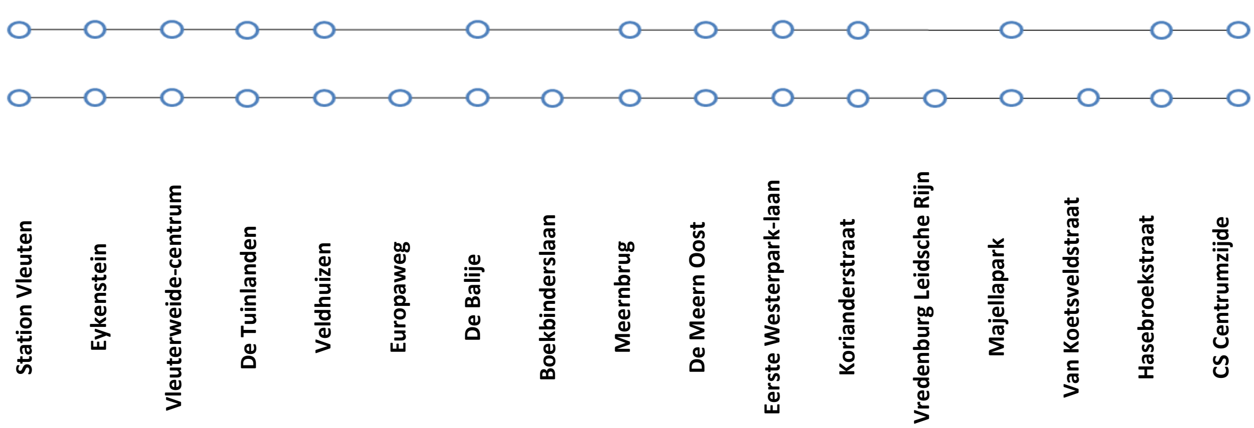


Figure 6-5: Configuration of the express and local service

6.5.2.2 Effects

Travel time in vehicle

The travel time savings in vehicle are the benefits associated with skipping a stop. As said, these are calculated by the number of passengers that are skipping a stop, multiplied by the average time gained from skipping a stop.

From expert judgement (Ydema, 2015), combined with an ad hoc field measurement, an average delay of 25 seconds is approximated as the profit of skipping a stop (including deceleration and acceleration time of the vehicle). The travel time profits in vehicle, in case the four stops are skipped, are 4028 seconds (see Table I-3 for this calculation). This corresponds to a travel time profit of around € 232.000 per year.

Travel time for access and egress transport

The travel time losses for access and egress transport are the costs associated with skipping a stop. As said these are calculated by the number of people wanting to use the skipped stop, multiplied by the average extra walking distance, divided by the walking speed. The travel time losses related to increased access and egress times, in case the four stops are skipped, are for one trip 2207 seconds (see Table I-4 for this calculation). This corresponds to a travel time loss of around € 127.000 per year.

Operational costs

By implementing an express service it is expected that for these trips the travel time is reduced by 1:40 min. This corresponds to a decrease of the operational costs of around € 62.000 per year.

Reliability

Two effects are likely to influence the level of reliability, one positively and one negatively:

- Positively: Four stops, associated with a low demand, are skipped. In this analysis, it is assumed that these stops are all served. However, because of limited demand, these stops are sometimes already skipped. By implementing an express service, these stops are always skipped, by which the variability of the driving times decreases.
- Negatively: In the current configuration, vehicles cannot pass each other. With the implementation of an express service, it could happen that an express vehicle gets stuck behind a non-express vehicle. To assess the need of passing opportunities, the planning of the service should be analysed on a more operational level (investigation of the timetable setup).

Investment costs

No investment cost are investigated; instead two effects on the operational costs are investigated. Since some vehicles have a slightly shorter driving time, the scheduled driving time, and thus the operational costs, can be slightly reduced. Also, because of a more efficient driving pattern (less accelerations and decelerations) the fuel consumption can be slightly reduced. In this study, these effects are not evaluated in more detail.

Nuisance for other traffic

No significant effects are distinguished.

6.5.3 Type of intersection

6.5.3.1 Introduction

The type of intersection that is advised by the BRT design scanner (type 3) is in accordance with the realized type. In practice however, since no sufficient priory is provided to bus vehicles, the intersection priority treatment is malfunctioning. This section analyzes what improving the intersection treatment, by providing full priority, can yield.

To determine the travel time losses because of malfunctioning intersection priority treatment, field measurements are performed. It became clear that on several intersections, much travel time is lost. All these problems occurred at intersections where cars were involved. At some intersections, only 5 seconds are maximally lost, at others a delay of 2 minutes is no exception. From averaging these measures, five intersections are indentified were generally a significant amount of time is lost. Below, together with an approximation of the potential travel time profit upon improving the intersection treatment, these five intersections are presented. Figure 6-6 indicates the location of these intersections.

1. Busbaan Vleuterweide – Stroomrugbaan -30 seconds
2. Rijksstraatweg – Meerndijk -90 seconds
3. Weg naar Parkwijk/Laurierweg – Grauwaartsingel -90 seconds
4. Laurierweg – Stadsbaan -30 seconds
5. Vleutenseweg - Thomas à Kempisweg/Spinozaweg -15 seconds

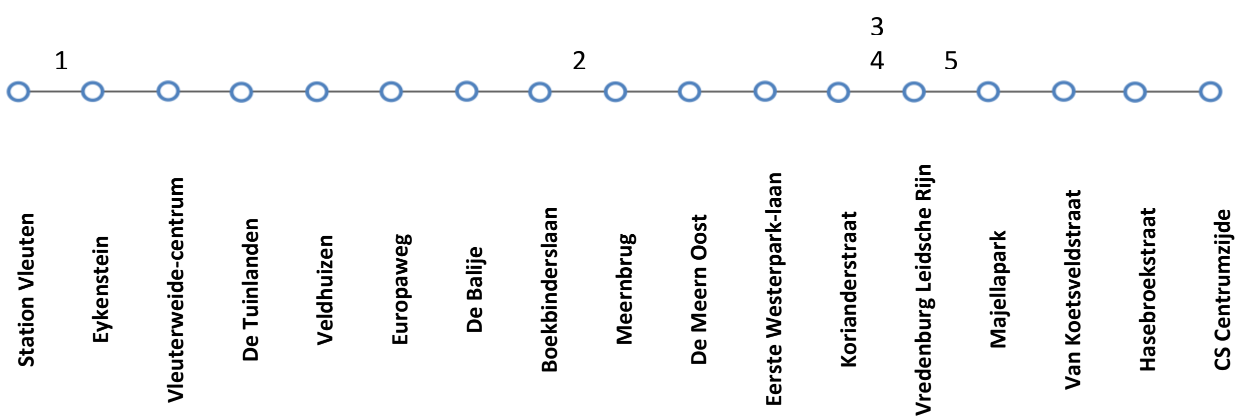


Figure 6-6: Location of identified intersections

6.5.3.2 Effects

Travel time in vehicle

The travel time loss in vehicle is computed by multiplying the number of people in the vehicle by the travel time loss on the intersection. The travel time profits in vehicle, in case the intersection treatment is improved, are 12593 seconds (see Table J-1 for this calculation). This corresponds to a travel time profit of € 1.450.000 per year.

Travel time for access and egress transport
When impacting the intersection treatment, there is no influence on the access and egress times.

Operational costs
By the suggested measures the travel time can be reduced by 4:15 minutes. This corresponds to decrease of the operational costs by around € 317.000 per year.

Investment costs
All the identified intersections are already equipped with traffic lights that provide a certain level of priority to busses. It is assumed that all these traffic lights (and additional installations to make them function correctly) are capable of providing full priority to busses. Since this implies that only the configuration needs to be adjusted, no costs are assumed.

Reliability
By improving the intersection treatment of the intersections on the investigate trajectory, a major increase of the reliability of the service will be realized. Since the type of infrastructure has little influence (almost completely of type 3: dedicated lane, at-grade intersections) on the reliability, the intersection treatment is the major determinant of the realized reliability. In Appendix N.1 an analysis of the current driving performance is presented. From this it can be concluded that the level of reliability is currently quite low. Therefore, modifying the intersection treatment in favour of the bus will result in a very significant improvement of the reliability

Nuisance for other traffic
By adjusting the intersection treatment, bus vehicles have always full priority. By this adjustment, the number of times bus vehicles will interrupt and abort the normal traffic light regulation will be increased. The interference with crossing car users, and with that the nuisance, will therefore increase. By profiting from its priority, this adjustment may however result in a small improvement for car users travelling in the same direction as the bus vehicles. An attempt to quantify this further was not undertaken.

6.5.4 Fare collection

6.5.4.1 Introduction
As was suggested in Section 4.4.1, by modifying the fare collection process, the dwell time can be decreased. By checking in on the stop, it is assumed that the variable boarding time per passenger can be reduced from 1 second to 0,5 second per boarding. It should be noticed that this assumption implies that there is a linear relation between the number of people boarding and the boarding time. In reality this will not be exactly the case but for this study this is assumed to be sufficient.

6.5.4.2 Effects
Travel time in vehicle
To determine the potential profit of travel time in vehicle, first the average time needed for boarding is assessed. By subsequently speeding up the boarding process, the original trip time can be shortened by around 50 seconds. By taking the occupation on the trajectory into consideration, a decrease of 1474

person seconds can be achieved. This decrease corresponds to around €170.000 per year. The method and application of this calculation is described in more detail in Appendix K.

Travel time for access and egress transport

When impacting the alighting and boarding procedure, there is no influence on the access and egress times.

Operational costs

A decrease of the travel time of 0:50 minutes is realized. This corresponds to a decrease of operational costs by around € 62.000 per year.

Investment costs

The new check in units that need to be added on the bus stops are the only investment costs that are identified. Depending on the required employability of the busses on other trajectories, the check in units in the bus can be removed.

Reliability

The reduced boarding time per passenger reduces the impact of the number of boarding's on the boarding time. This will result in an improved reliability of the service.

Nuisance for other traffic

When impacting the alighting and boarding procedure, there is no significant influence on the nuisance to other traffic.

6.5.5 Evaluation of the proposed measures

Table 6-3 summarizes the effects of the measures presented in the previous sections. Important to understand is that the travel time values represent the total effects, in the morning peak (8:00-8:59), for one trip between Station Vleuten and Utrecht CS.

Table 6-3: Summary of effects of presented measures

	Travel time gains during morning peak (min)	Collective travel time in vehicle (€/year)	Collective travel time for access and egress transport (€/year)	Operational costs (€/year)	Reliability	Investment costs	Nuisance for other traffic
Express service	-1:40	- € 232.000	+ € 127.000	- € 62.000[2]			
Intersection treatment	-4:15	- € 1.450.000		- € 317.000			
Fare collection	-0:50	- € 170.000		- € 62.000			
	-6:55	**- € 1.852.000**	**+ € 127.000**	**- € 441.000**	+		
				- € 2.166.000			

Small deterioration	
No effect	
Small improvement	
Great improvement	

From this analysis is can be concluded that the suggested measures can significantly reduce the travel time and result in very high gains on a yearly basis. Additional to these calculated profits of around € 2.200.000 per year, also the reliability is greatly improved. On the other hand the investment costs and the nuisance for other traffic will increase. In the remainder of this section, each of the effects is shortly elaborated on.

Travel time

The scheduled travel time between Station Vleuten and Utrecht CS, in the morning peak, is 30 minutes (U-OV, 2015). The suggested improvements can reduce this time by 6:55 minutes, which correspond to

[2] Because the profits originating from an express service (-1:40 min) are only applied to half of the busses, the decrease of operational costs are the same as for the fare collection process (-0:50 min).

a decrease of 23%. This decrease of 23% in travel time, corresponds to an increase of the operational speed from 21,6 km/h[3] to 28,1 km/h.

Collective travel time

By multiplying the passengers in vehicle by the travel times between each stop, the total collective travel time in vehicle is computed to be 19:04 hours for one trip. The profits in the collective travel time are computed to be 4:31 hours for one trip. This means that, by implementing these measures, the collective travel time can be reduced by 24%. On a yearly basis, the suggested improvements lead a collective travel time gain of around € 1.725.000 (€ 1.852.000 - € 127.000).

Operational costs

All three measures will decrease the operational costs. Since this decrease is linear with the travel time profits, the modifications to the intersection treatment (associated with the largest travel time profits), mainly determine the total decrease of operational costs of € 441.000.

Investment costs

Implementing the express service and improving the intersection treatment will not result in any significant investment costs. Only the facilities to accommodate checking in on the stop, will cost a significant amount of money. However, looking at the benefits related to the speed and travel time, it is expected these improvements will be cost-effective.

Reliability

Since all three presented measures will reduce the variability in the driving time; the reliability of the service will be greatly impacted. Since the largest variability in travel times are originating from malfunctioning intersection treatment, improving this intersection treatment will have the largest effect.

Nuisance other traffic

Both, implementing an express service and improving the fare collection process will not impact the nuisance for other traffic. However, a significant effect will be noticeable when the intersection treatment is improved. As elaborated on in Section 4.5.2, for each of the intersections the magnitude of the effects will differ. To be able to assess these effects, further analyses are required. However, when wanting to create a fast and reliable bus service these modifications to the intersection treatment are necessary.

Increase of the demand

As was presented in Section 3.2, many factors impact the perceived quality of the service and with that its demand. In that section, also the importance of the factors speed and reliability was highlighted. The proposed improvements will increase the speed and reliability of the service, and with that the demand for the bus service.

[3] Computed from the fact that 10.8 km is covered in 30 minutes

Based on the results of the study, the expected increase of the demand resulting from the reduced travel time can be estimated, for the reliability this cannot be done

A way to relate changes in the travel time to changes in the demand is by using the travel time elasticity. The travel time elasticity indicates the increase or decrease of the demand, in case of an increase or decrease of the travel time. From expert judgement (Genot, 2015c) and (Balcombe et al., 2004; Coffeng, 2011) this elasticity is set at -0,75. This value indicates that a decrease of the travel time of 1% results in an increase of the demand of 0,75%.

For an exact computation of the changes in the demand, between each origin and destination pair, the changes in travel times need to be determined. However, for the desired level of detail it is assumed to be sufficient to work with the total reduction in travel time between Station Vleuten and Utrecht CS (23%). Based on this assumption, the potential increase of the demand, resulting from the decreased travel time, is estimated to be 17,25%.

As described before, the feedback of this increased demand (increased travel time profits, higher operational revenues for instance), is not considered in this research.

6.6 Improvements to enhance the predictive quality of BRT design scanner

This section presents improvements for the BRT design scanner that are identified to enhance the predictive quality of the scanner.

In Section 5.1 a set of requirements were formulated for the design of the BRT design scanner. It is identified that all except one of these requirements are met. It is identified that the requirement *easy understandable and quickly usable* is not always met for the input variables. By removing these ambiguities in the interpretation, the local conditions can be better captured and the predictive quality of the scanner can be enriched. These improvements are related to the interface of the scanner and are presented in Section 6.6.1.

Another requirement was that the BRT design scanner '*should implement the model formulated in Chapter 4'*. Although this requirement is met, still many additions and modifications to the model are possible by which the predictive quality of the scanner can be enhanced. A number of these improvements, which are related to the internals of the scanner, are presented in Section 6.6.2.

6.6.1 Improvements to the interface of the BRT design scanner

The improvements, presented in this section, are intended to remove ambiguities in the interpretation of the input variables and by that improve the predictive quality of the tool. For each of the suggested improvements, the goal is to improve the tool, without making the tool too complex by adding these features. For the improvements presented in this section this is considered to be the case.

Input variable: Expected travel demand

An important feature that is lacking is the absence of a feedback relation between the proposed appearance of the system and the expected travel demand. This feedback is lacking for the definition of the infrastructure and intersection type. The expected travel demand is entered a priory, however in reality, the resulting appearance will influence this expected demand again. This effect influences the determination of the type of infrastructure and the type of intersection:

- Infrastructure type. In the current design, based on the policy context and the level of service of the traffic flow on the trajectory, the appropriate infrastructure type is determined. This infrastructure type determines the speed and reliability, which influences again the expected travel demand. This loop is not implemented.
- Intersection type. In the current design, an expected travel demand is entered. Based on this value, the amount of crossing traffic and the policy context, an appropriate intersection type is computed. This intersection type determines the resulting speed and reliability, which influences again the expected travel demand. This loop is not implemented.

Figure 6-7 below graphically indicates this missing correction.

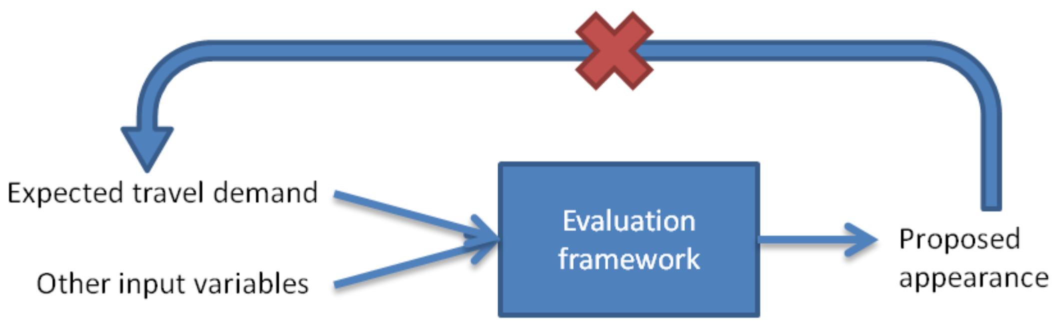


Figure 6-7: Visualization of missing feedback loop in the configuration of the BRT design scanner

To mitigate for this lacking loop, it is possible to a priory correct the expected travel demand. Within the current configuration of the scanner, the expected travel demand is an approximation of the user. In case this guess is the demand of a current, lower quality system, this loop is missing. In case the user already anticipated on the higher quality, and translated this in the value for the expected travel demand, the loop is not missing. To remove the need for this loop at all, the expected travel demand should be defined uniformly. Below, in a manner similar to the analysis in 6.5.5, a potential way to do this is presented:

1. Identify current travel demand on a trajectory together with the current travel time ratio (TTR) The TTR is computed by dividing the door to door travel time by public transport by the travel time by car.
2. Based on the policy context and the current TTR, determine the desired TTR in the new situation.
3. Based on approximated travel time elasticity's, the expected travel demand can be computed.

Input variable: Frequency

1) In the current setup of the scanner, the definition of the frequency is insufficient. For the investigated corridor through Leidsche Rijn, it appeared that several other bus lines are using different sections of the infrastructure. Currently, the possibility to enter this information is lacking. Only the frequency of

the HOV service can be entered. However, the frequencies of these non-HOV services influence the suggested type of intersection, and the need for passing opportunities. Providing the possibility to enter these non-HOV lines will improve both the clearness and the predictive quality of the scanner.

2) In the current configuration, no distinction is incorporated between peak hour intensities and non-peak hour intensities. To correct for this, the number of operational hours per day is assumed to be 10 instead of the actual scheduled hours. This implies that the entered peak hour intensity is 10% of the day volume (which is a common approximation). However, since this value will differ per system, differentiating between peak hour and non-peak hour intensities will improve the predictive quality of the scanner.

Input variable: Amount of crossing traffic

1) Without data available about traffic counting's, it proved to be difficult to define for each of the intersections the amount of crossing traffic (assign the intersection to one of the six categories). Translating this numbers into more tangible categories can potentially improve the usability. A possibility is to base the categories on the categorisation of the Dutch road network:

- Stroomweg
- Gebiedsontsluitingsweg – buiten bebouwde kom
- Gebiedsontsluitingsweg – binnen bebouwde kom
- Erftoegangsweg – buiten bebouwde kom
- Erftoegangsweg – binnen bebouwde kom

In the model implemented in the BRT design scanner, these types should be subsequently linked to average intensities.

2) The loss hours, associated with people walking or crossing the intersection by bicycle are not incorporated in the current configuration of the scanner. In case of a significant number of slow traffic on the intersection, omitting these users results in a significant underestimation of the number of person loss hours. Currently, slow traffic can be incorporated by adding them to the number of vehicles, divided by the average number of people per car (1,39). However, providing the possibility to separately add them, improves the usability of the scanner.

Input variable: Traffic flow on trajectory

In the current configuration of the scanner, one has to define the predominant type of infrastructure on a corridor. In reality, different sections can be distinguished which are presumably associated with different level of services. An improvement could be to divide the corridor into different sections, and subsequently define the level of service for each of these sections specifically.

Input variable: Distribution of travel demand over corridor

Instead of defining a distribution pattern A/B/C for the travel demand, it can be an improvement to define for each stop the share of the total travel demand. This addition can also be optional, in case this knowledge is available, users can enter the usage shares per stop, and otherwise still one of the three distribution patterns can be chosen.

Addition of input variables: improving the translation of the reality into the policy context input variables.

Currently the policy context variables only capture the importance of the speed and reliability of the bus service. However, as was presented in Section 3.2.1 also more societal goals play a role in the determination of the configuration. To better capture these interests, the variables presented below can be implemented. Subsequently the user of the tool has to indicate how important these aspects are. These variables are inspired by research of (Van der Bijl & Van Oort, 2014).

- System has to enhance urban development.
- System has to enhance economic growth.
- System has to reflect environmental awareness.
- System has to enhance the social quality.

Since in this research is focussed on the optimal design from the perspective of the user, these input variables are not included in this version of the BRT design scanner.

6.6.2 Improvements to internals of the BRT design scanner

This section reviews the internals of the BRT design scanner. These improvements will improve the predictive quality of the scanner, but are, contradictory to the improvements to the interface, not visible to the user of the scanner. This implies that the complexity of the scanner is not impacted.

Computation of intersection type

1) Currently the bus frequency is linearly linked to the number of 'closings' of the intersection. However, the higher the frequency, the bigger the possibility two vehicles are that close behind each other that the intersection is only closed one time, instead of two single times (for example, one time 20 seconds instead of two times 15 seconds). Also, in case of two busses passing each other in the opposite direction on an intersection, the closing time is computed two times. Correcting for these effects will increase the validity of the model. However, based on the available input variables, these effects will be difficult to estimate.

2) The costs associated with travel time losses are only based on the loss of travel time; the loss of reliability is not monetized. By correcting the intersection type for the entered score for 'level of competitiveness of the system on the aspect of reliability', this loss is however indirectly taken into account. Still, considering the importance of reliability, incorporating the loss of reliability more prominently in the decision for the intersection type is advised.

3) Currently, a uniform arrival pattern of car vehicles at the intersection is assumed. In reality, vehicles arrive, because of speed differences and preceding traffic lights, mostly more clustered at an intersection. Further research could result in the implementation of an arrival pattern with a higher predictive quality.

4) Currently, the extra travel time for car users, in case a bus acquires priority, are assumed to be equal to the closing time. However, the configuration of the traffic light determines the amount of extra travel time. In the scanner, the effects for vehicles which, because a longer queue than normal will be imposed

by an extra cycle length, are not computed. Additional research on how these effects can be taken into account is desirable.

5) Currently, the costs of all four types of intersections are computed and the most cost effective version is subsequently chosen. In this calculation, the relative differences between the costs are not taken into consideration. In case the costs of two types are practically the same, advising multiple intersection types can be advisable.

Decision for suggestion of express service

1) Express services and zone services are different types of services where along the trajectory stops are skipped. In the scanner only the express version is covered. Researching also the applicability of zone services can provide additional insights.

2) Currently, only a suggestion is provided if express services can probably improve the quality of the service. Based on the available data, it is however possible to give an indication of the potential gains of adding an express service: "skipping ... stops will result in an increase of operational speed of ... km/h". Adding this information will increase the insight in the potential profit of the express service.

Decision for elements to brand

In the current configuration of the scanner, the design variable: 'open or closed system' determines the output on the design variable 'elements to brand' As presented in Section 4.5.3, the 'open or closed system' output variable is difficult to determine. This implies that, if in this output variable is not predicted well, the suggested elements to brand also become wrong. Disconnecting these two output variables will improve the robustness of the scanner.

Decision for the need of passing opportunities

Currently, when an express service is suggested, a passing opportunity might be needed. However, by also considering the frequency, the difference in speed (approximation), the length of the trajectory, this approximation can be improved.

Computation of indication of infrastructure costs

The infrastructure costs are currently not dependent on the location of the system. The costs of creating a viaduct in a remote residential area are for instance incomparable with creating a viaduct in a dense urban environment. A better specification of these costs will improve the quality of this indicator.

6.7 Conclusion

This chapter presents a reflection on the BRT design scanner. By using the scanner to analyze the bus service between Station Vleuten and Utrecht CS, the quality of the advices generated by the scanner are analyzed and some potential improvements of the scanner are identified. The quality of advices, as provided by the scanner is assessed by:

Differences between the advised and realized configuration. Based on a reflection of the differences between the advised and realized configuration, the optimal configuration as outcome of the scanner seems to be plausible.

SCBA. Three of the advised improvements to the bus service are analyzed by means of a Societal Cost Benefit Analysis (SCBA). An in dept analysis of three design variables (*express service, intersection treatment and fare collection procedure*), indicated that the suggestions of the scanner for these design variables are useful for the investigated service. From this analysis is can be concluded that the suggested measures can significantly reduce the travel time and result in very high profits on a yearly basis. Additional to these calculated travel time profits of around € 2.200.000 per year also the reliability is greatly improved. On the other hand, the investment costs and the nuisance for other traffic will increase.

So, from an assessment of the suggested improvements, by both a reflection on the differences between the advised and realized configuration, as well as by an SCBA inspired method, it can be concluded that for the case of Leidsche Rijn, the advices of the scanner can result in major improvements of the performance of the system.

Finally, in this chapter a set of improvements are formulated to the interface and internals of the BRT design scanner. These improvements are identified to be able to enrich the usability and predictive quality of the scanner, but are however not implemented because of the restricted time available for this study. For the interface of the model it is primarily advised to:

- Facilitate a more uniform definition of the expected travel demand.
- Facilitate a more user friendly definition of the amount of crossing traffic.
- Facilitate a better definition of the frequency of the service

For the internals of the model it is primarily advised to:

- Improve the determination of the applicable type of intersection.
- Enhance the decision for the applicability of an express service.

The next chapter presents the final conclusions this research.

7 Conclusions

The aim of this research was to obtain insight in the applicability of different BRT configurations. This was done by researching the drivers behind, and results of design choices in a set of BRT systems. The insights acquired during this study were translated in a BRT design model which was subsequently implemented in the BRT design scanner. Spread over the Sections 7.1 to 7.5, the five sub questions and the main research question, as originally formulated in Section 1.2, are answered.

7.1 Determining the BRT configuration: state of the art

- **What is state of the art of the research into the configuration of BRT systems?**

From a diversity of definitions, BRT has been identified as a bus-based public transport service that performs well in terms of speed, reliability, comfort and capacity and beside that is associated with a high flexibility and relatively low costs. It has also been identified that this performance is generally reached by making improvements to the system elements:

- Infrastructure
- Stations
- Vehicles
- Fare collection
- ITS: Intelligent Transport Systems (passenger information, signal priority)
- Distinctive identity

From researching the appearance of BRT systems all over the world, it was concluded that a great variety of different design variables are associated to these system elements. It also appeared that the configuration of these design variables differs greatly.

In the literature, different categorization methods are formulated to capture these different implementations of design variables. However, it appeared to be difficult to categorize existing systems worldwide according to these methods. Systems appeared to often exhibit characteristics of both 'light' versions and 'advanced' versions.

The difficulty to identify standard configurations of BRT systems, has asked for an approach where the implementation of each specific design variable will be separately matched with the local conditions.

Existing BRT design models are researched to find which models provide such an approach. However, none of the four identified models appeared to use the same approach.

7.2 Relation between the configuration and performance of BRT systems

- **What are the impacts of design decisions on the performances in existing BRT systems?**

To answer this research question the performance indicators *infrastructure costs*, *operational speed*, *passengers per hour per direction*, and *passengers per day* are used. Also a set of 24 design/context variables is determined. Subsequently the characteristics (by design variables), and performances (by performance indicators) of reference systems are examined. By subsequently researching the relation between these two, insights were gathered about how these systems perform, and outliers were researched.

The main lesson that could be extracted from this research is the importance of commitment. In this context, commitment is explained as the willingness to create a system that first of all conforms to the primary goals of the system: the ‘dissatisfiers’ and the ‘satisfiers’. The importance of the secondary and tertiary goals seem to be important but these were not assessed in this study.

In the systems of Bogota, Brisbane, Rouen, this commitment was clearly present. In the case of Bogota and Brisbane this is highlighted by the fact that the design decisions are made, such that the all customer satisfaction aspects (dissatisfiers as well as the satisfiers) are met. To achieve this, in Bogota and Brisbane ‘heavy’ configurations were necessary. In Rouen even mixed traffic operations were possible on some sections. However, in all situations very successful systems were created that were very successful in terms of ridership and operational speeds.

It systems where this commitment appeared to be less strong, it seems that unbalanced systems are designed. The systems of Urumqi, Changzhou and Los Angeles are examples of such systems. For all of these systems the design decisions are made in such a way that a very ‘heavy’ appearance is created. However in all cases, the intersection treatment is not sufficient. This results in a poor performance in terms of speed and reliability, the main determinants of the level of customer satisfaction.

The case of Nagoya however indicates that the commitment to just create a system that performs well on the ‘dissatisfiers’ and the ‘satisfiers’ is also not the key to success. The case indicates that the design of the system should be considered within its local context.

So, each element should be cost-effectively updated to such a level the primary performance is reached. This level is however dependent on the local conditions. This founding’s confirmed that the approach, to separately match the implementation of each specific design variable with the local conditions, is appropriate.

7.3 Formulation of BRT design model and scanner

- **How can the acquired insights about the result of design decisions on the performance be captured in a BRT design model?**

Because of various reasons (among other: effect on primary performance of system, applicability for Dutch context, limited time available for this research) of the original 20, 12 design variables are selected. Of these 12 design variables, for 4 of these, the optimal configuration appeared to be relatively insensitive to the local conditions. For these design variables, notwithstanding the local conditions, the following is recommended:

- **Fare collection**: To reduce the dwell times, locating the fare collection process at to the stop is identified as an effective measure. For the Dutch situation, this implies that check in devices should be located on stops, and buying tickets from bus drivers should be discouraged.

- **Enhanced stations**: It is identified that it is preferable to enhance the quality of the stations, more than just providing the basic facilities shelter and seating. By (potential) customers, the stations should be identified as an access point of a high quality mode of public transport.

- **Station level boarding**: It is identified that to speed up the dwell procedure, providing station level boarding is a basic requirement.

- **Dynamic travel time information**: Considering the current state of art of vehicle following techniques, and the customer satisfaction it adds, dynamic travel time information is identified as a requirement.

The other 8 design variables, of which the optimal configuration appeared to be sensitive to the local conditions, are listed below.

- **Type of infrastructure**: Depending on the traffic flow on the trajectory and the priority to reach a high level of speed and reliability, the suitable infrastructure type can be assessed.

- **Type of intersection**: The type of intersection is identified to be crucial to the systems success. It is identified that in case the type of intersection is not adjusted to the local conditions, this can result in a service that performs badly in terms of speed and reliability. In many occasions this means that, to realize competitive levels of speed and reliability, full priority or grade separation on intersections is required.

- **Open or closed system**: To be able to define if either an open (operational mode is direct service) or closed system (operational model is trunk only or trunk feeder) is optimal, it is identified that it is essential to evaluate the origins and destinations of the users of the systems.

- **Express service**: Depending on the distribution of the travel demand and the stop spacing of the service, it is identified that express services could provide significant travel time profits. However, the reduction of the clearness of the system appears to be a disadvantage.

- **Branding of elements**: It is identified that the branding and identity is a vital aspect of a BRT system. The type of system (open or closed) appeared to be decisive when recommending the elements that should be branded.

- **Positioning of system in market**: As stated above, it is identified that the branding and identity is a vital aspect of a BRT system. It appeared that the presence of existing high quality public transport systems in the surrounding determine the optimal way the system is positioned in the market by connecting it to, or differentiating from, these existing systems).

- **Access and egress transport by bicycle**: It has been identified that larger stop spacings make the bicycle become a more attractive mode for access and egress transport. To capture this potential travel demand, as the stop spacing increases, high quality bicycle parking facilities become more necessary.

- **Passing opportunities**: It is identified that that in case expresses services are incorporated, to be able to guarantee the speed and reliability of these services, the need for passing opportunities should be assessed.

The advices for these eight design variables are the output variables of the BRT design model. Their recommended implementation is related to input variables that capture the local conditions. It appeared to be important to include in the input variables, besides the system characteristics (e.g. expected travel demand, frequency), also the policy context (both policy context and system characteristics). In some cases, also output variables are identified the influence other output variables. Table 7-1 below presents how the output values for each of the eight output variables is determined in the BRT design model.

Table 7-1: Overview of determination of output variables in the BRT design model

		Input variables - system characteristics							Input variables - policy context				Output variables			
		Expected travel demand	**Length of trajectory**	**Frequency**	**Number of stations**	**Predominant LOS on trajectory**	**Distribution of demand over corridor**	**Amount of crossing traffic**	**Investment period**	**Other successful high quality pt systems**	**Competitiveness speed**	**Competitiveness reliability**	**Open or closed system**	**Express service**	**Type of infrastructure**	**Type of intersection**
Output variables in BRT design model	**Type of infrastructure**					x					x	x				
	Type of intersection	x		x				x	x		x	x				
	Open or closed system		x				x									
	Express service		x		x		x									
	Elements to brand												x			
	Position in market									x						
	Access and egress transport by bicycle		x		x											
	Passing lanes													x		
	Indication of speed		x		x											x
	Indication of reliability														x	x
	Indication of infrastructure costs				x										x	x

- **How can the BRT design model be implemented in a software tool, the BRT design scanner?**

It was identified that a tool could be designed that is attractive and easy to work with, when conforming to the following requirements:

- Should implement the model formulated in Chapter 4
- Adjusted to audience
- Easy understandable and quickly usable
- Provide results quickly
- Interactive quality
- Visually attractive
- Modular design

To conform to these requirements, the BRT design scanner is constructed in Microsoft Excel and is supported by a graphical interface, constructed with Excel's supported programming language: Visual Basic for Applications (VBA). The tool implements and automates the relations of the BRT design model. By this, an interactive tool is created that links the input variables to the output variables.

7.4 Quality of BRT design scanner and underlying model

- **What is the applicability and quality of the BRT design scanner and its underlying model, based on a case study of the BRT service through Leidsche Rijn?**

7.4.1 Quality of provided advices

Differences between the advised and realized configuration. Based on a reflection of the differences between the advised and realized configuration, the optimal configuration as outcome of the scanner seems to be plausible.

SCBA. Three of the advised improvements to the bus service are analyzed by means of a Societal Cost Benefit Analysis (SCBA). An in dept analysis of three design variables (*express service, intersection treatment and fare collection procedure*), indicated that the suggestions of the scanner for these design variables are useful for the investigated service. From this analysis is can be concluded that the suggested measures can significantly reduce the travel time and result in very high profits on a yearly basis. Additional to these calculated profits of around € 2.200.000 per year also the reliability is greatly improved. On the other hand, the investment costs and the nuisance for other traffic will increase.

So, from an assessment of the suggested improvements, by both a reflection on the differences between the advised and realized configuration, as well as by an SCBA inspired method, it can be concluded that for the case of Leidsche Rijn, the advices of the scanner can result in major improvements of the performance of the system.

7.4.2 Applicability of the BRT design scanner

From the application of the BRT design scanner to the case of Leidsche Rijn, it appeared that the scanner works overly fine. However, a few ambiguities in the formulation of the input variables (related to the interface of the scanner), and a few improvements to the model internals are identified. Improving these can improve the quality of the BRT design scanner. For the interface of the model it is primarily advised to:

- Facilitate a more uniform definition of the expected travel demand.
- Facilitate a more user friendly definition of the amount of crossing traffic.
- Facilitate a better definition of the frequency of the service

For the internals of the model it is primarily advised to:

- Improve the determination of the applicable type of intersection.
- Enhance the decision for the applicability of an express service.

7.5 Main research question

The main research question of this research was in Section 2.1 formulated as follows:

- **How to decide on the applicable configuration of a BRT system?**

From this research it has become clear that BRT provides the possibilities to create well functioning public transport systems, which are able to attract a lot of users. The implementations of design variables, to create these well functioning systems, however differ among these systems. From the diversity in BRT configurations, of which some with a 'light' configuration are functioning well, and others with a 'full' configuration do not, it is concluded that there is no standard recipe to achieve such a well functioning BRT system.

It appeared that the local conditions of the system (the policy context and the system/spatial characteristics) are especially determining the applicable configuration of a set of design variables. In addition, also for a set of design variables, the optimal configuration appeared to be to be relatively insensitive to different local conditions.

In total 12 design variables are identified, on which the emphasis should be, in an early stage of the design procedure. For four of these the optimal configuration appeared to be to be relatively insensitive to different local conditions. For the other eight design variable the local conditions appeared to be determining the optimal configuration. The BRT design scanner and its underlying model, as formulated in this research, can be consulted to provide an insight in the applicable configuration, based on the specific local conditions.

The BRT design scanner suggests the applicable configuration for 12 important design variables. However, in the complex playing field a system is designed, compromising between different interests is more the norm than the exception. Therefore, key to a successful design is commitment, commitment to create a high quality system.

Although commitment to avoid compromises for each of the 12 design variables, the design variables impacting the speed and reliability are even less desired to be compromised on. These are identified to be the fare collection location, level of boarding, type of infrastructure and most importantly, the type of intersection.

8 Discussion and recommendations

This section discusses the applicability of the BRT design scanner and the used research methodology. For most of the considerations in this chapter, recommendations for further research can be derived. Additional to these recommendations, in Section 0 suggestions for additional research into the identified outliers were presented. For specific improvements to the BRT design scanner, Section 6.6 can be consulted.

8.1 Discussion of applicability of BRT design scanner

This research is focused on the applicability of BRT, the spectrum of public transport solutions is however much larger. Beside BRT, also Tram, Light Rail, Metro or even heavy rail services can be used to accommodate the wish for a high quality urban public transport service. Lots of research is available about the applicability of BRT compared to other modalities. Among other (Cain & Flynn, 2013; Cervero, 2013; Currie, 2005; Hidalgo et al., 2013; Tirachini et al., 2010) researched this topic. This research assumes the decision for BRT as fixed, and studies the applicability of BRT within its own modality. However, in the scanner, it could be useful to provide the link with other modalities to some extent. For example, considering the input variables, indicating if a tram is also a potential alternative can be a possible addition.

It is important to acknowledge that the focus in this research was on the optimal design of a BRT service form the perception of the user. Focusing on the design from the perspective of the society can provide additional insights. It is not researched how the implementation of a BRT service have an as high as possible positive effect, on the environment it is situated in. Several sources suggest that the effects of a service on its environment are however recognizable (Cervero & Kang, 2009; Deng & Nelson, 2012; Lindau et al., n.d.). It is recommended to research the implementation of design variables also from this perspective. Also, as was presented in Appendix P and noted by (Genot, 2014), there are ideas that in Leidsche Rijn, the integration of the bus service in the area is not optimal. Examples are the low building densities around bus stations (Eerste Westerparklaan and Korianderstraat), or the transfer station De Meern Oost which is exposed and far from any points of attraction. This makes that during subsequent research, Leidsche Rijn can serve again as an applicable case study area.

In Section 2.1 it was presented that there are lots of views about what is BRT, it was concluded that BRT is among other identified with improvements to the infrastructure and the intersection treatment. However, in the BRT design scanner, also non prioritized intersections and non segregated infrastructure are included. By filling in the system characteristics and required quality level (policy context), the advised design decisions are the result. This can either be a service that fits the definition of BRT or that does not fit this definition. This indicates the approach of this research: do what is sufficient in the specific situation.

It is important to understand the position of the BRT design scanner in the design procedure. Although the model is effectively able to reduce the design space so that only the most promising options remain, further analysis would be necessary for each of the relevant design variables. For example, for the configuration of the design variable *type of intersection*, the algorithm used provides a rough approximation of the vehicle loss hours for crossing traffic. In a later stage of the design procedure, advanced modelling software like VISSIM is however advisable to make a more precise computation of these vehicle loss hours.

The scanner functions by suggesting the appropriate configuration, based on input variables. However, reversing this order can also provide interesting insights. In this case, the user can define the intended BRT configuration; the BRT design scanner subsequently presents the required input characteristics.

Although this is not the intended goal of the scanner, the scanner can be used to get familiar with the characteristics and associated flexibility of the BRT mode.

It is acknowledged that the number and quality of considerations, as produced by the BRT design scanner, is impacted by time constraints. Within the available time, this research aimed to address the most important design variable from the perspective of the user. However, considering the complexities and flexibilities of the BRT mode, there are also many aspect of BRT that were not addressed. As such, the BRT scanner should be valued as preliminary version, which can be further expanded and improved. To encourage this, the contents of, and the current relations between the input and output variables is clearly reported on (see Appendix F).

8.2 Discussion of research methodologies

Below, spread over two sections, the used research methodologies is discussed.

8.2.1 Research of reference systems and formulation of BRT design model

It proved sometimes to be difficult to capture the patterns and outliers, when investigating the diagrams created by relating the design variables to the performance indicators. By using mathematical based correlation algorithms potentially additional patterns and outliers can be extracted from the data. However, it should be noted that the current data set is possibly too small to successfully apply these algorithms.

In Chapter 4, “Formulation of a BRT design model” it is clearly indicated why 8 of the 20 design variables are not considered for the remaining of this research. It is however less clearly indicated why the 12 other design variables are considered. For the investigation of the outliers as presented in Chapter 3, “Studying BRT in practice”, a lot of literature is consulted. This has led to insights about potential decisions, and insights why certain decisions are made. This literature research has resulted in the twelve design variables that are considered to be important to consider. Although each of these design variables were derived from the reference systems, a more explicit indication of why exactly these 12 design variables are important could have enriched the research.

8.2.2 Validation of BRT design scanner

Considering the limited time available for this research, it was inevitable to make concessions on the way the quality of the BRT design scanner has been validated. Below, four important considerations are presented.

The evaluation of the BRT design scanner is currently based on the evaluation of one case only, the case of Leidsche Rijn. It is recognized that by using more cases to review the scanner on, the validity of the suggested configuration of the output variables can be assessed better.

Also, by testing the scanner on more cases, the validity of the input variables can be assessed further. During the formulation of the scanner, on one side, it was important to balance between adding more and more complex input variables to improve the predictive quality of the scanner. Where on the other side, to secure the user friendliness of the scanner, these input variables need to be left out. By using more cases to review the scanner on, it can be investigated if the used input variables are also applicable and sufficient to capture the local conditions of other systems.

For the case of Leidsche Rijn, the case the scanner is currently reviewed on, it was a priory expected that a certain improvements could be suggested. In this way the quality of the advices provided by the scanner are evaluated. Another way to test the quality of the advices of the scanner is by trying to reproduce a BRT system that is considered to be of 'high quality'. By identifying the input variables of such a system, of which it is the idea that the design choices are optimal, it can be identified how the scanner conforms to this system. In fact, for the most thorough evaluation of the BRT scanner, it could have been tested against all the reference systems that have been studied.

In the current validation procedure, no sensitivity analysis is conducted. By analyzing how the output of scanner changes by certain changes of the input variables, the sensitivity can be tested.

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Appendix A Example of lack in alignment in categorization methods

Table A-1 and Table A-2 present the categorization of the systems of Changzhou and Los Angeles. This categorization method is based on a combination of the categorizations presented by (CERTU, 2010; ITDP, 2007, 2014). It is clear that these systems consist of both advanced and less advanced implementations of design variables.

Table A-1: Categorization of the BRT system of Changzhou

Changzhou	**High quality bus service**	**BRT-lite**	**Full BRT**
Priority treatment	Most intersections with priority treatment	Absolute priority	Absolute priority
Type of infrastructure	Non segregated dedicated infrastructure, at-grade intersections with other traffic	Segregated dedicated infrastructure, at-grade intersections with other traffic	Segregated dedicated infrastructure, at-grade and grade-separated intersections with other traffic
Location of infrastructure	Median or curbside	Median	Median
Station access	Level	Almost exclusively level	Almost exclusively elevated
Station facilities	Basic facilities (seating facilities, shelter)	Luxury facilities	Metro-like stations
Vehicle boarding	Platform level boarding, no platform level boarding or combination of both types	Platform level boarding	Platform level boarding
Vehicle type	Standard (12m) of articulated (18m)	Articulated (18m) or bi-articulated (25m)	Almost exclusively bi-articulated (25m)
Fare payment location	Fare payment location in vehicle or on the station	Fare collection on station	Fare collection on closed station

Table A-2: Categorization of the BRT system of Los Angeles

Los Angeles	High quality bus service	BRT-lite	Full BRT
Priority treatment	Most intersections with priority treatment	Absolute priority	Absolute priority
Type of infrastructure	Non segregated dedicated infrastructure, at-grade intersections with other traffic	Segregated dedicated infrastructure, at-grade intersections with other traffic	Segregated dedicated infrastructure, at-grade and grade-separated intersections with other traffic
Location of infrastructure	Median or curbside	Median	Median
Station access	Level	Almost exclusively level	Almost exclusively elevated
Station facilities	Basic facilities (seating facilities, shelter)	Luxury facilities	Metro-like stations
Vehicle boarding	Platform level boarding, no platform level boarding or combination of both types	Platform level boarding	Platform level boarding
Vehicle type	Standard (12m) of articulated (18m)	Articulated (18m) or bi-articulated (25m)	Almost exclusively bi-articulated (25m)
Fare payment location	Fare payment location in vehicle or on the station	Fare collection on station	Fare collection on closed station

Appendix B Implementation of design variables, context variables and performance indicators in the set of reference systems

This Appendix presents for the reference systems, the implementation of the design variables, context variables and the values of the performance indicators. Most of these data is origination from (BRTdata, 2014; Finn et al., 2011; World BRT, 2014). In case of differences between these sources, to investigate the exact implementation, additional data sources have been consulted. It should be considered that some systems have been developed over time. For instance, the quality of stations can have been updated or other types of busses can be put into operation. The used literature will not have always been adapted to these changes.

B.I Implementation of design variables and context variables

Table B-1 and Table B-2 present the implementation of each of the design variables. Table B-3 presents the implementation of each of the context variables.

Table B-1: Implementation of design variables in set of reference systems (1 of 2)

	Sliding doors at stations	Station access level/elevated	Station access open/closed	Enhanced stations[4]	Platform height[5]	Location of infrastructure	Level of segragation[6]	Signal priority	Real time travel info on next bus
Rouen	No	Level	Open	1	Low	Median or curbside	1	Dynamic	Yes
Utrecht	No	Level	Open	1	Low	Median or curbside	2	Dynamic	Yes
Almere	No	Level	Open	1	Low	Median	2	Fixed	Yes
Urumqi	Yes	Level	Closed	3	Low	Median or curbside	2	No	Yes
Metz	No	Level	Open	2	Low	Median or curbside	2	Dynamic	Yes
Nantes	No	Level	Open	1	Low	Median	2	Dynamic	Yes
Paris	No	Level	Open	1	Low	Median	3	Dynamic	Yes
Beijing	Some	A few elevated	Open	2	Low	Median	2	Dynamic	Yes
Changzhou	Yes	A few elevated	Closed	3	Low	Median	1	No	Yes
Los Angeles	No	Level	Open	2	Low	Median	2	Dynamic	No
Johannesburg	Yes	Level	Some closed	3	High	Median	2	No	Yes
Mexico City	No	Level	Closed	3	High	Median	2	Fixed	No
Lanzhou	Yes	Level	Closed	3	Low	Median	2	Fixed	Yes
Nagoya	No	Level	Open	3	Low	Median	3	n.v.t	Yes
Istanbul	No	Elevated	Closed	3	Low	Median	3	n.v.t.	No
Guangzhou	Yes	Elevated	Closed	3	Low	Median	2	Dynamic	Yes
Bogota	Yes	Elevated	Closed	3	High	Median	3	Dynamic	No
Amsterdam	No	A few elevated	Open	2	Low	Median	3	Dynamic	Yes
Brisbane	No	A few elevated	Open	3	Low	Median	3	nvt	Yes

[4] 1: Stations with basic facilities, 2: Luxury stations, 3: Metro like stations
[5] Low: in the approximate range of 30-35 cm, High: in the approximate range of 90-100 cm
[6] 1:Mixed traffic operation, 2: Segregated, intersections with other traffic, 3: Grade separated on intersections

Table B-2: Implementation of design variables in set of reference systems (2 of 2)

	Guided system	Operational mode	Express services	Distinctive system	% of stations with passing lanes	Main vehicle Configuration and number of doors	Fuel type	Pre board fare collection[7]	Platform level boarding
Rouen	Optical guidance at stations	Trunk-only	No	Station, bus, identity	0	Articulated (4)	Biodiesel	No	Yes
Utrecht	No	Hybrid (trunk-only and mixed)	No	None	0	Articulated (4)	Diesel	Yes + cash	Yes
Almere	No	Trunk-only	No	Bus	0	articulated (4)	Diesel	Yes + cash	
Urumqi	No	Trunk-only	No	Station, bus, identity	2	articulated (3)	CNG, Diesel	Yes	Yes
Metz	No	Direct service	No	Station, bus, identity	0	Bi articulated (4)	Hybrid diesel electric	Yes	Yes
Nantes	No	Trunk-only	No	Station, bus, identity	0	Articulated (4)	Diesel	Yes + cash	Yes
Paris	No	Trunk-only	No	Bus, identity	3	Articulated (3)	CNG	Yes + cash	Yes
Beijing	No	Trunk-only	No	Station, identity	0	Articulated (4)	Diesel	Yes	Yes
Changzhou	No	Direct-service	No	Station, bus, identity	0	Articulated (4)	Diesel	Yes	Yes
Los Angeles	No	Trunk-only	No	Station, bus, identity	89	Articulated (3)	CNG	Yes	No
Johannesburg	No	Hybrid (trunk-only and mixed)	Yes	Station, bus, identity	100	Standard (2) + articulated (3)	Diesel	Yes	Yes
Mexico City	No	Trunk-only	No	Station, bus, identity	0	Articulated (4) + bi articulated (6)	Diesel	Yes	Yes
Lanzhou	No	-	Yes	Station, bus, identity	100	Standard (2) + articulated (2)	CNG	Yes	Yes
Nagoya	Mechanical guidance	Direct service	No	Station, identity	0	Standard (2)	Diesel	Yes	Yes
Istanbul	No	trunk-only	No	Station, bus, identity	0	Articulated (4) + bi articulated (4)	Diesel, hybrid	Yes	Yes
Guangzhou	No	Direct service	Yes	Station, bus, identity	100	Standard (2) + articulated (3)	LPG	Yes	Some
Bogota	No	Trunk-feeder	Yes	Station, bus, identity	100	Articulated (4) + bi articulated (7)	Diesel	Yes	Yes
Amsterdam	No	Trunk only, but some in mixed	No	Bus, identity	0	Articulated (3)	Diesel	Yes + cash	Yes
Brisbane	No	Direct service	Yes	Station, identity	100	Standard (2) + articulated (2)	Diesel, some CNG	Yes + cash	Yes

[7] In case of the usage of chip cards, notwithstanding the location of this fare collection, 'yes' is entered.

Table B-3: Implementation of context variables in the set of reference systems

	Investigated corridors	Network length	Stop spacing (m)	Inhabitants of urban area (x1000)	Year system commenced
Rouen	T1,2,3	29,8	560	494	2001
Utrecht	Line 12	6,8	680	324	2001
Almere	Line 1	17,2	600	196	2004
Urumqi	Line 1-4	37,2	650	2.910	2011
Metz	Line A,B	17,8	484	288	2013
Nantes	Line 4	6,9	460	594	2006
Paris	TVM	20	758	10.516	1993
Beijing	BRT 1,2,3,4	79	1000	11.716	2004
Changzhou	Line 1,2	54	868	3.291	2008
Los Angeles	Orange Line	22,9	1636	3.793	2005
Johannesburg	Lines 1a,1b	43,5	946	957	2010
Mexico City	Lines 1,2,3	67	644	8.851	2005
Lanzhou	Line 1	9,1	650	1.980	2013
Nagoya	Guideway Bus system	6,7	720	2.262	2001
Istanbul	Metrobus corridor	51,7	1156	13.624	2007
Guangzhou	Zhongshan Avenue	22	860	11.071	2010
Bogota	All 11 corridors	112	836	7.761	2000
Amsterdam	Zuidtangent	56,7	1710	803	2002
Brisbane	South East Busway	16,5	1650	1.970	2001

B.II Values of performance indicators

Table B-4 presents the values of the performance indicators for the reference systems. When values were not acquired, they are left out.

Table B-4: Values of the performance indicators for the set of reference systems

	Operational speed (km/h)	Passengers per day	Passengers per hour per direction	Infrastructure costs (million €/km)
Rouen	17,5	57000	1770	5,6
Utrecht	17,5	40000	-	16,6
Almere	24	16000	-	-
Urumqi	11,5	400000	6950	-
Metz	20	23000	-	9,5
Nantes	21,5	35000	1200	8,3
Paris	23	66000	-	7,4
Beijing	19	305000	8000	17
Changzhou	19,5	350000	2650	6,6
Los Angeles	32	26883	1000	14,4
Johannesburg	30	42000	4510	15,7
Mexico City	18	750000	7550	3
Lanzhou	22	140000	6550	-
Nagoya	25	9000	500	40,3
Istanbul	35	750000	18900	15,6
Guangzhou	19	843000	27400	6,8
Bogota	26,2	2185617	37700	20,3
Amsterdam	38	32000	960	8
Brisbane	55	160200	19900	28,9

Appendix C Normalization of infrastructure costs

This appendix presents the normalization process of the infrastructure costs of the reference systems. The infrastructure costs, as found in literature, were displayed in different currencies, spent in different years and originating from different areas over the world. To make these costs mutually comparable, these three effects have been corrected for.

To do this, all costs are converted to Euros, with 2013 as reference year. Also is corrected for the difference in purchase power over the world. Three steps are undertaken:

1. Translating the different monetary units to Euros. To do this, the historic exchange rate is used of the concerned currency, for the year the system commenced. This translation is based on (OANDA, n.d.).
2. Correcting for inflation. For each year the system is in operation (up until the year 2013), the costs are multiplied by an inflation factor. This inflation factor is the average historic inflation over the concerned time period, in the concerned country (for the local currency). The used inflation factors are originating from (FXTOP, n.d.; GDP Inflation, n.d.).
3. Correcting for purchase power. There are differences in purchase power over the world. To correct for these differences, the purchase power parity (ppp) value can be used. This value yearly published by (Worldbank, n.d.), indicates the relative value of different currencies. These ppp values indicate the purchase power of each country compared to the United States of America. Since the purchase power in the Netherlands and France (the investigated European systems are situated in these countries) is comparable to the USA, these countries are all set as 1.

Table C-1 on the next page presents this normalization process.

Table C-1: Normalization of infrastructure costs per kilometre of reference systems to Euros.

	Corridor	Year system commenced	Infrastructure costs/km in millions in different monetary units	Million Euro	Million Euro with inflation correction	Million Euro with inflation and ppp correction
Rouen		2001	4,5 EUR	€ 4,50	€ 5,60	€ 5,60
Utrecht		2001	36,8 GLD	€ 16,70	€ 20,80	€ 16,60
Almere[8]		2004	-			
Urumqi		2011	-			
Metz		2013	12,4 USD	€ 9,50	€ 9,50	€ 9,50
Nantes		2006	7,4 EUR	€ 7,40	€ 8,30	€ 8,30
Paris		1993	7,1 EUR	€ 7,10	€ 7,40	€ 7,40
Beijing		2004	40,0 CNY	€ 3,80	€ 5,10	€ 17,00
Changzhou		2008	30,0 CNY	€ 2,80	€ 3,30	€ 6,60
Los Angeles		2005	14,3 USD	€ 10,90	€ 13,30	€ 13,30
		2005	16,7 USD	€ 12,70	€ 15,50	€ 15,50
Johannesburg[9]	1a	2010	13,6 USD	€ 9,50	€ 11,00	€ 18,40
	1b	2010	9,7 USD	€ 6,80	€ 7,90	€ 13,10
Mexico City[10]	1	2005	2,8 USD	€ 2,10	€ 3,00	€ 4,20
	2	2008	1,4 USD	€ 0,90	€ 1,20	€ 1,70
Lanzhou[11]		2013	52,8 USD	€ 40,30	€ 40,30	€ 67,10
Nagoya		2001	46,5 USD	€ 49,50	€ 48,30	€ 40,30
Istanbul		2007	8,8 USD	€ 6,80	€ 10,90	€ 15,60
Guangzhou		2010	30,0 CNY	€ 3,10	€ 3,40	€ 6,90
Bogota[12]	phase 1	2000	5,3 USD	€ 5,20	€ 5,20	€ 13,10
	phase 2	2006	13,3 USD	€ 11,00	€ 11,00	€ 27,50
Amsterdam		2002	6,5 EUR	€ 6,50	€ 8,00	€ 8,00
Brisbane		2000	24,2 AUD	€ 15,70	€ 23,10	€ 28,90

[8] The BRT corridor is simultaneously developed with the urban area. No distinct costs for only the BRT corridor could be identified.
[9] The average infrastructure costs of both corridors are used for the analyses in this report.
[10] The average infrastructure costs of both corridors are used for the analyses in this report.
[11] The height of the infrastructure costs are resulting from the simultaneous construction of a shopping mall under the BRT corridor.
[12] The average infrastructure costs of both corridors are used for the analyses in this report.

Appendix D Establishment of performance indicators regarding comfort and reliability

This appendix presents, based on the implementation of different design variables in the reference systems, an approximation of the level of reliability and the level of comfort.

D.I Performance on comfort

This performance indicator indicates the level of comfort associated to the bus service, taking into consideration both the waiting experience as well as the trip in vehicle. The value of the indicator is formed by the score on the following aspects:

Enhanced station?	Metro like (1)/Luxury stations (0,66)/Basic facilities (0,33)/No (0)
Platform level boarding?	Yes (1)/Some (0,5)/No (0)
Real time travel information?	Yes (1)/No (0)
Overcrowded vehicles?	Yes (1)/Some (0,5)/No(0)

The first three indicators are design variables; the fourth indicator is based on acquired insights during the analysis of the systems in detail. An assumption is done about the relative importance of the aspects. The weights are determined to produce a final score between 0 and 1. Table D-1 presents the weights together with all scores.

Table D-1: Assessment of comfort of set of reference systems

	Enhanced stations	Platform level boarding	Real time travel information	Overcrowded	Comfort score
Weight	0,4	0,1	0,2	0,3	
Rouen	0,33	1	1	1	0,7
Utrecht	0,33	1	1	0,5	0,6
Almere	0,33	1	1	1	0,7
Urumqi	1	1	1	0	0,7
Metz	0,67	1	1	1	0,9
Nantes	0,33	1	1	1	0,7
Paris	0,33	1	1	1	0,7
Beijing	0,33	1	1	0,5	0,6
Changzhou	1	1	1	0,5	0,9
Los Angeles	0,67	0	0	1	0,6
Johannesburg	1	1	1	1	1,0
Mexico City	1	1	0	0,5	0,7
Lanzhou	1	1	1	0,5	0,9
Nagoya	1	1	1	1	1,0
Istanbul	1	1	0	0	0,5
Guangzhou	1	0,5	1	0,5	0,8
Bogota	1	1	0	0	0,5
Amsterdam	0,67	1	1	1	0,9
Brisbane	1	0	1	0,5	0,8

D.II Performance on reliability

This performance indicator indicates the level of reliability associated to the bus service. The score on the indicator is formed by the score on the following design variables:

Signal priority?	Segregated (1)/Signal priority (0,5)/No (0)
Level of segregation?	All grade separated on intersections (1)/Segregated, with intersections with other traffic (0,5)/Mixed traffic operations(0)
Platform level boarding?	Yes (1)/No (0)
Fare collection location?	On station (1)/In vehicle (0,5)

The weights are together with all scores presented in Table D-2.

Table D-2: Assessment of reliability of set of reference systems

	Signal priority	Level of segregation	Platform level boarding	Fare collection location	Reliability score
Weight	0,4	0,4	0,1	0,1	
Rouen	0,5	0	1	0,5	0,4
Utrecht	0,5	0,5	1	0,5	0,6
Almere	0,5	0,5	1	0,5	0,6
Urumqi	0	0,5	1	1	0,4
Metz	0,5	0,5	1	1	0,6
Nantes	0,5	0,5	1	0,5	0,6
Paris	0,5	1	1	0,5	0,8
Beijing	0,5	0,5	1	1	0,6
Changzhou	0	0,5	1	1	0,4
Los Angeles	0,5	0,5	1	1	0,6
Johannesburg	0	0,5	1	1	0,4
Mexico City	0,5	0,5	1	1	0,6
Lanzhou	0,5	0,5	1	1	0,6
Nagoya	1	1	1	1	1,0
Istanbul	1	1	1	1	1,0
Guangzhou	0,5	0,5	0,5	1	0,6
Bogota	0,5	1	1	1	0,8
Amsterdam	0,5	1	1	0,5	0,8
Brisbane	1	1	0,5	0,5	0,9

Appendix E Evaluation of the set of reference systems

To analyze the performance of the reference systems, more diagrams are constructed than presented in Chapter 3. This Appendix presents these diagrams. Due to lack of time, a share of these diagrams is not assessed in detail. However, since this data was collected and the diagrams were constructed, these are presented for archival purposes.

Figure E-1 presents the relation between the operational speed and the percentage of dedicated infrastructure.

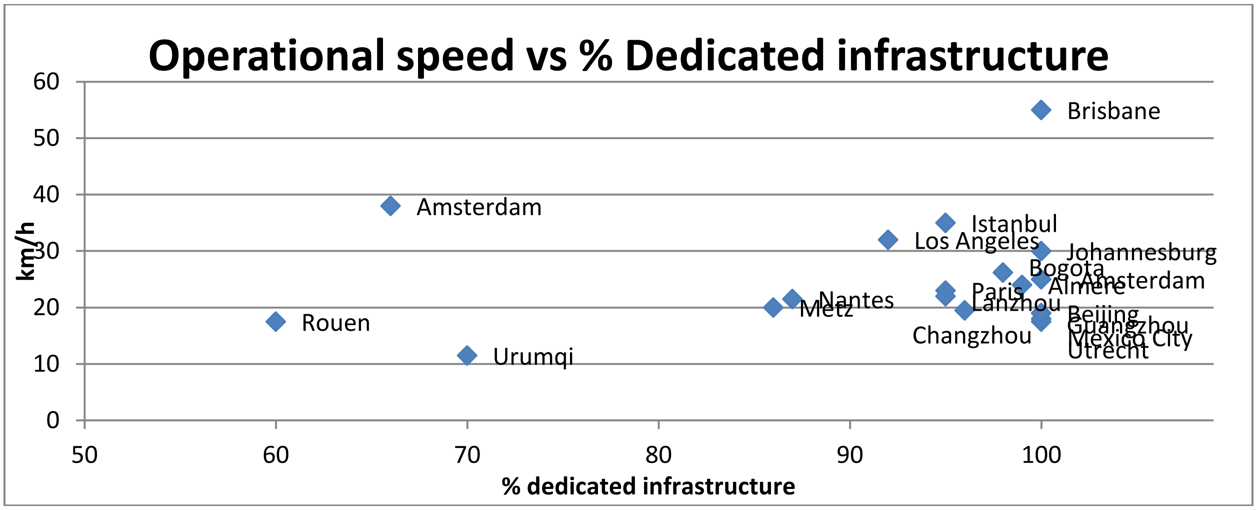


Figure E-1: Relation between the operational speed and the percentage dedicated infrastructure

Figure E-2 presents the relation between the operational speed and the level of segregation of the infrastructure. A value of 1 indicates mixed traffic operations, a value of 2 indicates segregated infrastructure but intersections with other traffic and a value of 3 indicates grade separated on intersections.

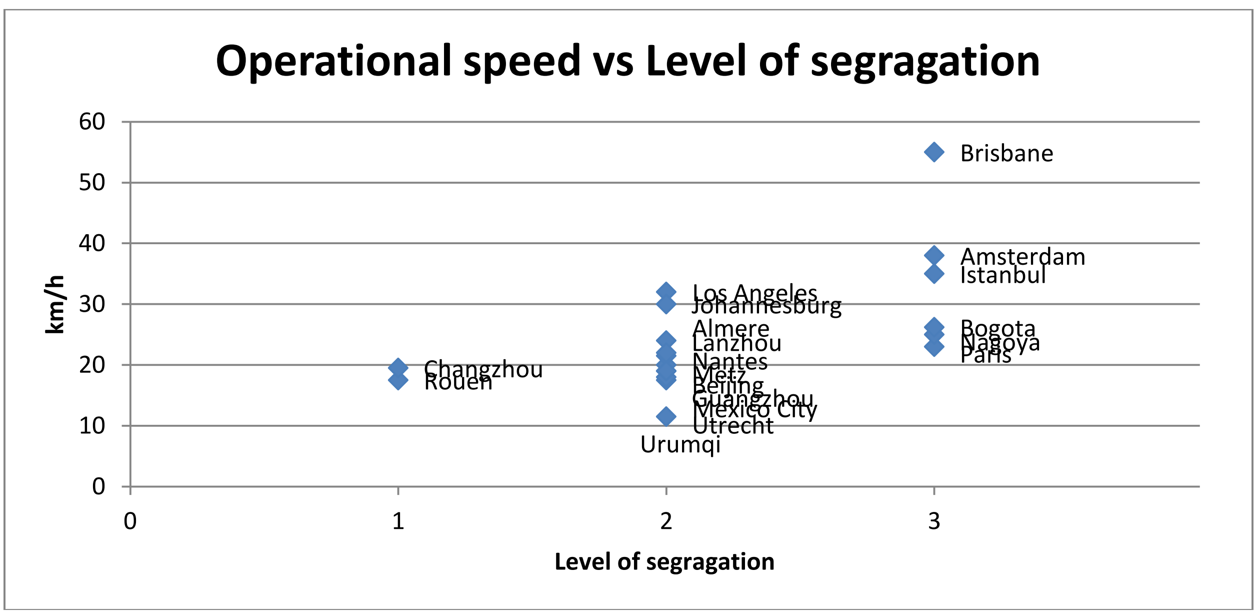


Figure E-2: Relation between the operational speed and the level of segregation

Figure E-3 presents the relation between the operational speed, the stop spacing and the level of segregation of the infrastructure.

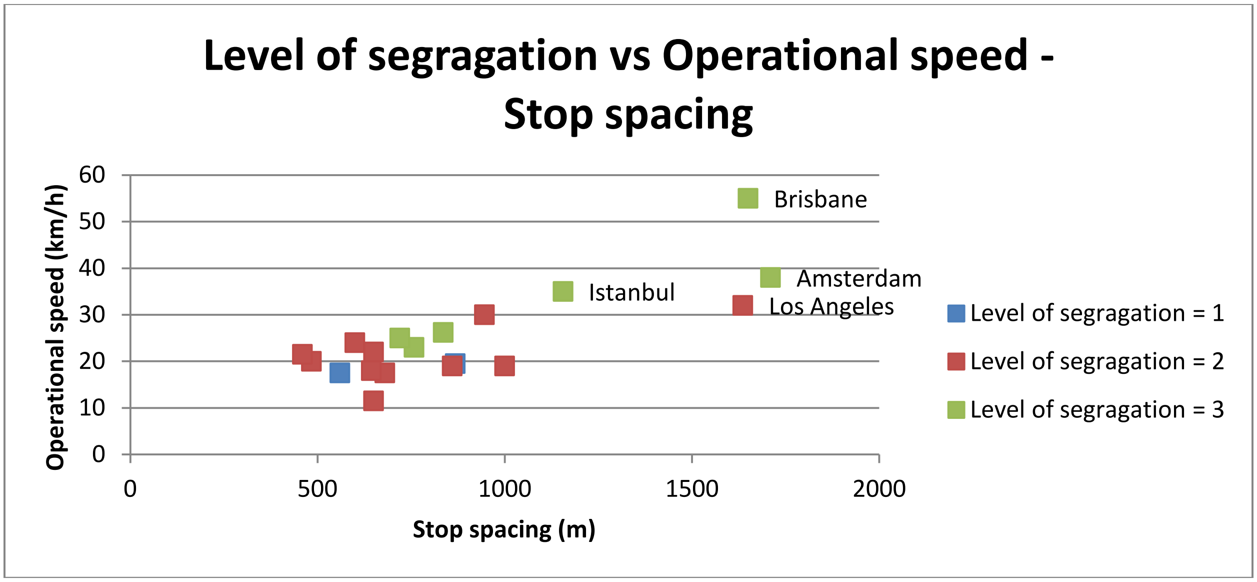


Figure E-3: Relation between the level of segregation, the operational speed and the stop spacing

Figure E-4 presents the relation between the operational speed, the stop spacing and the type of signal priority. The numbers indicate: no signal priority (1), fixed signal priority (2), dynamic signal priority (3), and grade separated intersections (4)

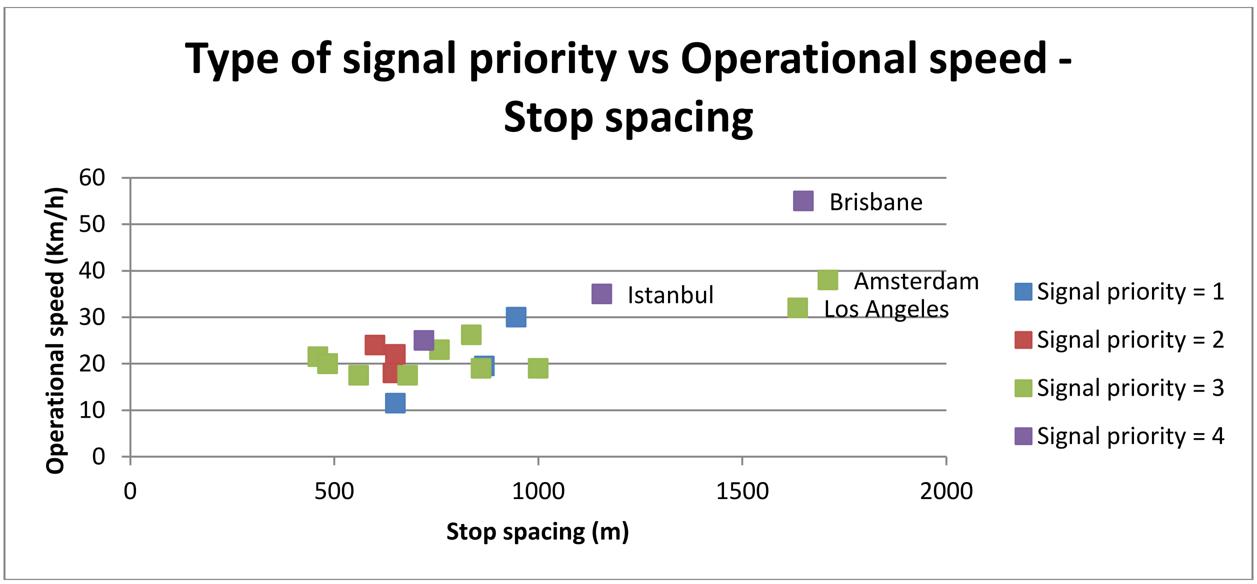


Figure E-4: Relation between the type of signal priority, the operational speed and the stop spacing

Figure 3-10 presented the regression function of the stop spacing and the operational speed. Figure E-5 presents an alternative way of relating these two variables. The stop spacing is divided by the operational speed and presented as index values.

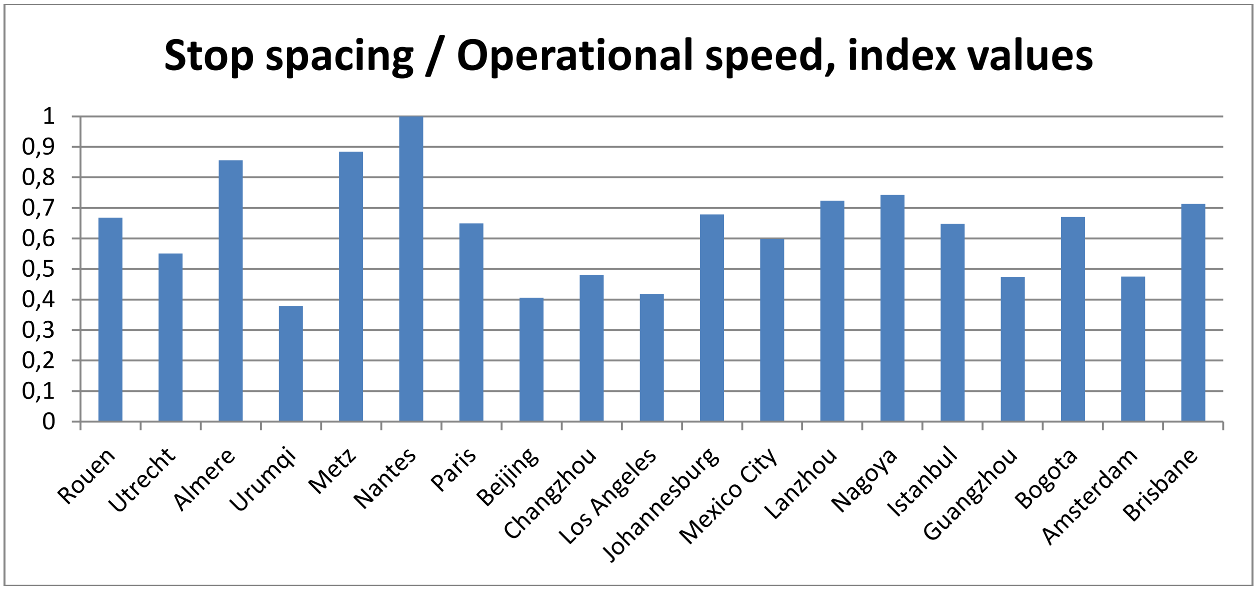


Figure E-5: Relation between the stop spacing and the operational speed displayed by index values

Figure E-6 relates the passengers per day to the urban area the systems are located in. Bogota is removed; with its characteristics (112 km, 2,185 million passengers per day) it distorts the diagram.

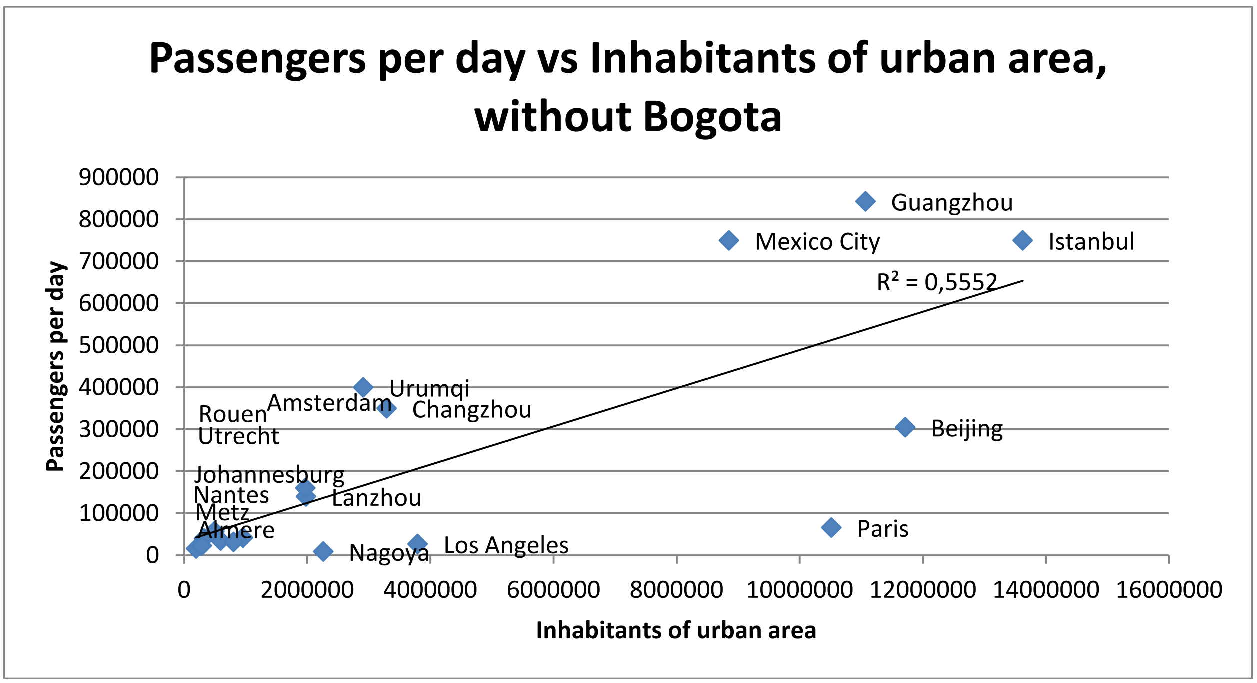


Figure E-6: Relation between the passengers per day and the inhabitants of the urban area

Another way of presenting this data is by comparing the ratio between these two values. This ratio is indicated as the market share of the BRT system. As was presented in the causal diagram in 3.2.2, this ratio is influenced by a lot of factors, among other:

- Availability and quality of other modes
- Quality of the service

- Network size
- Network shape (only radial or tangential lines)

This is only a rough estimation. The definition of the sphere of influence of the system is based on the size of the urban area the system is located in. The location within this area however determines the real sphere of influence. Paris for instance, a city with around 11 million inhabitants consists of a BRT line in the south of the city. People in the northern part of the city presumably never use the line, although they are taken into account in this ratio. Also the passengers per day are not necessary originating from the urban area. In Utrecht for instance, a lot of students arrive by train in Utrecht and subsequently take the considered BRT line. Figure E-7 presents the identified market shares.

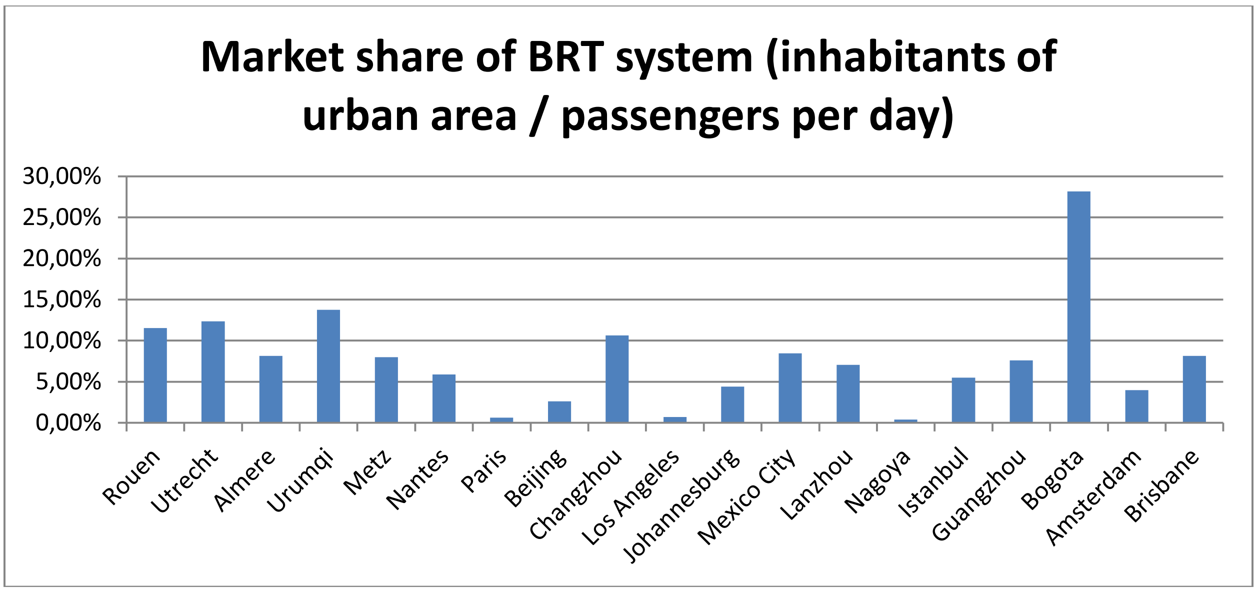


Figure E-7: Market share of the BRT systems of the set of reference systems

Figure E-8 present the relation between the network size and the number of passengers per day. Bogota is removed, with its characteristics (112 km, 2,185 million passengers per day), it distorts the diagram.

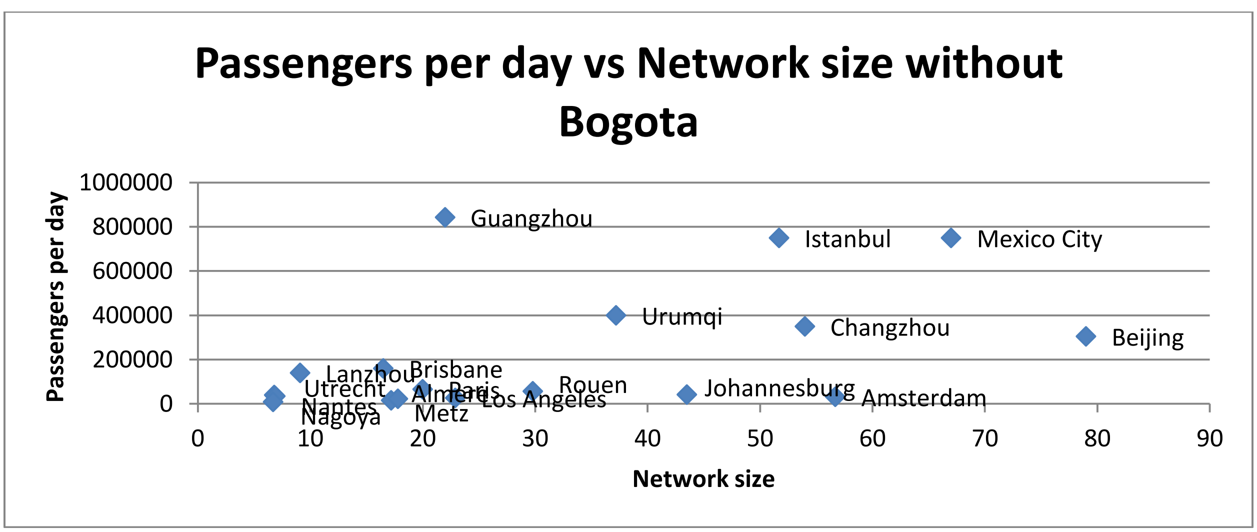


Figure E-8: Relation between the passengers per day and the network size

Figure E-9 and Figure E-10 present the relation between the passengers per day and the network length, and between the passengers per hour and the network length.

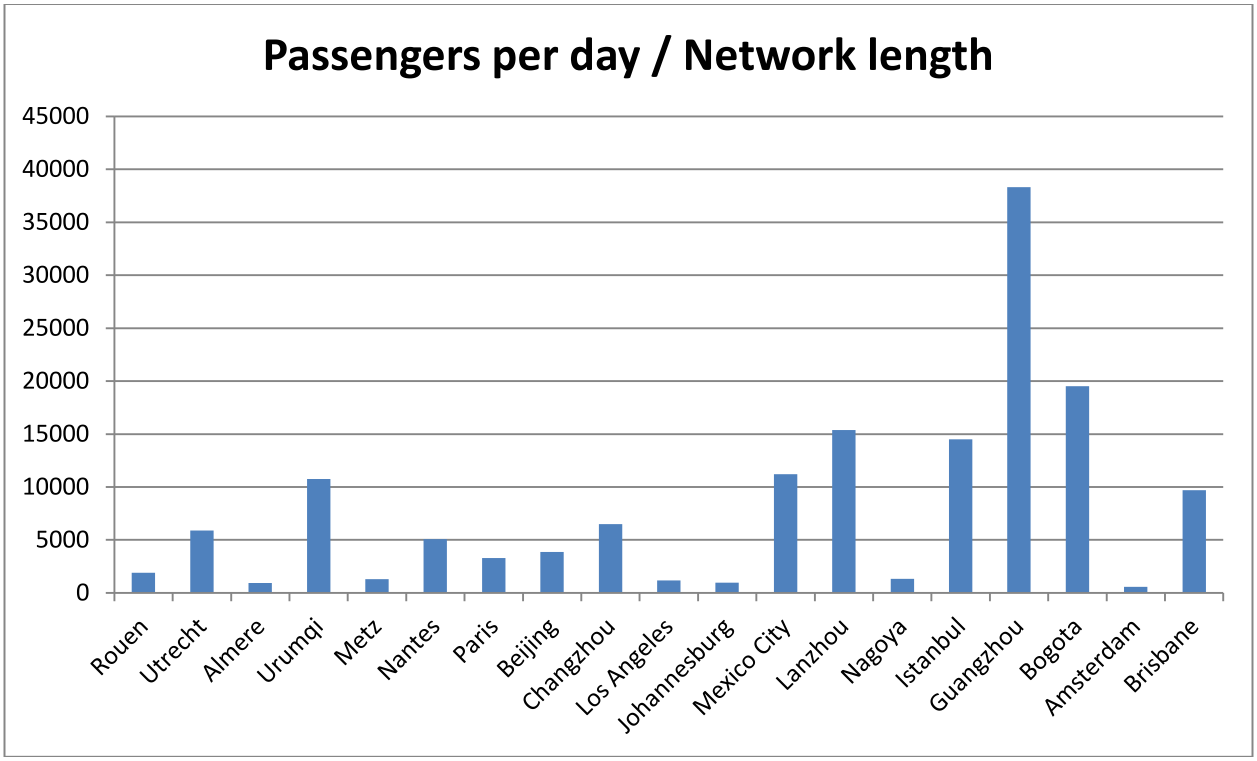


Figure E-9: Relation between the passengers per day and the network size

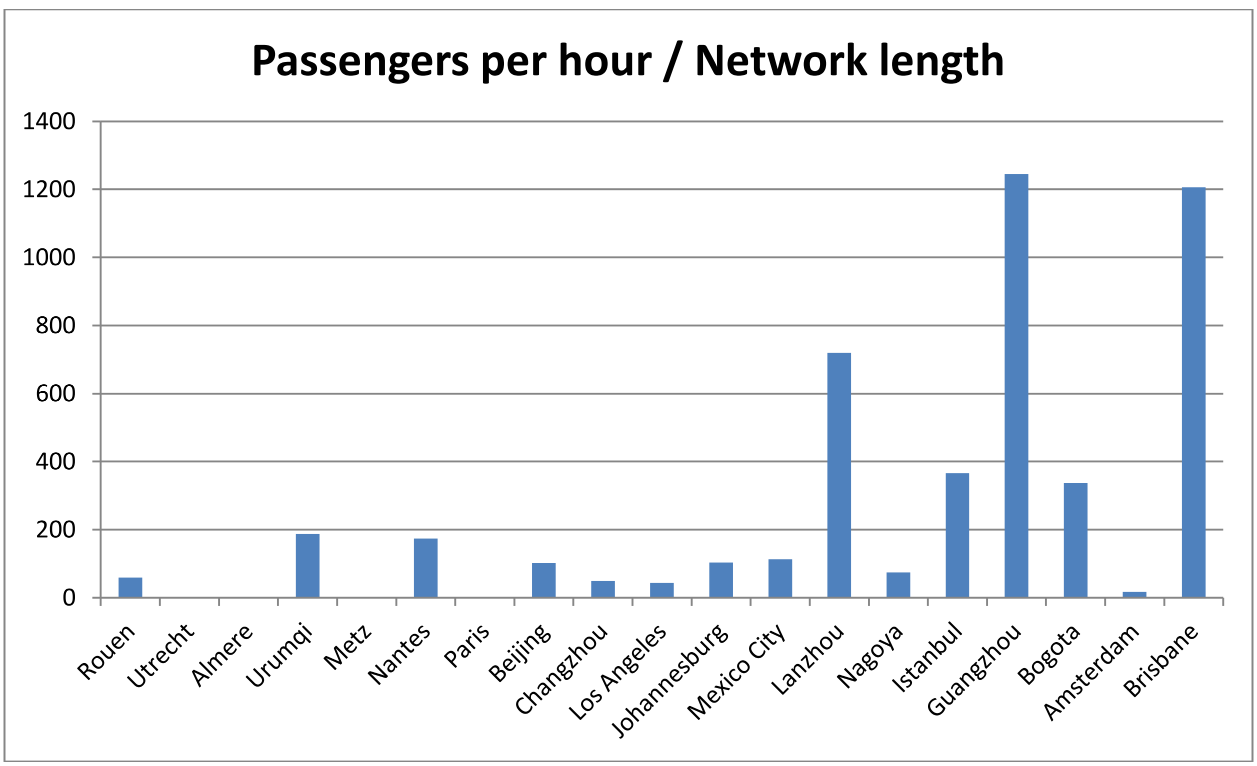


Figure E-10: Relation between the passengers per hour and the network length

Appendix F Determination of output values in the BRT Design model

This appendix presents an overview of how the values of each of the output variables are determined in the BRT design model. The output values are based on:

- Input variables – system characteristics
- Input variables – policy context
- Result of other output variables

In case is the stop spacing is referred to as input variable, this variable is based on the *number of stations* and *length of trajectory*.

F.I Type of infrastructure

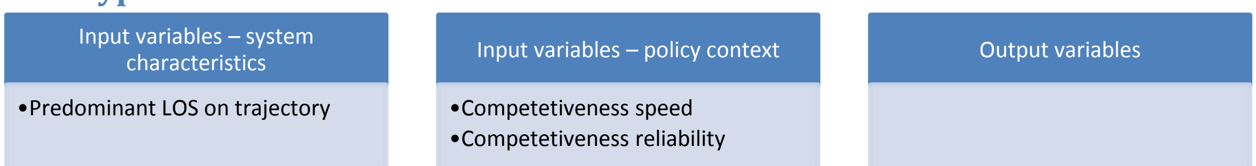


Figure F-1: Variables influencing the type of infrastructure in the BRT design model

- **Predominant LOS on trajectory.** As presented in Figure F-2, the entered LOS on the trajectory is directly linked to a type of infrastructure

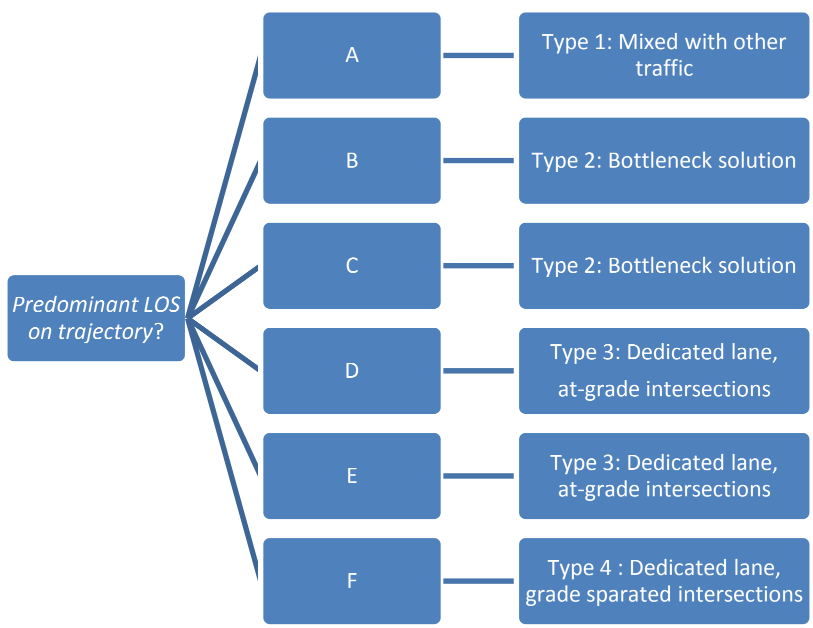


Figure F-2: Determination of infrastructure type based on LOS

This type of infrastructure, based on the predominant LOS on the trajectory, is an intermediate result. Also, the sum the input values of the two policy context variables (both associated with a score between 1 and 3) are computed. This is indicted in Figure F-3. Finally, based on the choice for the type of infrastructure (based on the LOS) and the sum of the competitiveness scores, the preferred type of infrastructure is defined. This is indicated in Table F-1.

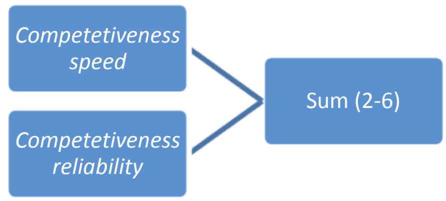


Figure F-3: Sum of competitiveness scores related to the policy context

Table F-1: Final determination of type of infrastructure

Choice of type based on LOS	Sum of competitive-ness scores	**Final choice for type of infrastructure**	Choice of type based on LOS	Sum of competitive-ness scores	**Final choice for type of infrastructure**
1	2	**1**	3	2	**3**
1	3	**1**	3	3	**3**
1	4	**2**	3	4	**4**
1	5	**2**	3	5	**4**
1	6	**2**	3	6	**4**
2	2	**2**	4	2	**3**
2	3	**2**	4	3	**3**
2	4	**3**	4	4	**4**
2	5	**3**	4	5	**4**
2	6	**3**	4	6	**4**

F.II Type of intersection

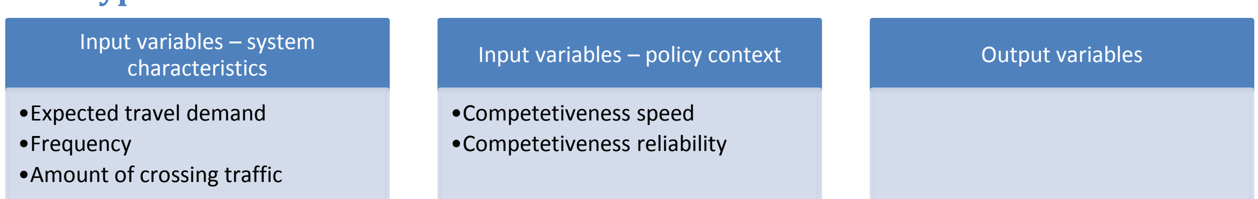


Figure F-4: Variables influencing the type of intersection in the BRT design model

The travel time losses for bus travellers, the travel time losses for car users, the costs of the solution and the policy context determine the type of intersection that is preferred. For the formulation of the model all these aspects are taken into consideration. For each type of intersection the following cost components are determined:

- Costs for car users in case of the specific intersection type
- Costs for bus users in case of the specific intersection type
- Infrastructure costs

When summing these cost components for each of the intersection types, the least expensive type can be determined. Also the policy context is taken into account. Therefore, the least expensive type is subsequently adjusted to the importance the user of the model attaches to the speed and reliability of the service.

For the determination of the cost components, the analogy with a railway crossing is used. To indicate the time a railway crossing is closed, the so called closing times can be used. The longer this period, and the more often this happens per hour, the bigger the impact on car users and other slow traffic. This concept is adapted to an intersection between a flow of busses and a flow of cars. Figure F-5 indicates this principle.

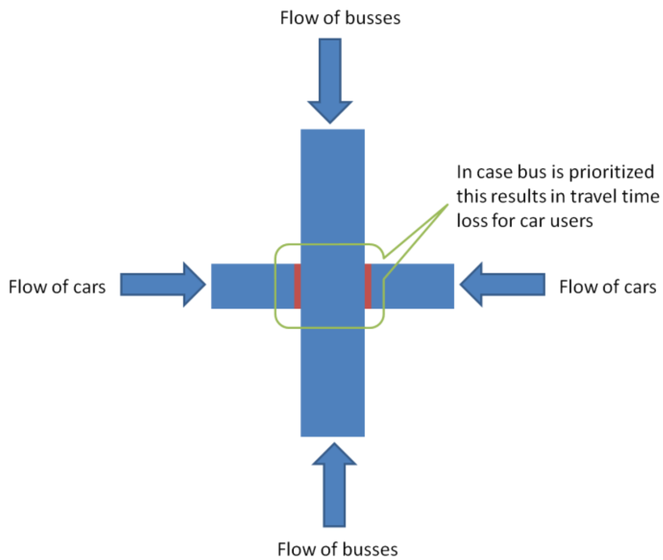


Figure F-5: Visualization of the closing time of the intersection

F.II.I Costs for car users

The costs for car users are determined by:

- **Closing time.** Each type of intersection is associated with a specific closing time. For type 4, because busses do not interact with other traffic, the closing time is zero seconds. For type 1, although there is no priority, the bus still interferes with car traffic flowing in the same direction. Since this situation is worse than in case of implementing type 4, the closing time for type 1 is set at three seconds. For type 2 and type 3, 15 seconds are assumed as time the intersection is closed. Table F-2 summarizes these values.

Table F-2: Closing times associated to the different intersection types

	Type 1	Type 2	Type 3	Type 4
Closing time (s)	3	15	15	0

- **Crossing traffic per hour (sum of both directions).** An arrival rate (λ) is assumed which is uniformly distributed over time. This arrival rate (λ) is translated in an inter arrival time (τ): $\tau = \lambda/3600$.

$$Total\ travel\ time\ lost\ for\ car\ users\ because\ of\ closed\ intersection: \int_{t=closing\ time}^{0} \tau * t$$

In the BRT design model, the user can in define the volumes of crossing traffic for the intersections present on the trajectory (volumes are limited to six predefined categories). Table F-3 presents the arrival rates and inter arrival times associated with these traffic demands.

Table F-3: Arrival rates and inter arrival times related to the predefined traffic flows

Crossing traffic per hour (vehicles per hour)	Assumed arrival rate(λ)	Inter arrival time (τ)
<200	100	0,03
200-500	350	0,10
500-1000	750	0,21
1000-1500	1250	0,35
1500-2000	1750	0,49
>2000	3000	0,83

- **Frequency (sum of both directions).** Determines number of times the intersection is closed.
- **Average number of people per vehicle.** Based on (Otten, 't Hoen, & den Boer, 2014) set at 1,39.
- **Operational hours per day.** Set at 10 hours. In reality this is generally more, however, this value is used to be able to define the arrival rate for the peak hour (as indication for a peak hour, an average of 10% of the daily traffic is used).
- **Days per year.** Set at 350 days per year. This is to correct for lesser occupied days over the year.
- **Value of time (system parameter) (euro/hour).** Based on (KiM, 2013) set at 9,25.
- **Investment period.** The numbers of years the investments are considered for.

➔ *Costs for car users = cumulative time lost because of closed intersection ∗ frequency ∗ operational hours per day ∗ days per year ∗ investment period ∗ average number of people per vehicle ∗ value of time*

F.II.II Costs for bus users

The costs for bus users are determined by:

- **Expected travel demand per day.** Sum of the number of bus passengers per day in both directions.
- **Delay for bus users.** The travel time lost for a passenger inside a bus, when traversing a certain type of intersection. In case of type 1, the time lost at an intersection is set at 25 seconds (based on average level of service (C) as found in (Urban kchoze, 2015)). In case of type 2, less time is lost, but since there is still some interaction with other traffic, a delay of 15 seconds is assumed. In case of the other two types, there is no interaction with other traffic and the delay is set at 0 seconds. Table F-4 summarizes these values.

Table F-4: Delay for bus users associated to the different intersection types

	Type 1	Type 2	Type 3	Type 4
Delay for bus users (s)	25	15	0	0

- **Operational hours per day.** Set at 10 hours. In reality this is generally more, however, this value is used to be able to define the arrival rate for the peak hour (as indication for a peak hour, an average of 10% of the daily traffic is used).
- **Days per year.** Set at 350 days per year. This is to correct for lesser occupied days over the year.
- **Value of time (euro/hour).** Based on (KiM, 2013) set at 9,25.

➔ $Costs\ for\ bus\ users = expected\ travel\ demand\ per\ day * delay\ for\ bus\ users * operational\ hours\ per\ day * days\ per\ year * investment\ period * value\ of\ time$

F.II.III Infrastructure costs

Table F-5 presents the assumed average infrastructure costs for the four types of intersections:

Table F-5: Infrastructure cost associated to each of the intersection types

	Type 1	Type 2	Type 3	Type 4
Infrastructure costs (€)	100.000	500.000	1.000.000	5.000.000

F.II.IV Assessment of applicable intersection type

As is presented in Figure F-6, the three cost components together determine the total costs for each of the intersection types. Additionally, as is indicted in Figure F-7, also the sum the input values of the two policy context variables (both associated with a score between 1 and 3) are computed. Finally, based on least expensive type of intersection and the sum of the competitiveness scores, the preferred type of intersection is defined. This is indicated in Table F-6.

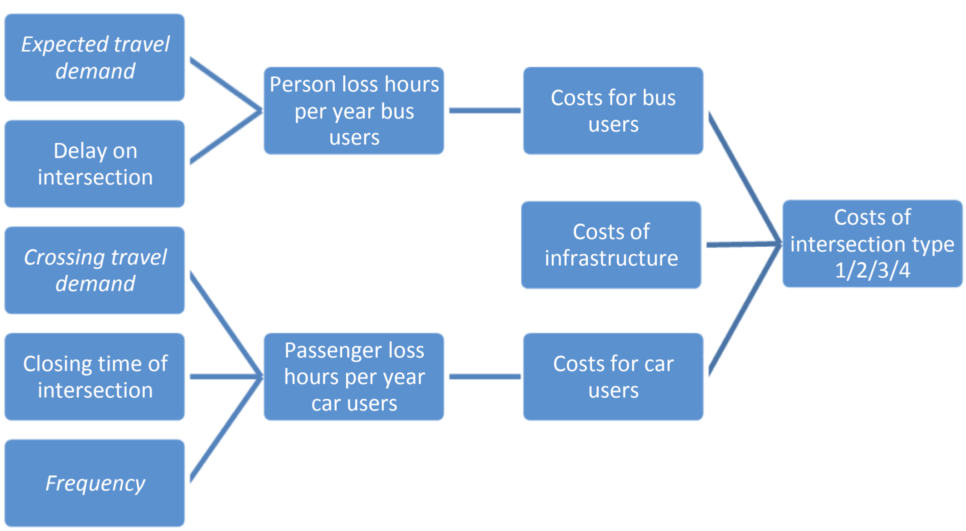


Figure F-6: Determination of infrastructure type based on the different cost components

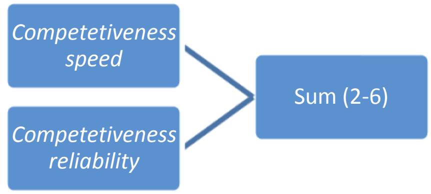


Figure F-7: Sum of competitiveness scores related to the policy context

Table F-6: Final determination of type of intersection

Choice of type based on costs	Sum of competitive-ness scores	**Final choice for intersection type**	Choice of type based on costs	Sum of competitive-ness scores	**Final choice for intersection type**
1	2	**1**	3	2	**3**
1	3	**1**	3	3	**3**
1	4	**2**	3	4	**4**
1	5	**2**	3	5	**4**
1	6	**2**	3	6	**4**
2	2	**2**	4	2	**3**
2	3	**2**	4	3	**3**
2	4	**3**	4	4	**4**
2	5	**3**	4	5	**4**
2	6	**3**	4	6	**4**

F.III Open or closed system

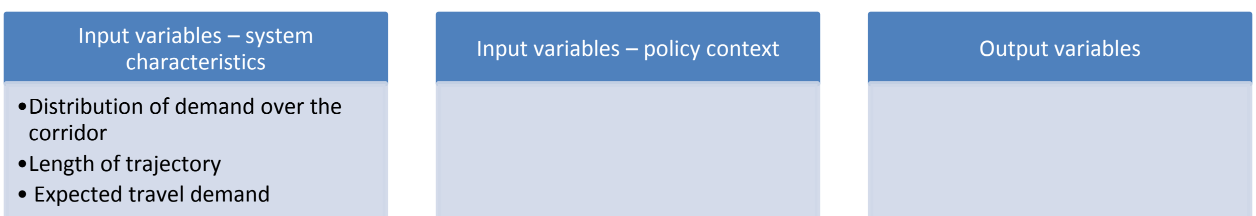


Figure F-8: Variables influencing the type of system (open or closed) in the BRT design model

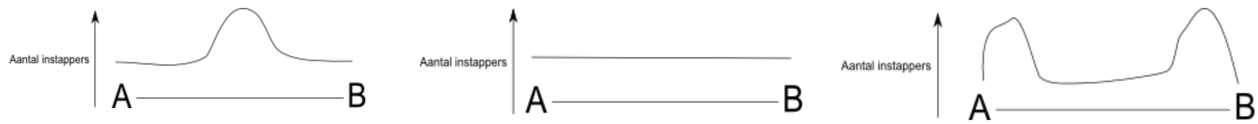
(ITDP, 2007) states that a trunk/feeder or trunk-only service is likely effective under the following conditions:

- Main corridors have relatively high demand
- Population densities are significantly different between different areas of the city
- The distance between the city centre and the feeder areas is relatively far (e.g. 10 km)

These three statements are all verified in the BRT design model based on the following three input variables:

- **Expected travel demand.** A relatively high demand is assumed to be 10.000 travellers per day (sum of both directions).

- **Distribution of demand over corridor.** Three different distributions of the travel demand over the corridor are identified (A/B/C) (see Figure F-9). Population densities are assumed to be significantly different when *Distribution A* or *Distribution C* is entered.



Distribution A **Distribution B** **Distribution C**

Figure F-9: Different distributions of the demand over the indentified corridor

- **Length of trajectory.** 10 km is assumed as boundary.

Figure F-10 and Figure F-11 visualize the way this decision is made.

Figure F-10: Verification if travel demand is sufficient to eventually operate a closed system

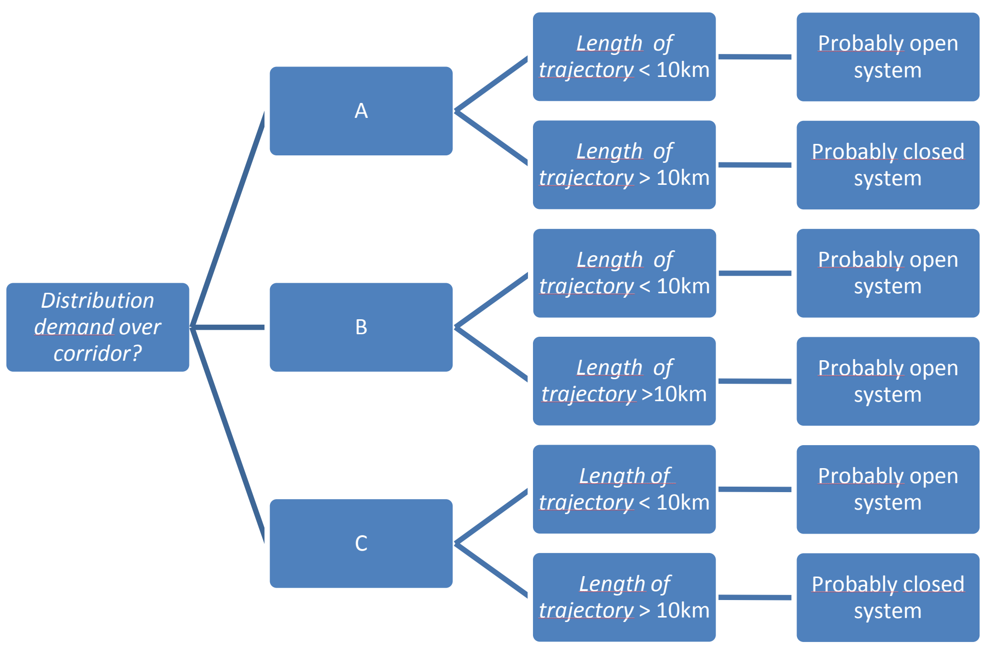


Figure F-11: Final determination of the decision for an open or closed corridor based on the distribution of the travel demand and the length of the corridor

F.IV Express service

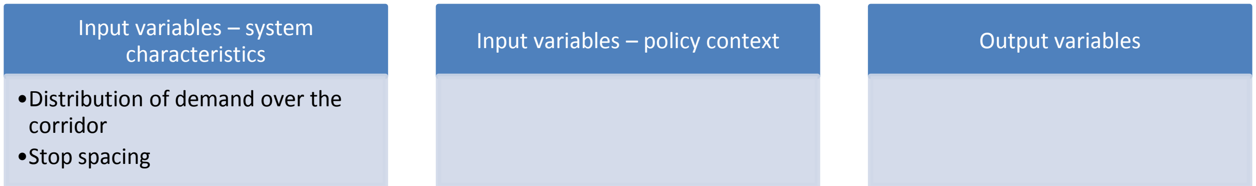


Figure F-12: Variables influencing the decision for an express service in the BRT design model

- **Distribution of the demand over the corridor.** As input variable, the user makes the decision for a distribution of the demand (A/B/C) that represents best the analyzed situation. In case there is a significant difference in the distribution of the demand over the corridor (case A and case C), there are 'important stops' and 'less important stops'. Serving only the most important stops can result in travel time benefits for a large share of the travellers. An express service therefore might be a good option.
- **Stop spacing.** In case of a short stop spacing, the speed is generally also low. Skipping stops in this situation can result in a relatively greater increase in speed than in case of a longer stop spacing. Intuitively, an increase in speed from 15 to 20 km/h is valued as more important, than an increase from 40 to 45 km/h. Also, because the impact of skipping a stop on the access and egress time is much smaller in case of a short stop spacing, the resistance to skip a stop will be much lower. To include this fact into the BRT design model, a stop spacing of 1000 m is assumed for which an express service is still attractive.

Figure F-13 visualizes this decision for an express service.

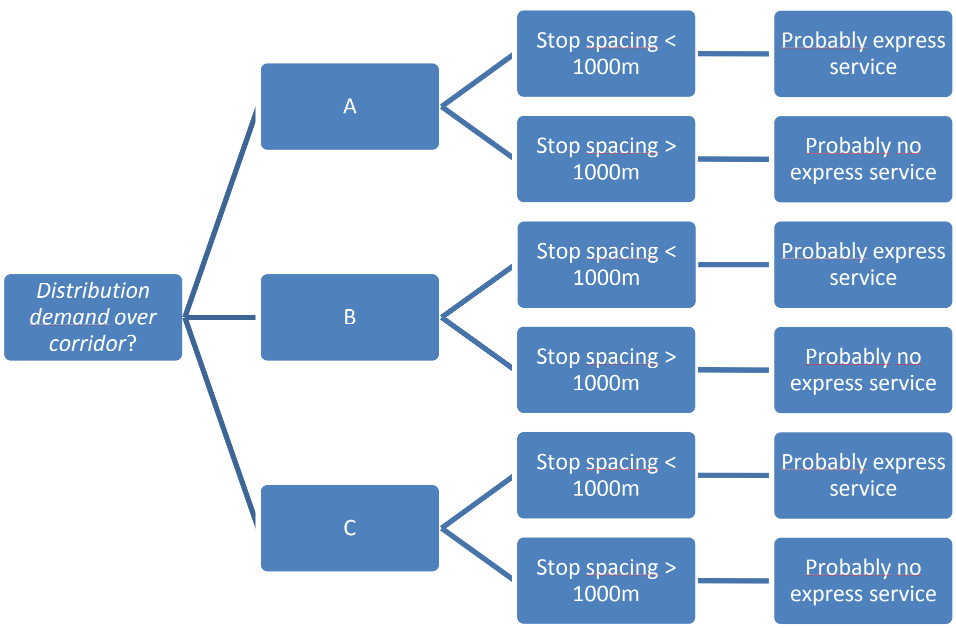


Figure F-13: Overview of the way the decision for an express service is made in the BRT design model

F.V Branding of elements

Figure F-14 presents the variables that influence the decision for the branding of elements in the BRT design model.

Input variables – system characteristics	Input variables – policy context	Output variables
		• Open or closed system

Figure F-14: Variables influencing the branding of elements in the BRT design model

The decision for an open or closed system determines the elements that should be branded. In case of an open corridor, one should strive to brand the stations; in case of a closed corridor it is important to brand both the stations and the vehicles. Figure F-15 visualizes the way this decision is made.

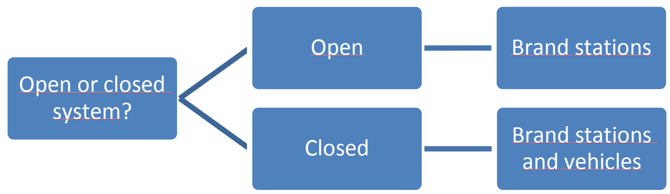


Figure F-15: Overview of the way the decision for the elements to brand is made in the BRT design model

F.VI Position in market

Input variables – system characteristics	Input variables – policy context	Output variables
	• Other succesfull high quality public transport services nearby?	

Figure F-16: Variables influencing the way the system is positioned in the market in the BRT design model

In case there are already existing high quality public transport services nearby, one is advised to look into the possibilities to connect. In case there is no high quality public transport service nearby, one is advised to differentiate the system. Figure F-17 visualizes the way this decision is made:

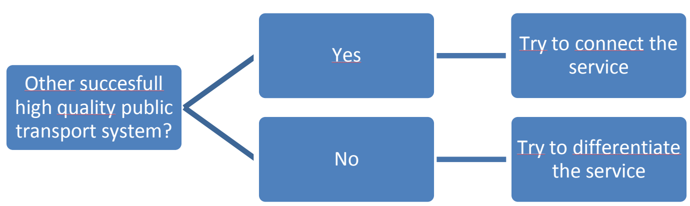


Figure F-17: Overview of the way the system should be positioned in the market is made in the BRT design model

F.VII Access and egress transport by bicycle

Input variables – system characteristics	Input variables – policy context	Output variables
• Stop spacing		

Figure F-18: Variables influencing the importance of facilities stimulating the access and egress transport by bicycle in the BRT design model

A lot of factors determine the share of people accessing the system by bicycle. The stop spacing is an important indicator of the speed and with that of the catchment area of the public transport system.

According to (Kennisplatform Verkeer en Vervoer, 2006) and (Murray & Wu, 2003), a travel time of 5 minutes to a regular bus stop is by people seen as reasonable. Assuming a walking speed of 5 km/h, and a correction for the street pattern of 30% (people are bound to follow the street pattern when accessing a stop, this distance travelled is longer than the distance the crow flies). 5 minutes walking corresponds to a catchment area of 300 m. This corresponds to a stop spacing of 600 m. This 600 m is used as the first boundary value. In case of a stop spacing greater than 600 m, the bicycle parking facilities become increasingly more important. As final boundary value, 1200 m assumed. Table F-7 presents these assumed boundaries and Figure F-19 summarizes the way the design decisions are made.

Table F-7: Assumed boundaries for the stop spacing when determining the need for bike parking facilities

Stop spacing	**Bicycle parking facilities are**
Stop spacing < 600m	Not particularly important
Stop spacing 600-1200m	Important
Stop spacing > 1200m	Necessary

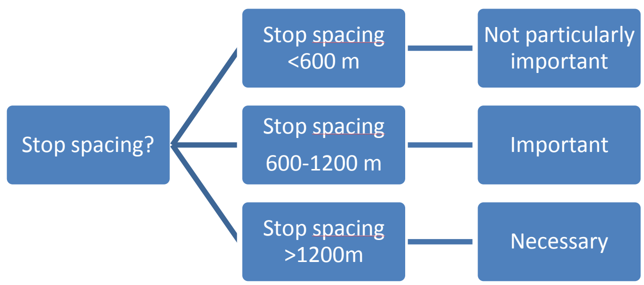


Figure F-19: Overview of the way the importance of bike parking facilities is made in the BRT design model

F.VIII Passing opportunities

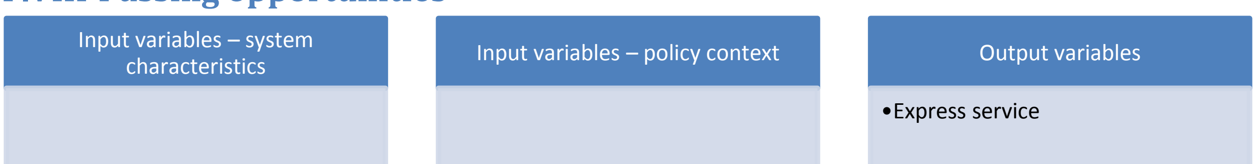


Figure F-20: Variables influencing the need for passing opportunities in the BRT design model

In case express service is suggested a passing opportunity might be needed, in case no express service is suggested no passing opportunity is needed. Figure F-21 below visualizes this consideration.

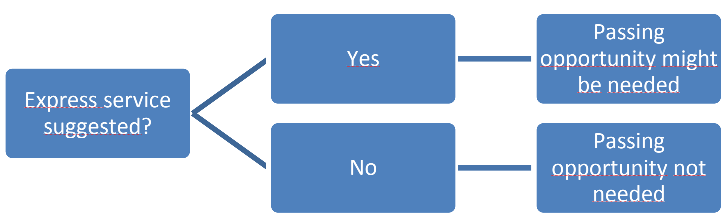


Figure F-21: Overview of the way the need for a passing opportunity is made in the BRT design model

F.IX Indication of operational speed

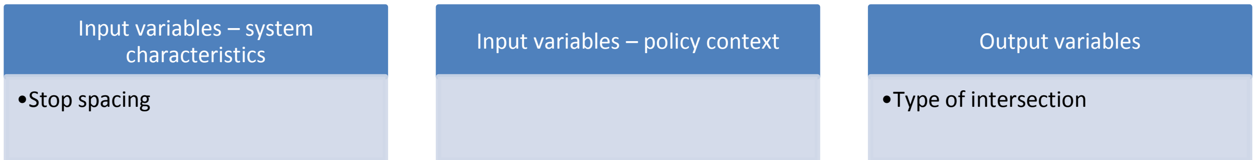


Figure F-22: Variables influencing the indication of the operational speed in the BRT design model

The operational speed is computed based on the stop spacing and on the type of intersections that are suggested.

Stop spacing. Figure 3-10 indicated the relation between the stop spacing and the operational speed in the set of reference systems. Nearly all of these researched systems have a form of signal priority or grade separated intersections. It was identified that the only exceptions are a few Chinese systems; here the priority is either not implemented or not functioning properly. These systems can be clearly identified by lying clearly under the trend line in Figure 3-10. To be able to determine for a system consisting of properly functioning signal priority or grade separated intersections, the relation between the operational speed and the stop spacing, Urumqi, Changzhou, Beijing and Guangzhou are deleted.

The new function following from this regression is: *Speed = 0,0198 * stop spacing + 8,7274.* Because in this formula, in case of a stop spacing of 0 m, the speed is 8,7 km/h, an additional function is used for the stop spacing range between 0 and 400 meter: *Speed = 0,045 * stop spacing.*

Type of intersection. The functions above are irrelevant in case intersections without priority are suggested (type 1). In case these are suggested the speed is reduced. This reduced is dependent on the number and the intensity of the crossing traffic flows. The total extra time (translated into speed by using the length of the trajectory) travelled is computed as presented in Table F-8.

Table F-8: Assumed average time lost at an intersection for the identified traffic flows

Crossing traffic flow (vehicles/hour)	<200	200-500	500-1000	1000-1500	1500-2000	>2000
Average time lost on intersection (sec)	20	30	30	30	30	40

The time lost on an intersection of type 1 is dependent on the flow of vehicles crossing the bus corridor. This distinction is made because, in case of a greater flow of crossing traffic, it is assumed the level of service is lower. This flow of crossing traffic is assumed to impact the length and number of phases on an intersection. Also in the chance of standing over is likely improved. The average time lost is inspired on (Urban kchoze, 2015). Figure F-23 below summarizes the way the indication of the operational speed is determined.

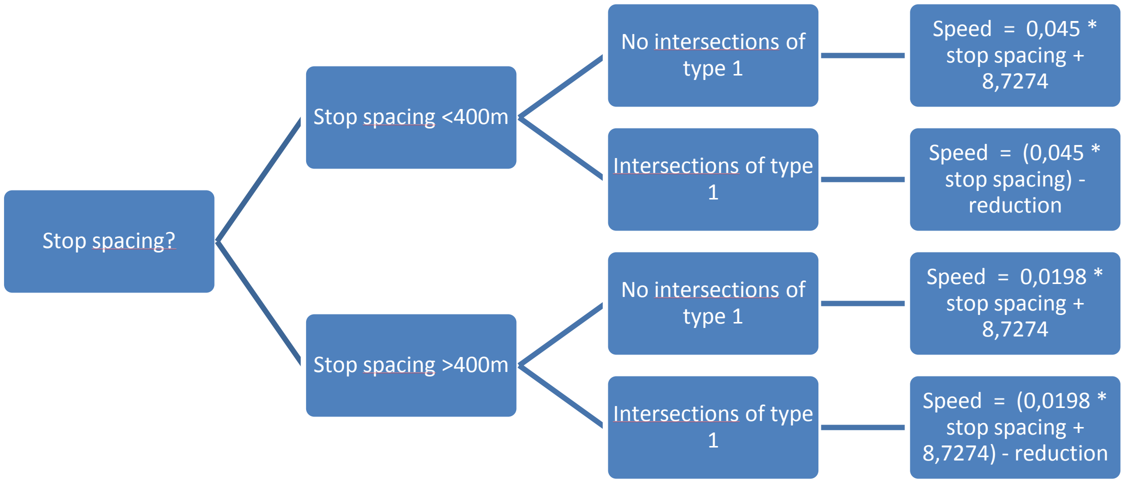


Figure F-23: Overview of the way the indication of the operational speed is made in the BRT design model

F.X Indication of reliability

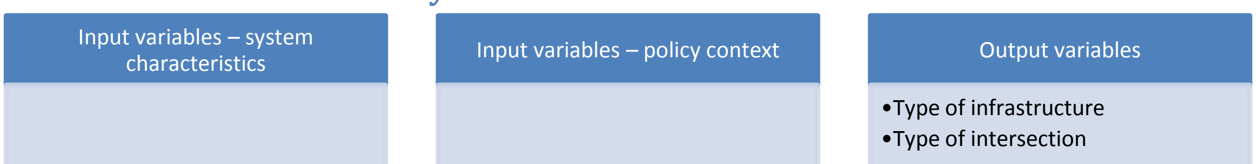


Figure F-24: Variables influencing the indication of the reliability in the BRT design model

The two design variables: type of infrastructure and type of intersection determine in this model the level of reliability. Both are assigned a score in the range of 1 to 4. Subsequently the sum (in the range 2 to 8) gives an indication of the level of reliability.

Type of infrastructure. In case of type 1 a score of 1 is assigned, in case of type 2 a score of 2 is assigned, etc.

Type of intersection. Because on a trajectory different types of intersections can be advised, a weighted average type of intersection is determined. The number of intersections of each type is multiplied with their score (1 in case of type 1, 2 in case of type 2, etc.). The total score is subsequently divided by the number of intersections. This value is rounded and forms the score for the type of intersection.

The sum of these two scores gives an indication of the level of reliability. These scores are translated to the different outputs according to Table F-9 below. Figure F-25 below summarizes the way the indication of the reliability is determined.

Table F-9: Translation of the type of infrastructure and the type of intersection in an indication of the reliability

Sum	Indication of reliability
2	Limited reliable
3	Limited reliable
4	Limited reliable
5	Predominantly reliable
6	Predominantly reliable
7	Very reliable
8	Very reliable

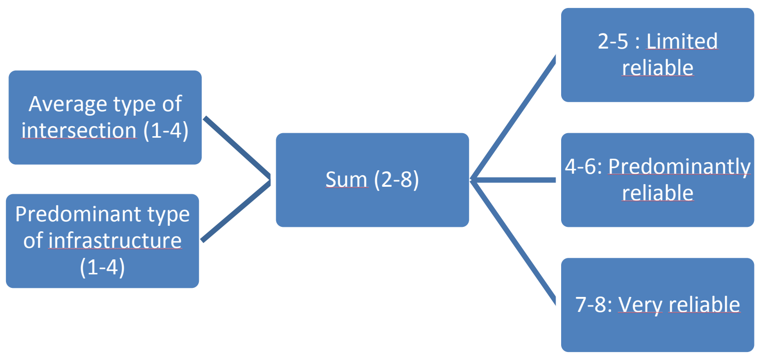


Figure F-25: Overview of the indication of the reliability is determined in the BRT design model

F.XI Indication of infrastructure costs

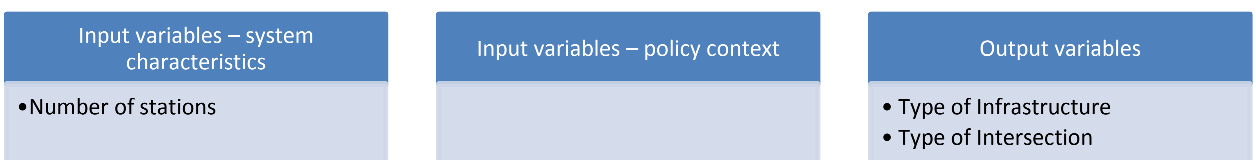


Figure F-26: Variables indication the infrastructure costs in the BRT design model

In practice a lot of factors impact these infrastructure costs. In this research, the infrastructure costs are based on the type of infrastructure, the type of intersections, the number of stations. Table F-10 displays the assumed costs.

Table F-10: Costs used to indicate the infrastructure costs in the BRT design model

	Type 1	Type 2	Type 3	Type 4
Costs of infrastructure (€/km)	200.000	300.000	1.000.000	2.000.000

	Type 1	Type 2	Type 3	Type 4
Costs of Intersections (€/km)	100.000	200.000	300.000	1.000.000

	Per pair
Costs of stations(€/pair)	450.000

Appendix G Public transport facilities in Utrecht and Leidsche Rijn

This appendix presents an overview of the characteristics of the public transport network of Utrecht and more specifically Leidsche Rijn.

G.I Public transport in Utrecht

With around 330.000 inhabitants, Utrecht is the fourth largest city of the Netherlands and an important node in the Dutch railway network (CBS, n.d.). Utrecht Central station is the serves around 230.000 passengers daily, the most of all Dutch stations (Treinreiziger.nl, 2009). This is much more than the other train stations of Utrecht, which do not serve intercity trains (trains used for the connection of larger stations, over larger distances and with a relatively high speed): Zuilen, Lunetten, Overvecht, Terwijde, Leidsche Rijn and Vleuten. This is one of the reasons there is a significant demand of travellers from the outskirts of Utrecht to the central station/city centre. The most important outskirts (associated with the largest demand) are connected to Utrecht CS by a HOV (Hoogwaardig Openbaar Vervoer) connection. HOV is a characterized by own bus and tram lanes, high quality vehicles and dynamic travel time information. It is applied to decrease car mobility and with that improve the accessibility, liveability and air quality of an area (Bennink, 2011). HOV is implemented on OD-relations with a high demand and which can be competitive with car transport. Leidsche Rijn, the study area, is one of the regions that is served by such a HOV connection. Figure G-1 presents the HOV-bus network of Utrecht. Additionally to these bus corridors, also a HOV-tram connection is present between Utrecht CS and Nieuwegein (southerly of Utrecht). From 2018 also a tram connection should be operational between Utrecht CS and the Uithof (easterly of Utrecht).

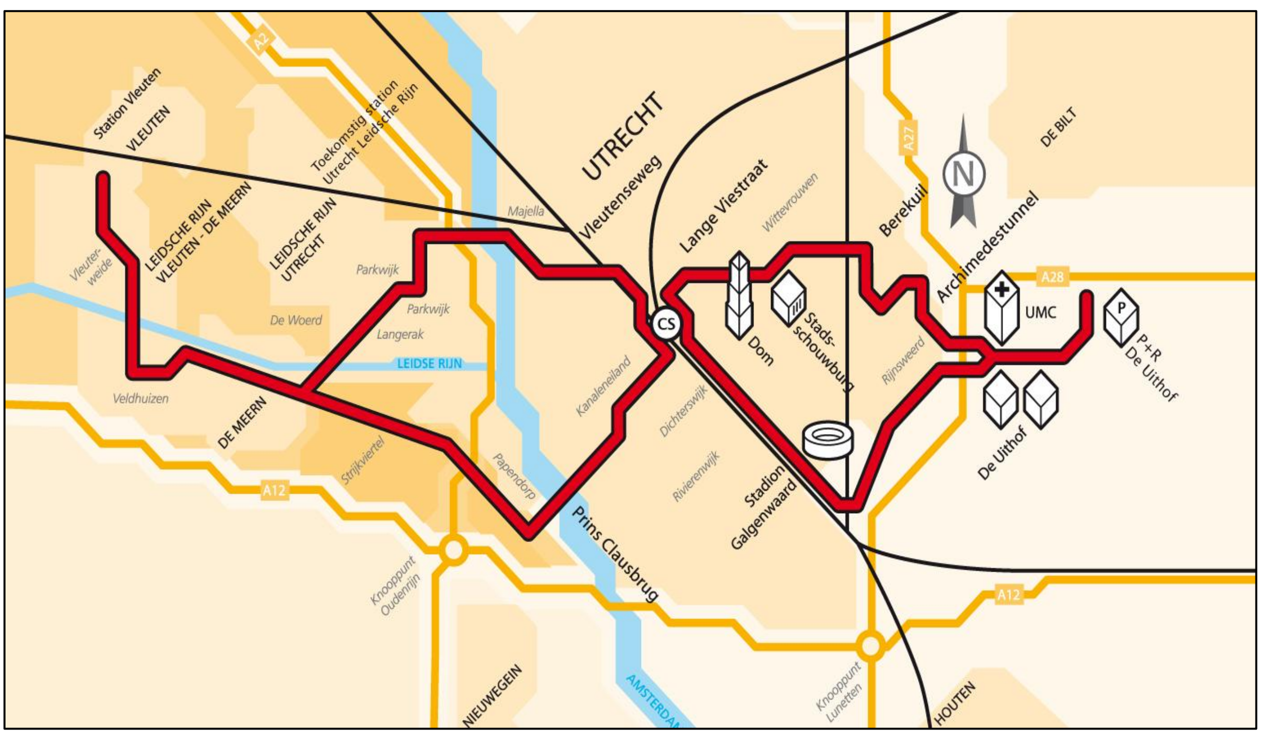


Figure G-1: HOV-bus network of Utrecht. Figure reprinted from (OV-magazine, 2014b)

G.II Public transport in Leidsche Rijn

Leidsche Rijn is a city district in the west of Utrecht with currently 74.000 inhabitants. The number of inhabitants has grown strongly over recent years and some sections are still under construction (Leidsche Rijn Centrum). After the projected finish in 2018 a fully fledged new city centre is created. In the considered area three train stations are located: Vleuten, Terwijde and Leidsche Rijn Centrum. As stated before, none of them are intercity stations. From Utrecht CS, Leidsche Rijn can be reached by bus via the north (28) or the south (24/102/103/107). These lines consist of mainly dedicated infrastructure and come together at De Meern Oost. Additionally several local bus lines are operated in the area.

Appendix H Input variables for BRT design scanner

This appendix presents the origin of the input variables of the bus service through Leidsche Rijn. This service is used to evaluate the quality of the constructed BRT design scanner.

H.I Input variables - Policy context

• Investment period	20 years
• Other successful high quality public transport service nearby?	Yes
• Competitiveness of the system compared to other modalities looking at speed?	Reasonably competitive
• Competitiveness of the system compared to other modalities looking at reliability?	Very competitive

Referring to the light rail connection to Nieuwegein (SUNIJ, the question regarding other high quality public transport services, is answered with *yes*. As assumption, the investment period is set at 20 years. The other two input variables are originating from an email conversation (14-04-2015) with Rob Tiemersma, consultant mobility at the Municipality of Utrecht.

H.II Input variables - System characteristics

- **Expected travel demand** **8.000**

This information is originating from the OD-matrices acquired from (Wegewijs, 2014b) (see Appendix N.II). According to this data, around 189.000 people travelled on the investigated corridor during the month March 2014. This data is originating from OV-chipcard registrations. Because some users are travelling without OV-chipcard, BRU (Wegewijs, 2014a) assumed this number is an underestimation of around 11%. March 2014 consisted of 21 workdays and 5 Saturdays and 5 Sundays. It is assumed that the average demand on weekday is twice the demand of a day in the weekend. Therefore, the resulting 210.000 monthly travellers are divided by 26 days. This results in around 8.000 travellers on an average workday.

- **Length of trajectory** **10,8 km**

This information is originating from a field measurement. Currently, the trajectory is slightly longer because of a detour in the station area. However, when these constructions works are finished, the original trajectory will be used again.

- **Frequency (peak, sum of both directions)** **20**

Table H-1 below presents the frequencies on the trajectory in both directions[13]. These frequencies are determined based on the schedule of the 1st of September 2013. The highest frequency is achieved on workdays between 7:30 and 9:00 on the trajectory De Meern Oost - Utrecht CS (12 vehicles per hour). This is the result of the addition of line 27, a support of line 28 on for this particular trajectory in the morning peak. Since the frequency is 8 vehicles per hour during this time frame in the opposite direction, a frequency of 20 vehicles per hour is used as input value.

[13] The 5 identified periods are chosen to align with the available driving time data as presented in N.I. The time frames inside the table are rounded on quarters.

Table H-1: Frequencies over the day on different sections of the trajectory of bus line 28

		05:45-7:00	7:00-9:00	9:00-16:00	16:00-18:00	18:00-23:59
Vleuten - De Meern	Workday	4	8	8	8	6
	Saturday	3	3 (7:00-8:00) 4 (8:00-9:00)	4 (9:00-9:30) 8 (9:30-16:00)	6	4
	Sunday	0	2 (7:30-9:00)	4 (9:00-11:00) 6 (11:00-17:00)	6 (16:00-17:00) 4 (17:00-18:00)	4
De Meern - Utrecht CS	Workday	4	8 (7:00-7:30) 12 (7:30-9:00)	8	8	6
	Saturday	3	3 (7:00-8:00) 4 (8:00-9:00)	4 (9:00-9:30) 8 (9:30-16:00)	6	4
	Sunday	0	2 (7:30-9:00)	4 (9:00-11:00) 6 (11:00-17:00)	6 (16:00-17:00) 4 (17:00-18:00)	4
Utrecht CS - De Meern Oost	Workday	4	4 (7:00-7:45) 8 (7:45-9:00)	8 (9:00-15:00 12 (15:00-16:00)	12 (16:00-18:00)	6
	Saturday	3	3 (7:00-8:00) 4 (8:00-9:00)	6 (10:00-11:00) 8 (11:00-16:00)	8	4
	Sunday	0	2 (7:30-9:00)	4 (9:00-11:00) 6 (11:00-17:00)	6 (16:00-17:00) 4 (17:00-18:00)	4
De Meern - Vleuten	Workday	4	4 (7:00-7:30) 8 (7:30-9:00)	8	8	6
	Saturday	3	3 (7:00-8:00) 4 (8:00-9:00)	6 (10:00-11:00) 8 (11:00-16:00)	8	4
	Sunday	0	2 (7:30-9:00)	4 (9:00-11:00) 6 (11:00-17:00)	6 (16:00-17:00) 4 (17:00-18:00)	4

- **Number of stations (pairs)** **17**

Because of the construction works in the station area, over time, stations have been removed (Kanonstraat) or added (Vredenburgviaduct). In this study, the stations presented in Figure H-1 are taken into consideration (17 station pairs).

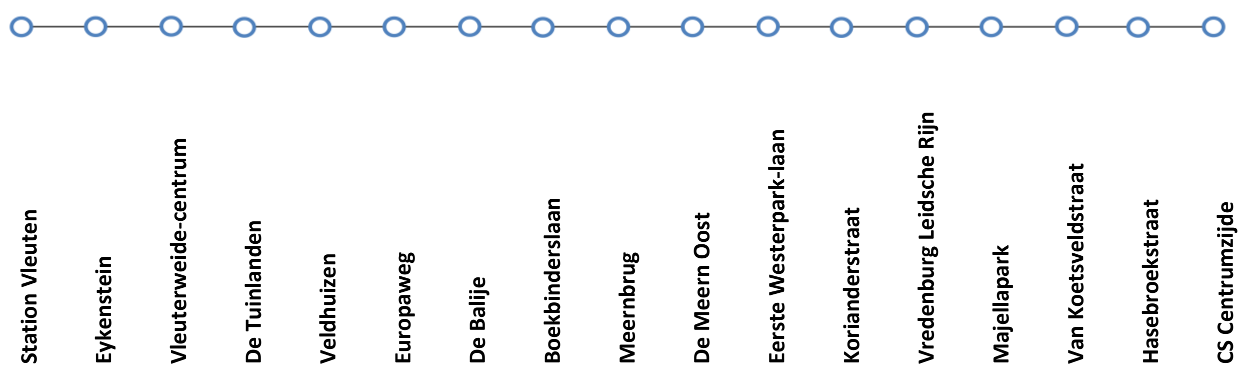


Figure H-1: Stops on the identified trajectory of bus line 28

- **Predominant level of service (LOS) on trajectory (peak)** **D**

In the morning peak, the most saturated sections are: Majellapark - Van Koetsveldstraat and the Korianderstraat - Vredenburg Leidsche Rijn. Based on field measurements, the impression is that the level of service during the morning peak is best represented by LOS D: approaching unstable flow.

- **Distribution of the demand over the trajectory** **C**

None of the three distribution patterns exactly fits the situation on the investigated trajectory. Based on the visualisation of the usage of each of the stops, as presented in Figure N-14, it is assumed that distribution pattern C represents the real distribution of the number of people boarding the best.

- **Amount of crossing traffic (peak, sum of both directions)**
    - **<200** **8**
    - **200-500** **7**
    - **500-1000** **3**
    - **1000-1500** **2**
    - **1500-2000** **1**
    - **>2000** **1**

Because of the lack of data available and considering the limited time available for this research no exact counting's available. Instead, from field measurements for each of the intersections it is estimated which type the intersection presumably belongs to. In Table H-2 below, each of the identified intersections is presented with the estimated sum of crossing vehicles (intersections where cars are involved only). To give an idea of the location of the intersection the stops are displayed as well.

Table H-2: Intersections on the identified trajectory of bus line 28

Intersection	Demand of crossing vehicles (sum of both directions)
Stop: Station Vleuten	
Busbaan Vleuterweide - Stroomrugbaan	1000-1500
Stop: Eykenstein	
Stop: Vleuterweide Centrum	
Busbaan Vleuterweide - Sparrendaal	200-500
Busbaan Vleuterweide - Landschapsbaan	1000-1500
Stop: De Tuinlanden	
Busbaan Vleuterweide - Zandweg	<200
Busbaan Veldhuizen - Rijksstraatweg	<200
Busbaan Veldhuizen - Winkel	<200
Stop: Veldhuizen	
Busbaan Veldhuizen - Zeldertpolder	<200
Busbaan Veldhuizen - Vlowijkerpolder	<200
Stop: Europaweg	
Busbaan Veldhuizen - Europaweg	200-500
Stop: De Balije	
Stop: Boekbinderslaan	
Rijksstraatweg - Regenboog	200-500
Rijksstraatweg - Meerndijk	500-1000
Stop: Meernbrug	
Busbaan de Woerd - Meentweg	200-500
Stop: De Meern Oost	
Busbaan de Woerd/Parkwijk - Langerakbaan	500-1000
Stop: Eerste Westerparklaan	
Busbaan Parkwijk - Eerste Oosterparklaan	<200
Busbaan Parkwijk - Bladvlinder/Melissekade	<200
Stop: Korianderstraat	
Busbaan Parkwijk - Maartvlinder/Korianderstraat	<200
Weg naar Parkwijk/Laurierweg - Grauwaartsingel	500-1000
Laurierweg - Stadsbaan	1500-2000
Stop: Leidsche Rijn Vredenburg	
Verlengde Vleutenseweg - Vleutenseweg	200-500
Vleutenseweg - Thomas à Kempisweg/Spinozaweg	>2000
Stop: Majellapark	
Vleutenseweg - Majellapark/Groeneweg	200-500
Stop: Van Koetsveldstraat	
Stop: Hasebroekstraat	
Vleutenseweg - Hasebroekstraat/Johannes Camphuysstraat	200-500

Appendix I SCBA - Express service

This appendix presents the method and application used to assess the potential profit of implementing an express service through Leidsche Rijn.

I.I Method

The method used for determining which stops profitably can be skipped is adapted from (Roeske, 2014). In this research, a model was described to evaluate which stops can be skipped on multiple light rail trajectories in Rotterdam. The concept is to analyze for each of the stops the costs and benefits of stopping on that particular stop. The benefits of skipping a stop are related to travel time gains for travelers who are not using the stop as origin or destination. The costs are related to increased access and egress times for people who were originally using the stop as origin or destination.

The costs and benefits can be determined for each of the stops and presented as cost benefit-ratio. In case this value is higher than 1, skipping the stop results in a profit. The BC-ratios (benefits/costs) can be determined by calculating for each stop:

Benefits

*People in vehicle*time gained by skipping a stop*

- *People in vehicle*: extracted from OD-matrix (see Appendix N.II).
- *Time gained by skipping a stop*: based on an ad hoc field measurement and expert opinion by (Ydema, 2015), 25 seconds is assumed for this value.

Costs

Assuming people are travelling to the nearest stop: *extra travel time*usage of the stop*

- *Extra travel time:* Average extra walking distance (D_{aw})/walking speed
    - $D_{aw} = (D_{far} * D_{near})/(D_{far} + D_{near})$. Where D_{far} and D_{near} represent the distance to the stops the closest and the furthest to the considered stop. This function also assumes that:
        - The demand is equally spread over the area.
        - The influence area of a stop is half of the distance to the next stop.
        - The area consists of a grid pattern where it is assumed people walk along the line to the next stop.
    - *Walking speed:* assumed to be on average 5 km/h. This corresponds to 1,389 m/s.
- *Usage of stop:* sum of number people boarding and alighting on a particular stop.

When these BC-ratios are computed, an initial insight is gained in which stops possibly can be skipped. However, since the demand of a skipped stop is distributed over the two surrounding stops the BC ratios change. By skipping a stop, the demand of the stops nearby will increase, as well as an increase of the walking distances to the stops. These effects result in a decreased BC-ratio of the surrounding stops.

A greedy algorithm is used to comply with this phenomenon. A finite number of iterations are carried out until all BC-ratios are smaller than 1. See Figure I-1 for a visualization of this procedure.

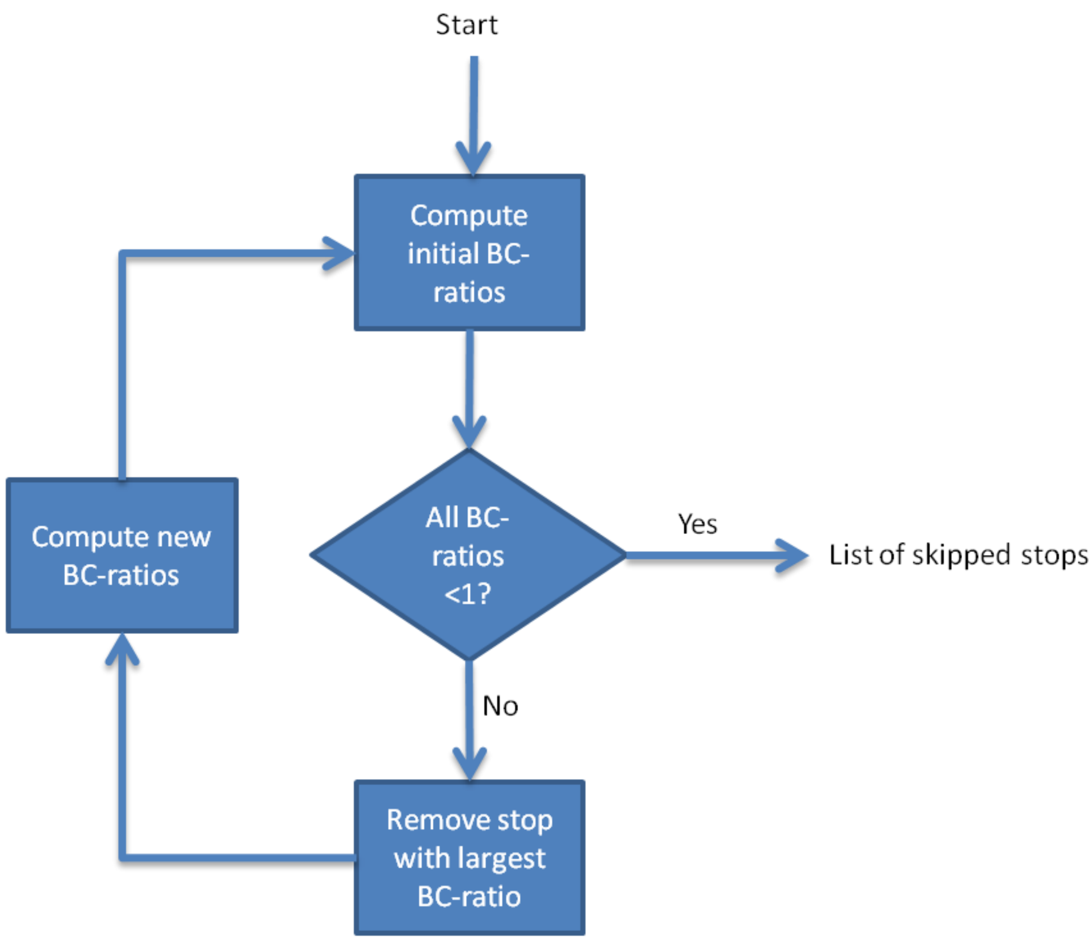


Figure I-1: Visualization of the greedy algorithm used to determine the skips that could be skipped

Compared to the method as used by (Roeske, 2014), a few aspects of this method are not captured because of data and time constraints:

- (Roeske, 2014) uses 3 levels: stop-level, line-level, and network-level. In this study only the stop level (initial BC ratios) and line level (removing the stops with the greedy algorithm) are analyzed. The network effects (people migrating to other lines or transportation modes) are not considered.
- It is not differentiated in the costs of skipping a stop among different usage groups.
- Reductions of the travel demand because of further walking distances are not considered. However, since the potential growth of the demand, because of a faster service, is also not considered, these two effects are assumed to compensate each other.

I.II Application

Table I-1 presents the initial BC ratios, Table I-2 the BC-ratios after four iterations with indicated the four skipped stops. Table I-3 and Table I-4 present the calculations of the travel time savings and travel time losses. Finally, Table I-5 presents the parameters used to determine these travel time savings and losses.

Table I-1: Initial BC-ratios

Station	Dist. near	Dist. far	D_{aw}	People in vehicle after	Avg. people Boarding	Avg. people Alighting	Usage	Benefits	Costs	BC-ratio
Eykenstein	297	790	173	7,6	2	0,6	2,6	190	323	0,59
Vleuterweide-Centrum	297	659	205	22,6	16,7	1,7	18,4	565	2712	0,21
De Tuinlanden	659	706	341	23,9	2,1	0,8	2,9	598	712	0,84
Veldhuizen	372	706	244	23,2	2	2,8	4,8	580	842	0,69
Europaweg	372	458	205	24,2	1,7	0,7	2,4	605	355	1,71
De Balije	458	458	229	25,5	1,7	0,4	2,1	638	346	1,84
Boekbinderslaan	458	488	236	25	0,6	1,1	1,7	625	289	2,16
Meernbrug	488	631	275	23,7	3,3	4,6	7,9	593	1565	0,38
Busstation De Meern Oost	631	1010	388	27,2	5	1,4	6,4	680	1790	0,38
Eerste Westerparklaan	861	1010	465	29	6,2	4,5	10,7	725	3581	0,20
Korianderstraat	861	960	454	52,1	26,4	3,3	29,7	1303	9706	0,13
Vredenburg Leidsche Rijn	960	1241	541	51,9	0,7	0,9	1,6	1298	624	2,08
Majellapark	397	1241	301	58,4	11,4	4,9	16,3	1460	3530	0,41
Van Koetsveldstraat	310	397	174	63,2	6,2	1,3	7,5	1580	940	1,68
Hasebroekstraat	310	507	192	67,1	7,8	3,9	11,7	1678	1621	1,04

Table I-2: BC-ratios after four iterations with indicated the four skipped stops

Station	BC-ratio initial	BC-ratio 1^{st} it.	BC-ratio 2^{nd} it.	BC-ratio 3^{rd} it.	BC-ratio 4^{th} it.
Eykenstein	0,47	0,47	0,47	0,47	0,47
Vleuterweide-Centrum	0,21	0,21	0,21	0,21	0,21
De Tuinlanden	0,84	0,84	0,84	0,84	0,84
Veldhuizen	0,69	0,69	0,69	0,34	0,34
Europaweg	1,71	1,71	1,71		
De Balije	1,84	0,96	0,96	0,49	0,49
Boekbinderslaan	2,16				
Meernbrug	0,38	0,25	0,25	0,25	0,25
Busstation De Meern Oost	0,38	0,38	0,38	0,38	0,38
Eerste Westerparklaan	0,20	0,20	0,20	0,20	0,20
Korianderstraat	0,13	0,13	0,10	0,10	0,10
Vredenburg Leidsche Rijn	2,08	2,08			
Majellapark	0,41	0,41	0,35	0,35	0,19
Van Koetsveldstraat	1,68	1,68	1,68	1,68	
Hasebroekstraat	1,04	1,04	1,04	1,04	0,50

Table I-3: Calculation of travel time savings in vehicle

Skipped stop	Travel time savings in vehicle (s)
Europaweg	23,7*25 = 591,3
Boekbinderslaan	25,1*25 = 628,6
Vredenburg Leidsche Rijn	51,9*25 = 1297,2
Van Koetsveldstraat	60,4*25 = 1511,2
	4028 seconds

Table I-4: Calculation of travel time losses for access and egress purposes

Skipped stop	Travel time losses access and egress (s)
Europaweg	(2,4*205,3)/1,389 = 354,7
Boekbinderslaan	(1,7*236,3)/1,389 = 289,2
Vredenburg Leidsche Rijn	(1,6*541,3)/1,389 = 623,6
Van Koetsveldstraat	(7,5*174,1)/1,389 = 940,0
	2207 seconds

Table I-5: Parameters used to determine the total travel time losses and profits

	People in vehicle after stop		Usage of stop				
	Local	Express	Local	Express	D_{aw}	Travel time losses (s)	Travel time savings (s)
Eykenstein	7,6	7,6	2,6	2,6	172,7		
Vleuterweide-Centrum	22,6	22,6	18,4	18,4	204,7		
De Tuinlanden	23,9	23,9	2,9	2,9	340,8		
Veldhuizen	23,2	23,7	4,8	6,1	243,6		
Europaweg	24,2		2,4		205,3	354,7	591,3
De Balije	25,5	25,1	2,1	4,1	229,0		
Boekbinderslaan	25,0		1,7		236,3	289,2	628,6
Meernbrug	23,7	23,6	7,9	8,7	275,2		
Busstation De Meern Oost	27,2	27,2	6,4	6,4	388,4		
Eerste Westerparklaan	29,0	28,9	10,7	10,7	464,8		
Korianderstraat	52,1	51,9	29,7	30,6	453,9		
Vredenburg Leidsche Rijn	51,9		1,6		541,3	623,6	1297,2
Majellapark	58,4	60,4	16,3	20,3	300,8		
Van Koetsveldstraat	63,2		7,5		174,1	940,0	1511,2
Hasebroekstraat	67,1	67,1	11,7	15,9	192,4		
						2207	**4028**

Appendix J SCBA - Intersection treatment

This appendix presents the method and application, used to assess the potential profits of improving the intersection treatment for the bus service through Leidsche Rijn.

J.I Method

To determine the potential gain of collective in vehicle travel time, the average expected time gain per intersection is multiplied with the number of people in the vehicle. For each intersection, the following computation is executed:

*Current time lost at intersection * average number of people in bus on that specific intersection*

J.II Application

Five intersections are identified where generally a significant amount of time is lost. Table J-1 presents the potential travel time gain, the number of people in the vehicle and the total travel time profits.

Table J-1: Identified intersections with a display of the potential time gain, number of people in the vehicle and the total travel time profits

Intersection	Potential travel time gain (s)	People in vehicle	Collective travel time profit in vehicle (s)
Busbaan Vleuterweide - Stroomrugbaan	30	6,2	30*6,2 = 186
Rijksstraatweg - Meerndijk	90	25	90*25 = 2250
Weg naar Parkwijk/Laurierweg - Grauwaartsingel	90	52,1	90*52,1 = 4689
Laurierweg - Stadsbaan	30	52,1	90*52,1 = 4689
Vleutenseweg - Thomas à Kempisweg/Spinozaweg	15	51,9	51,9*15 = 779
	255 = 4:15 min.		**12593**

Appendix K SCBA - Fare collection

This appendix presents the method and application, used to assess the potential profits of modifying the fare collection procedure for the bus service through Leidsche Rijn.

K.I Method

The alighting and boarding procedure is a part of the total dwell procedure. The time for this procedure is highly dependent on the number of people wanting to board a vehicle. The time loss per bus stop is therefore variable because of different number of boarding's. By improving the fare collection process, the variable time per person boarding can be reduced from 1 second to 0,5 seconds. This method implies that it is assumed in this analysis that the relation between the number of people boarding and the time per boarding are linear. The collective loss of travel time is computed for each stop by:

*Number of people in vehicle when arriving at stop * number of people boarding * time per boarding*

K.II Application

Table K-1 below presents the calculation for each of the stops on the trajectory Vleuten - Utrecht CS. The time loss in collective seconds is displayed for the old and new situation (2949 vs. 1474 seconds). Also the total boarding time is displayed for the old and the new situation (100 vs. 50 seconds).

Table K-1: Determination of the reduction of the time lost because of the improved fare collection procedure

	People boarding	People in vehicle before stop	Current boarding time (s)	New boarding time (s)	Current time loss in vehicle (s)	New time loss in vehicle (s)
Station Vleuten	6,2	0	6,2	3,1	0	0
Eykenstein	2	6,2	2	1	12,4	6,2
Vleuterweide-Centrum	16,7	7,6	16,7	8,35	126,92	63,46
De Tuinlanden	2,1	22,6	2,1	1,05	47,46	23,73
Veldhuizen	2	23,9	2	1	47,8	23,9
Europaweg	1,7	23,2	1,7	0,85	39,44	19,72
De Balije	1,7	24,2	1,7	0,85	41,14	20,57
Boekbinderslaan	0,6	25,5	0,6	0,3	15,3	7,65
Meernbrug	3,3	25,0	3,3	1,65	82,5	41,25
Busstation De Meern Oost	5	23,7	5	2,5	118,5	59,25
Eerste Westerparklaan	6,2	27,2	6,2	3,1	168,64	84,32
Korianderstraat	26,4	29,0	26,4	13,2	765,6	382,8
Vredenburg Leidsche Rijn	0,7	52,1	0,7	0,35	36,47	18,235
Majellapark	11,4	51,9	11,4	5,7	591,66	295,83
Van Koetsveldstraat	6,2	58,4	6,2	3,1	362,08	181,04
Hasebroekstraat	7,8	63,2	7,8	3,9	492,96	246,48
			100	**50**	**2949**	**1474**

Appendix L Analysis Mobiliteitsscan

This Appendix presents the analysis of Leidsche Rijn with the Mobiliteitsscan. The Mobiliteitsscan is a software tool developed by CROW, a knowledge institute in the field of infrastructure, public space, transport and traffic safety. In the Mobiliteitsscan the VRU 3.1u of Utrecht is implemented. This is the most recent traffic model of the municipality of Utrecht (released November 2013), which is an elaboration of the regional traffic model 3.0 developed by Bestuur Regio Utrecht (BRU). It is a macroscopic static traffic model that consist of calculated and measured traffic data (car, bicycle, public transport), which can be used for public transport studies. In this Appendix the following outputs of the scan are presented:

- Travel time isochrones
- Development factors/economic potentials
- Trip generations
- Trips from and to an area
- Travel time ratios

All analyses are performed for the scenario: *morning peak 2015*.

Travel time isochrones

Travel time isochrones from the northern part of Veldhuizen (black dot in Figure L-1). It can be concluded that from the northern part of Veldhuizen, especially the northern part of Utrecht is badly accessible by public transport.

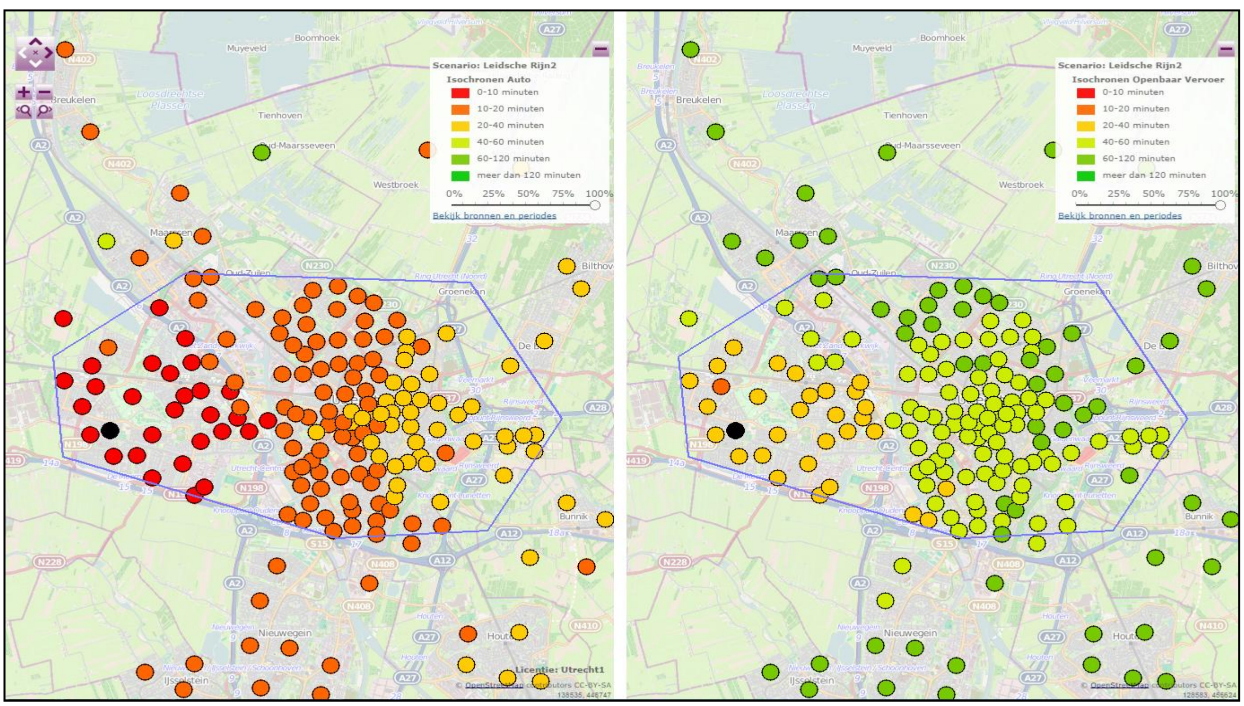


Figure L-1: Travel time isochrones

Development factors

The development factors, as presented in Figure L-2, indicate how many jobs can be reached from a specific location by car (left) or by public transport (right). As could be expected, it is indicated that the city centre is relatively better accessible by public transport and for the outskirts this is the case for car transport.

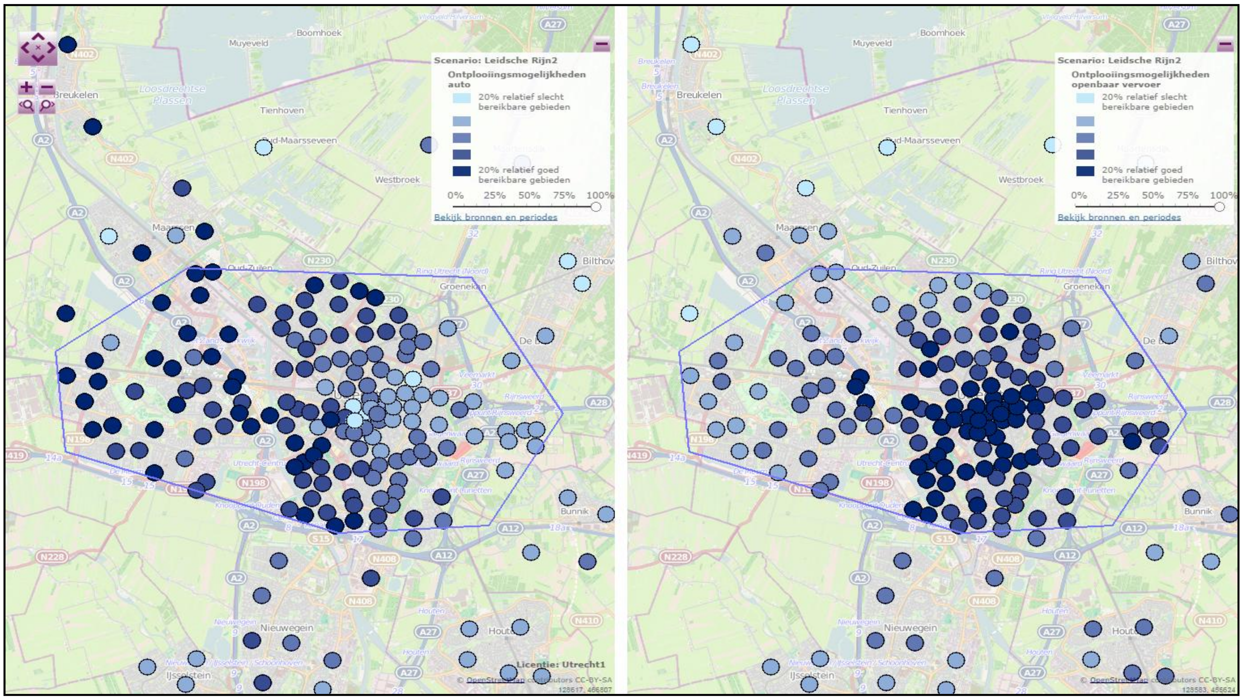


Figure L-2: Development factors

Economic potential

The economic potential, as presented in Figure L-3, indicates how many people can reach the location in case of settlement here. The left figure indicates the economic potential by car, the right figure the economic potential by public transport. As could be expected, it is indicated that the city centre is relatively better accessible by public transport and for the outskirts this is the case for car transport.

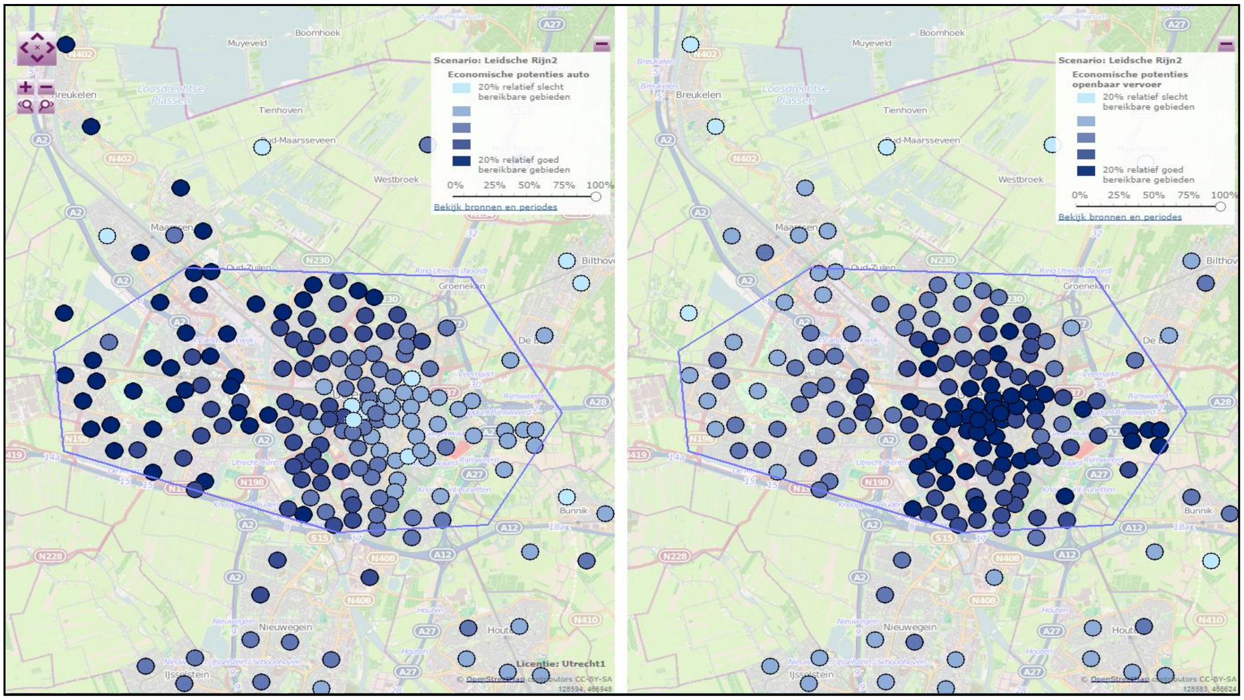


Figure L-3: Economic potential

Trip generation

Figure L-4 presents the trip generations in the morning. The left figure indicates the departures; the right figure indicates the arrivals. Since Leidsche Rijn is a residential area, without many points of interest, the investigated pattern of more people leaving than arriving, is as expected.

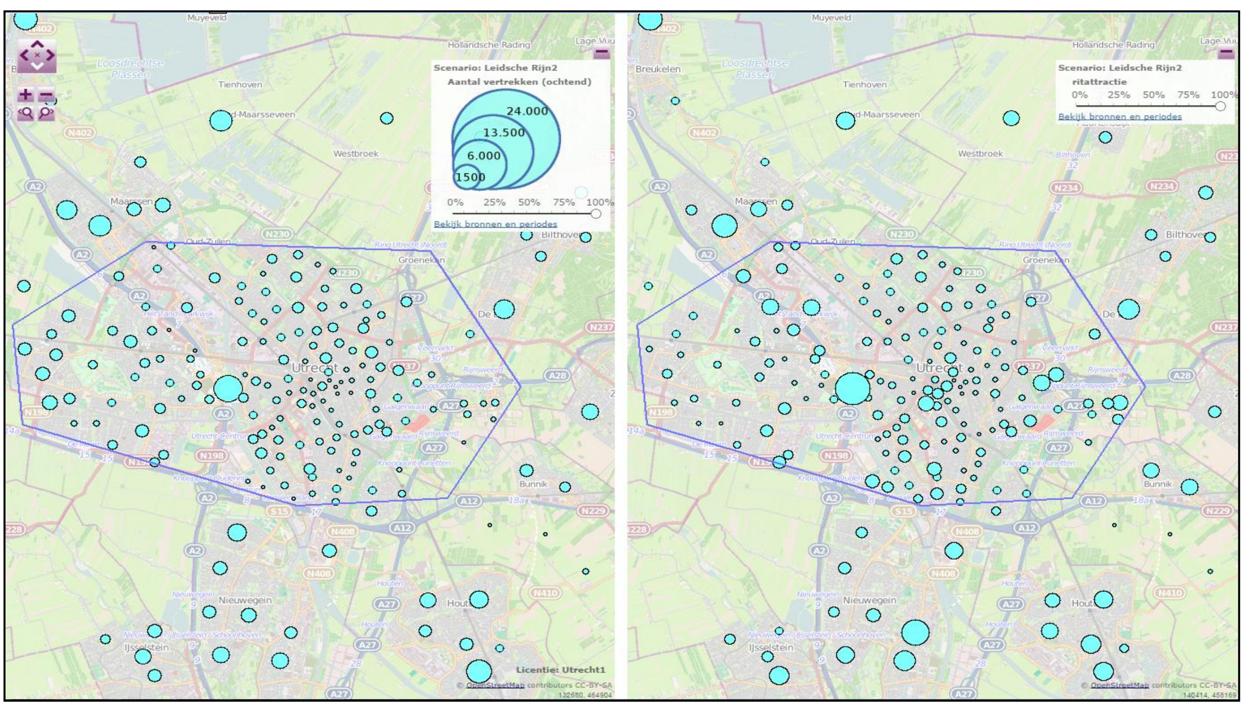


Figure L-4: Trip generation

Departures from and to an area

Figure L-5 indicates the number of departures to and from the centre of Leidsche Rijn. It is notable that the relation with Amsterdam is really important (indicated with the thick blue line to the above left corner).

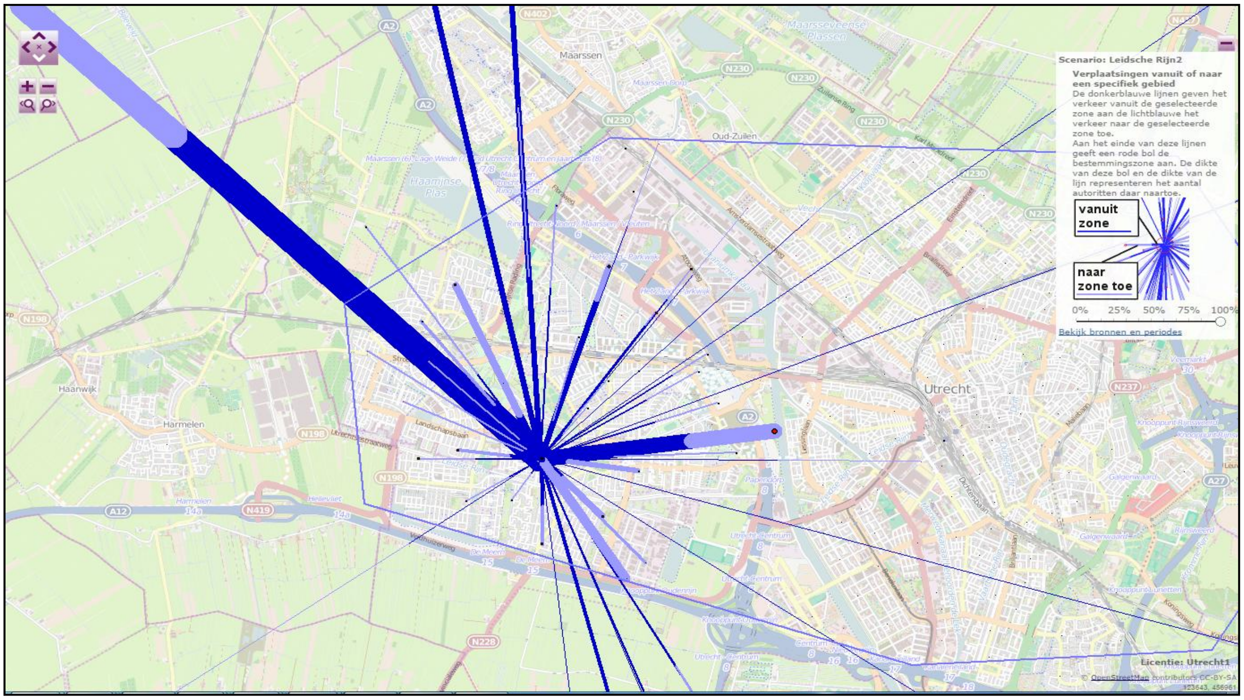


Figure L-5: Departures to and from area

Travel time ratios

The travel time ratio indicates the difference between the door to door travel time by car, compared to public transport. Figure L-6 and Figure L-7 present the travel time ratios from Leidsche Rijn and from De Meern. The interpretation of these two figures is done in consultation with Rob Tiemersma (Gemeente Utrecht):

- Relation between Amsterdam and Leidsche Rijn is identified as problematic (high travel time ratio).
- Relation between Overvecht/Zuilen and Leidsche Rijn is identified as problematic. In particular the relation between Overvecht/Zuilen and the hospital of Leidsche Rijn.
- The travel time ratios between Vleuten and Lage Weide are unrealistically low.

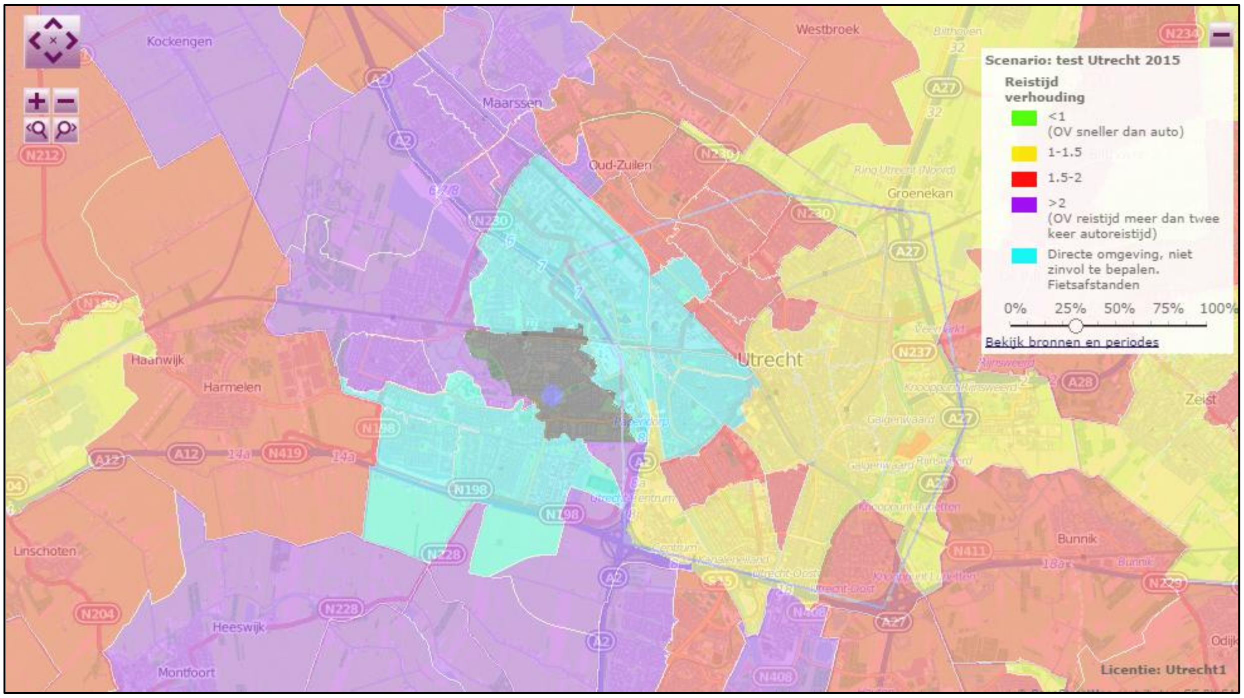


Figure L-6: Travel time ratios from Leidsche Rijn

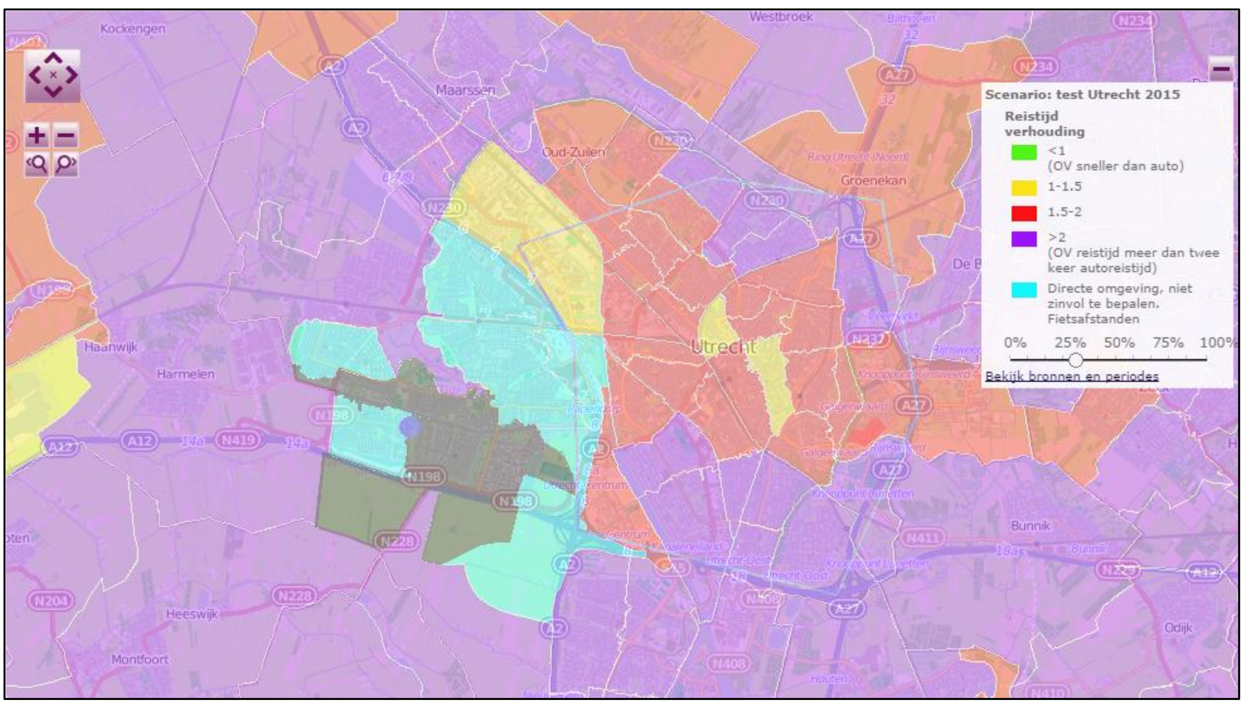


Figure L-7: Travel time ratios from De Meern

Appendix M Analysis of starting points prior to design

Four documents have been acquired which describe the considerations/starting points about the design of the HOV connection to Leidsche Rijn. This appendix presents the conclusions from each of these documents. In these documents the term HOV is used. HOV-bus is the Dutch term being used for BRT systems.

Ontwikkelingsvisie (Projectbureau Leidsche Rijn, n.d.)

- Sufficient competitive strength of bus service: a minimum of 8 trips per hour.
- Residential buildings around HOV stations in higher densities. Offices and other points of interest are situated within 300 m of HOV station.
- HOV-bus corridors should be convertible to light rail corridors in the future.

Masterplan Leidsche Rijn (Projectbureau Leidsche Rijn, 1995)

- 80% of residential buildings need to be in sphere of influence of HOV-stations.
- Bundling of lines on limited amount of axes: dedicated lanes and priority treatment on intersections.
- HOV-bus corridors should be convertible to light rail corridors in the future.

HOV Utrecht (Planbureau, 1999)

- HOV is no collection of individual parts but coherent and sophisticated set of product components and services.
- Implementation of brand. Corporate identity applied to all visible parts of the system.
- System provides signal priority on intersections.
- Guided docking on station, indication on station of where doors of the bus vehicle will be located.

Wonen op het HOV (GVU/Midned, 1998)

- As much people should be living within a walking distance of 400 m of a HOV station.
- HOV can be core of urban design, stations will be linked to public space.
- By building distinctive apartment buildings, the density is increased, special accents are added to the public space and the recognisability of stops will be increased.

Appendix N Analysis of driving performance bus line 28

This Appendix presents the driving performance of bus line 28 during the month of March 2014. Consecutively, the driving time data is analyzed (Section N.I), the Origin-Destination data is interpreted (Section N.II) and the usage of the service over the day is analyzed (Section N.III).

N.I Driving time data

Via (Wegewijs, 2014b), the driving time data for the following time slots has been acquired:

- Working day 07:00-9:00, 09:00-16:00, 16:00-18:00, 18:00-23:59
- Saturday 00:00-23:59
- Sunday 00:00-23:59

The data is originating from the GOVI (Grenzeloze Openbaar Vervoer Informatie) database, a database that keeps track of the characteristics of bustrips. These data consists for several measurements the 15, 50 and 85 percentile values (such as partial driving time, departure punctuality, dwell time). As is indicated by (van Oort, Sparring, & Goverde, 2013) based on this data, the planning of public transport can be optimized. This section analyzes in detail the speed between stops, the operational speed, dwell times and departure punctuality.

N.I.I Operational speed

Table N-1 and Table N-2 present the average operational speeds in both directions, for four different time slots[14]. Since Sunday is the day with the lowest travel demand, the time slot of Sunday is used as reference.

Table N-1: Average operational speed between Station Vleuten and Utrecht CS during various time slots

Average operational speeds Station Vleuten -> Utrecht CS

	Working day 7:00-9:00	Working day 9:00-16:00	Working day 16:00-18:00	Sunday 0:00-24:00
15%	24,7	26,4	25,9	26,7
50%	22,4	23,7	23,2	24,4
85%	21,0	22,7	22,0	21,9

Table N-2: Average operational speed between Utrecht CS and Station Vleuten during various time slots

Average operational speeds Utrecht CS -> Station Vleuten

	Working day 7:00-9:00	Working day 9:00-16:00	Working day 16:00-18:00	Sunday 0:00-24:00
15%	26,6	26,4	24,0	26,9
50%	23,6	23,6	22,4	23,3
85%	20,6	20,6	19,5	20,5

[14] Values based on cumulative driving times till the last station before Utrecht CS or from the first station after Utrecht CS. Added to this are the partial driving times from this station from and to Utrecht CS. The distance between Station Vleuten and Utrecht CS, used to compute these speeds is 10,9 km.

On Sundays in both directions in general the highest speeds are realized, the differences with a working day are however not significant. From this data also the existence of a peak hour direction is identifiable. See Appendix N.III for a further assessment of this phenomenon.

Figure N-1 and Figure N-2 below present the operational speed over the trajectory. In the tables above, no significant difference in operational speed between the day (9:00-15:59), the morning peak (7:00-8:59) and evening peak (16:00-17:59) could be identified. Therefore, in the diagrams below, only the two peak periods are displayed.

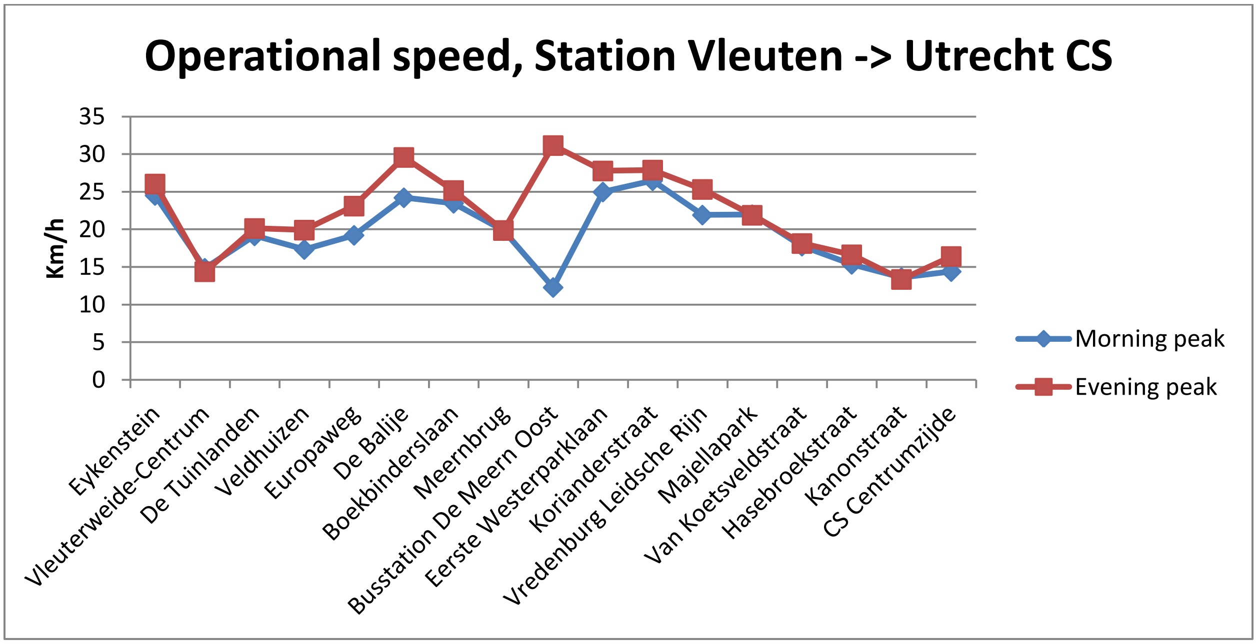


Figure N-1: Operational speed between Station Vleuten and Utrecht CS during the morning and evening peak

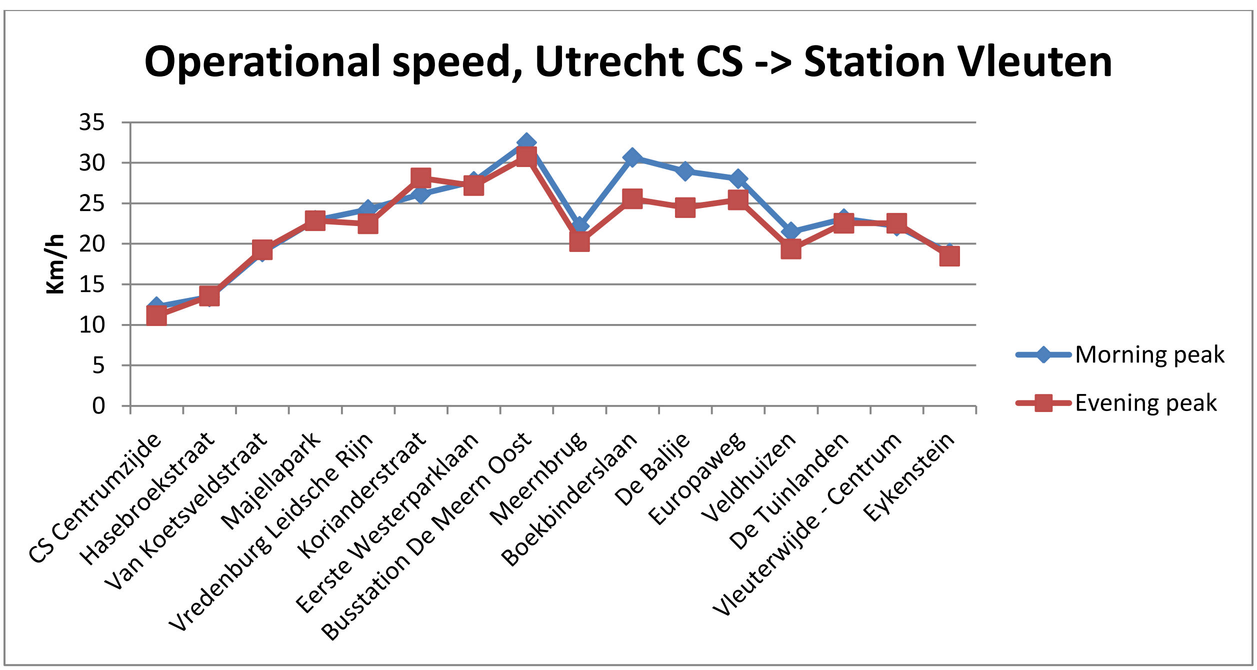


Figure N-2: Operational speed between Utrecht CS and Station Vleuten during the morning and evening peak

The patterns between morning and evening peak are in general very similar. Only in the direction Vleuten - Utrecht CS, there are at De Meern Oost large differences between morning and evening peak. This difference can presumably be explained by the awaiting of a transfer in the evening peak. The lower operational speeds towards the ends of the line are also recognisable. Towards Utrecht this is explainable by the large volume of crossing traffic and the lower stop spacing. Towards Vleuten this low operational speed is more surprising because:

- This is mainly a residential area with little intersections with other traffic flows.
- The stop spacing is larger than the trajectory towards Utrecht CS.

N.I.II Speed between stops

The average speed between stops indicates, the average speed reached between two adjacent stops. Figure N-3 to Figure N-6 present the realized speeds between each of the adjacent stops. Additional to these average speeds between the stops, also the differences between the 15% and 85% percentile are presented. These diagrams provide an indication of the level of variability. Again, only the morning and evening peak are displayed.

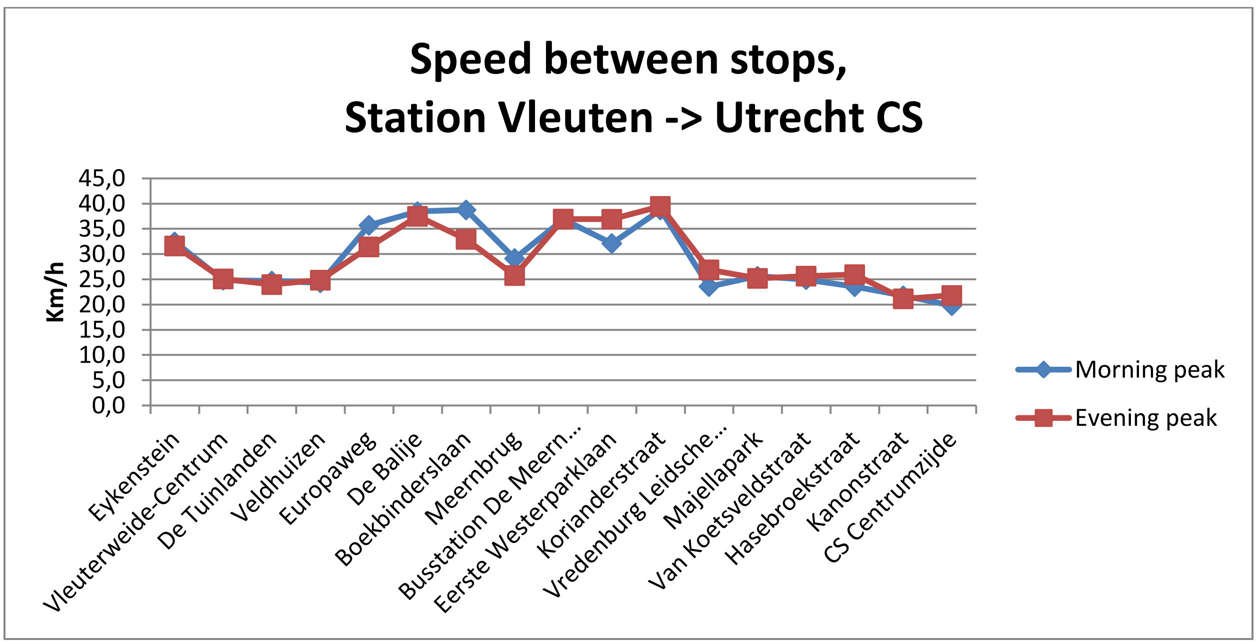


Figure N-3: Average speed between each particular stop between Station Vleuten and Utrecht CS during the morning and evening peak

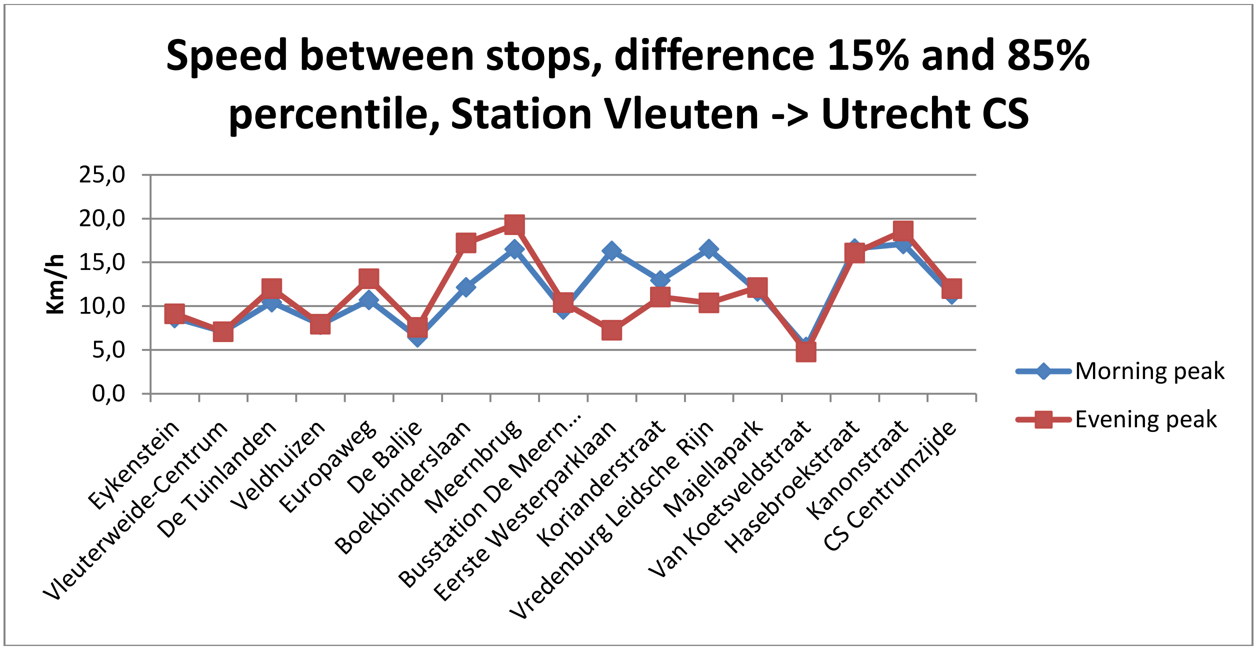


Figure N-4: Difference between 15% and 85% percentile values for the average speed between each particular stop, between Station Vleuten and Utrecht CS, during the morning and evening peak

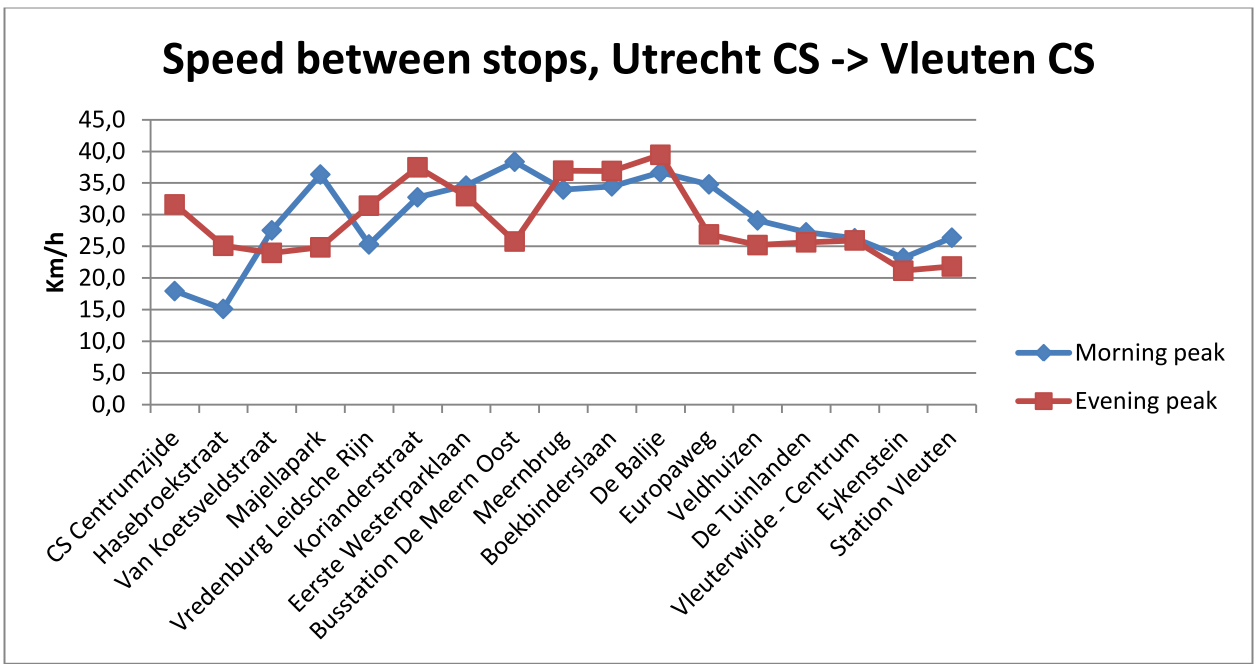


Figure N-5: Average speed between each particular stop between Utrecht CS and Station Vleuten during the morning and evening peak

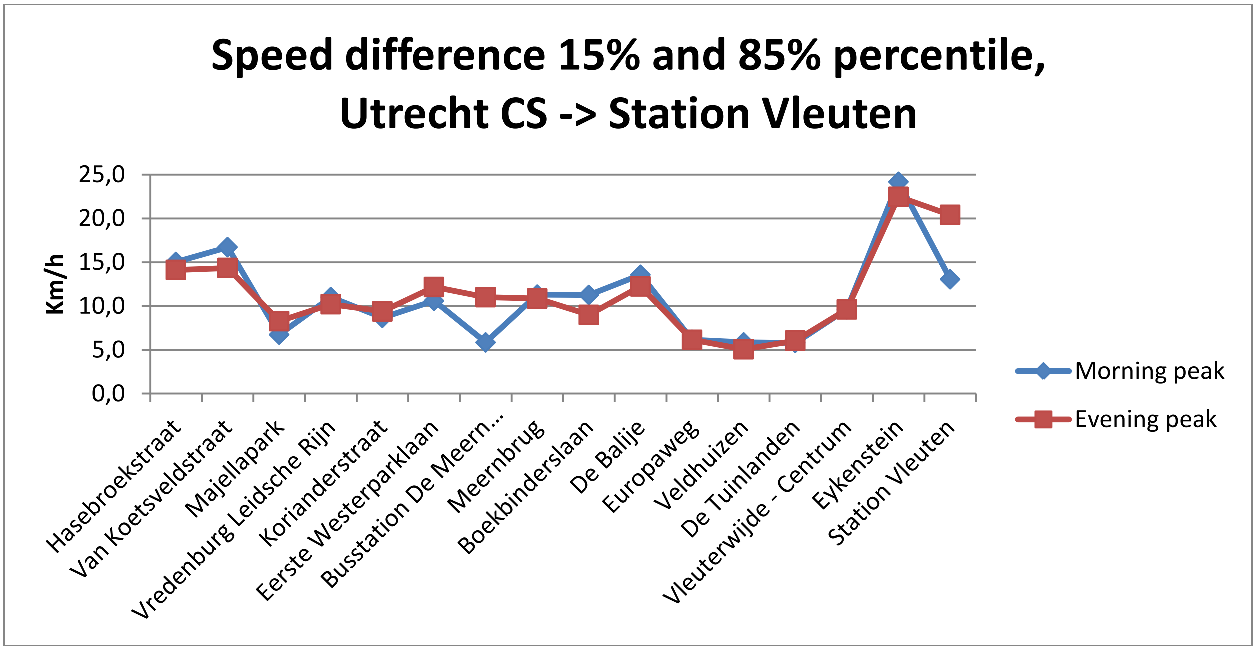


Figure N-6: Difference between 15% and 85% percentile values for the average speed between each particular stop, between Utrecht CS and Station Vleuten, during the morning and evening peak

Analysis of these diagrams provided a few interesting results:

- In general the difference between 15% and 85% percentile is larger, and has a higher variation in the direction of Utrecht than in the direction of Vleuten.
- The speeds in the direction of Utrecht are in general lower, and have a higher variation than in the direction of Vleuten. This can be the result of the interference with traffic flows in the same direction and waiting times at intersections.
- Large difference in percentile values on trajectory Vleuterwijde Centrum - Eykenstein in the direction of Station Vleuten (Figure N-6). Inexplicable is also the large difference with the opposite direction: Eykenstein - Vleuterwijde Centrum (Figure N-4).

N.I.III Departure punctuality

Figure N-7 to Figure N-12 presents diagrams indicating the departure punctuality. In these diagrams, the positive values should be interpreted as late departures; the negative values should be interpreted as early departures.

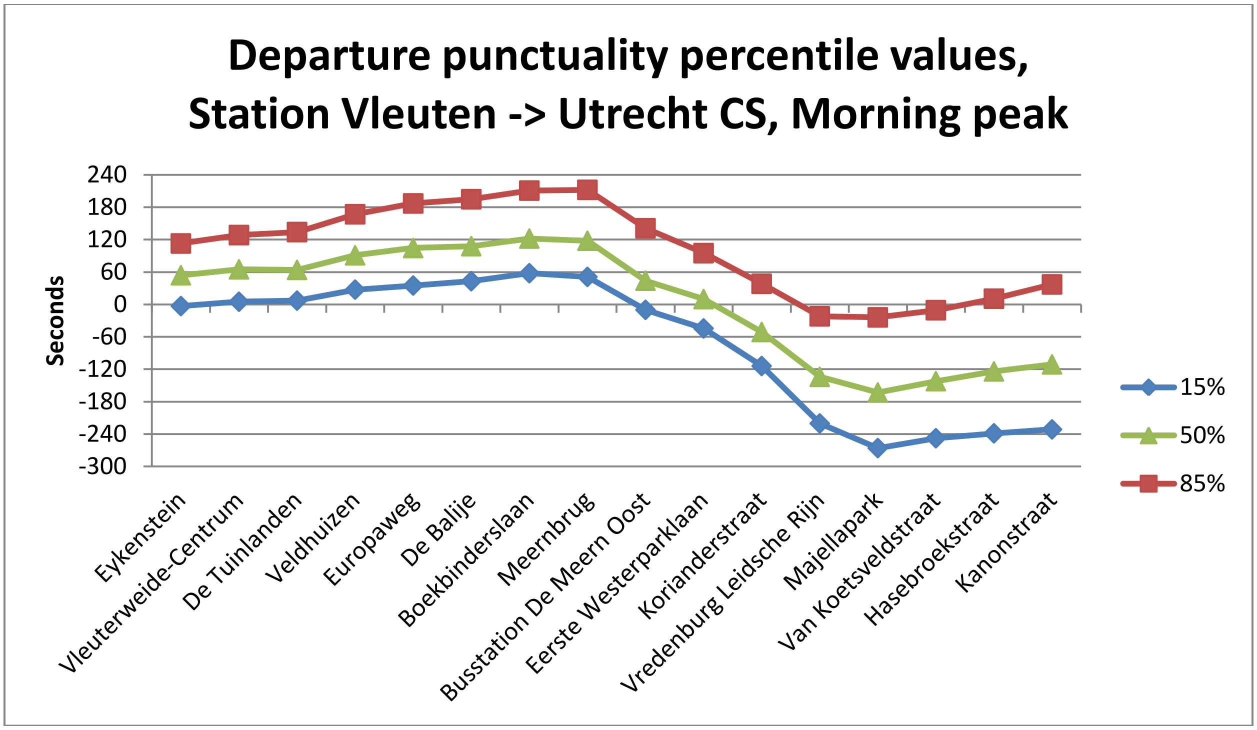


Figure N-7: Percentile values indicating the departure punctuality between Station Vleuten and Utrecht CS during the morning peak

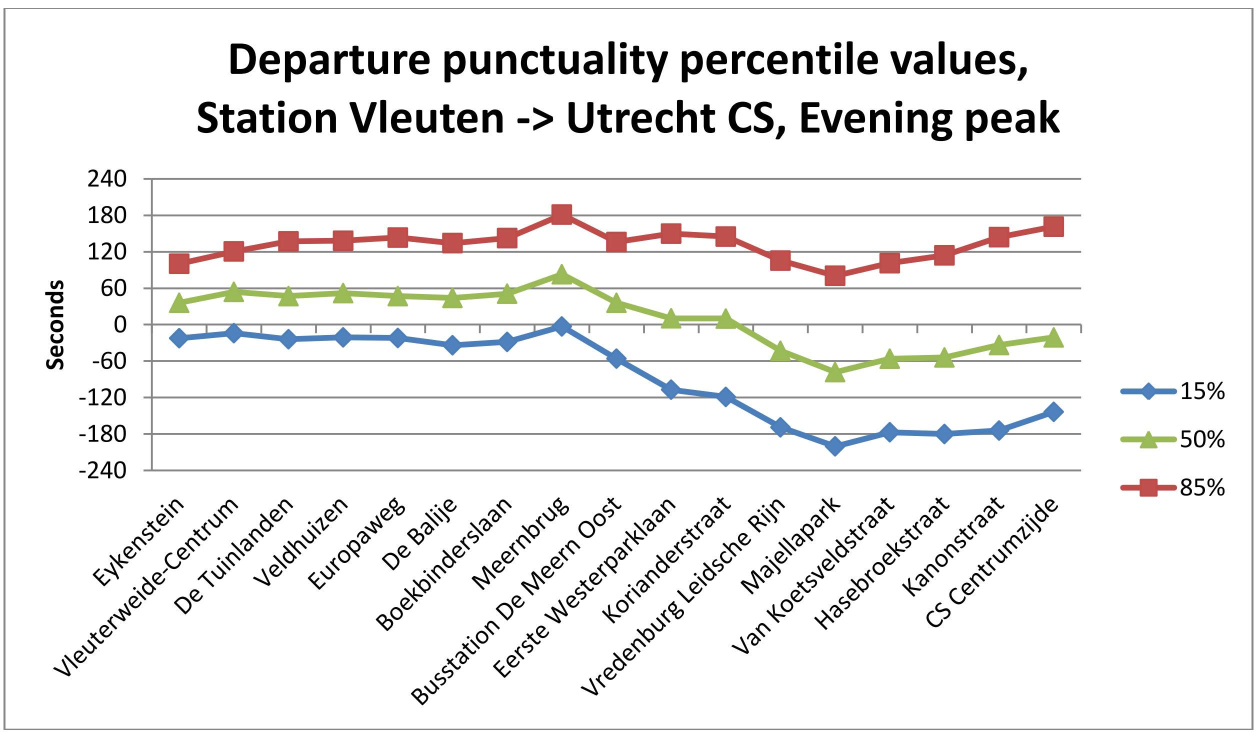


Figure N-8: Percentile values indicating the departure punctuality between Station Vleuten and Utrecht CS during the evening peak

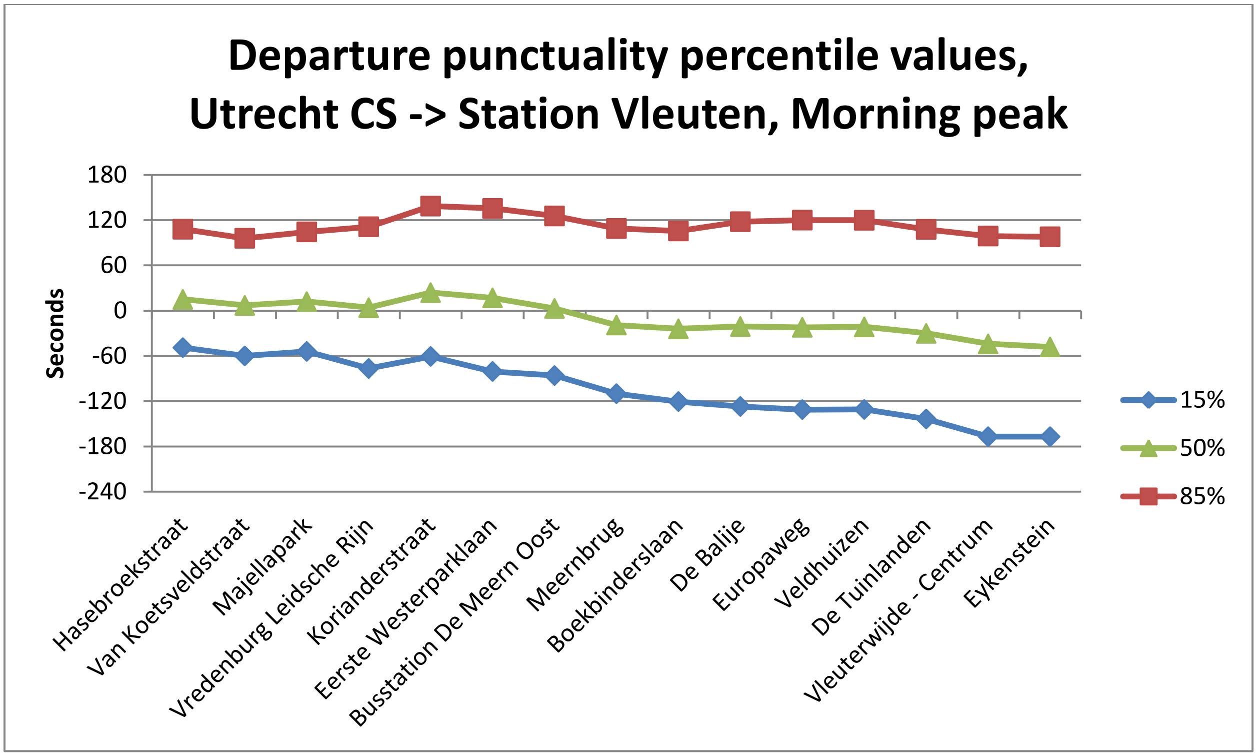


Figure N-9: Percentile values indicating the departure punctuality between Utrecht CS and Station Vleuten during the morning peak

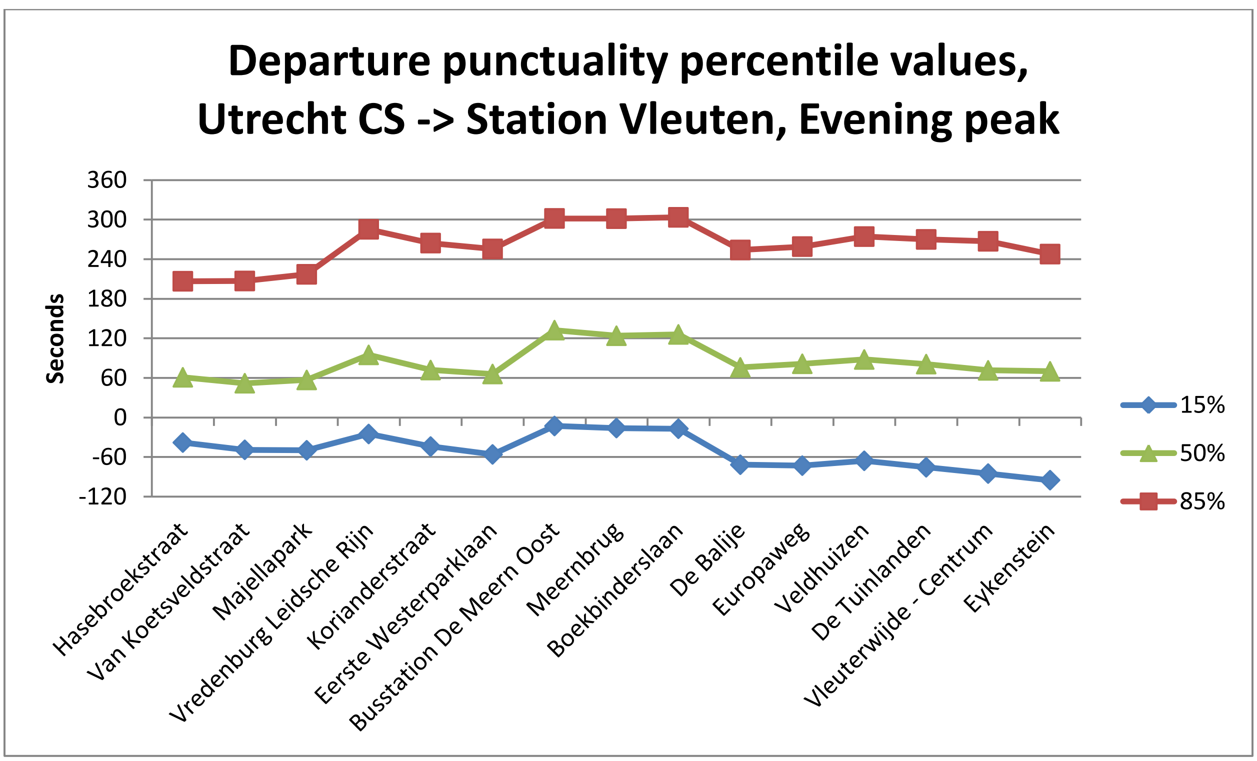


Figure N-10: Percentile values indicating the departure punctuality between Utrecht CS and Station Vleuten during the evening peak

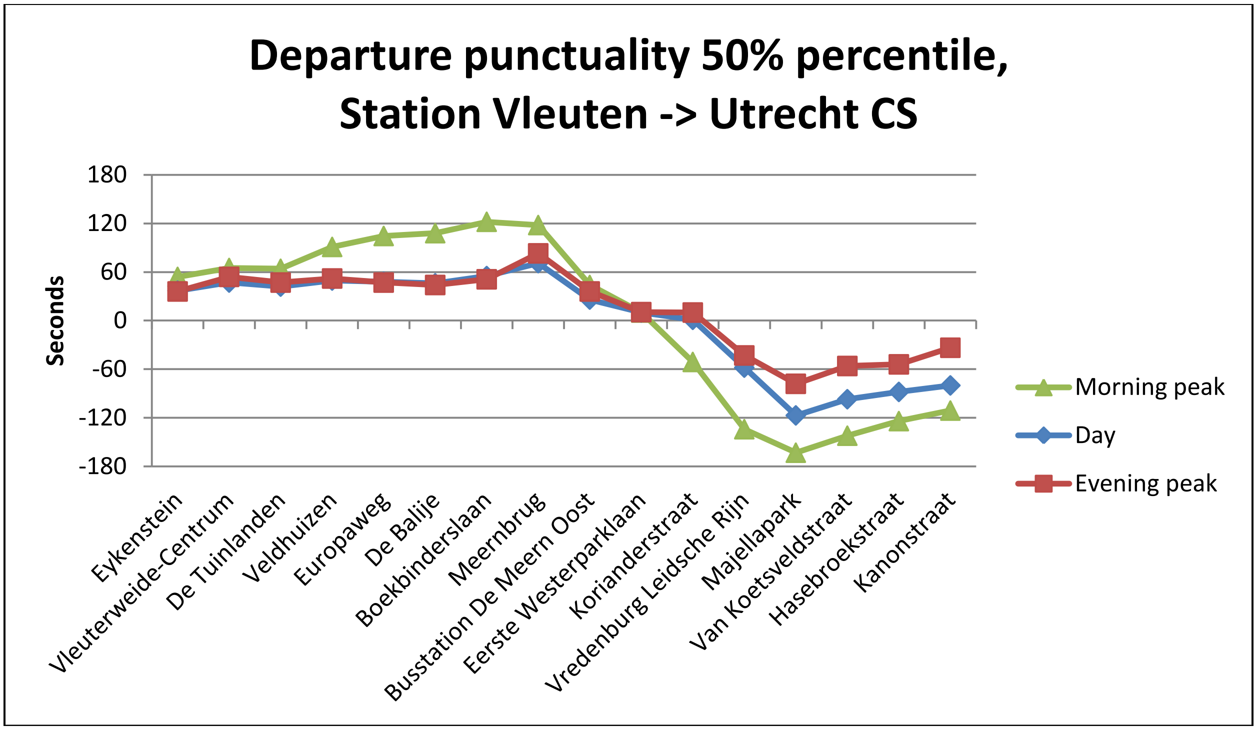


Figure N-11: 50% percentile value indicating the departure punctuality between Station Vleuten and Utrecht CS during different periods of the day

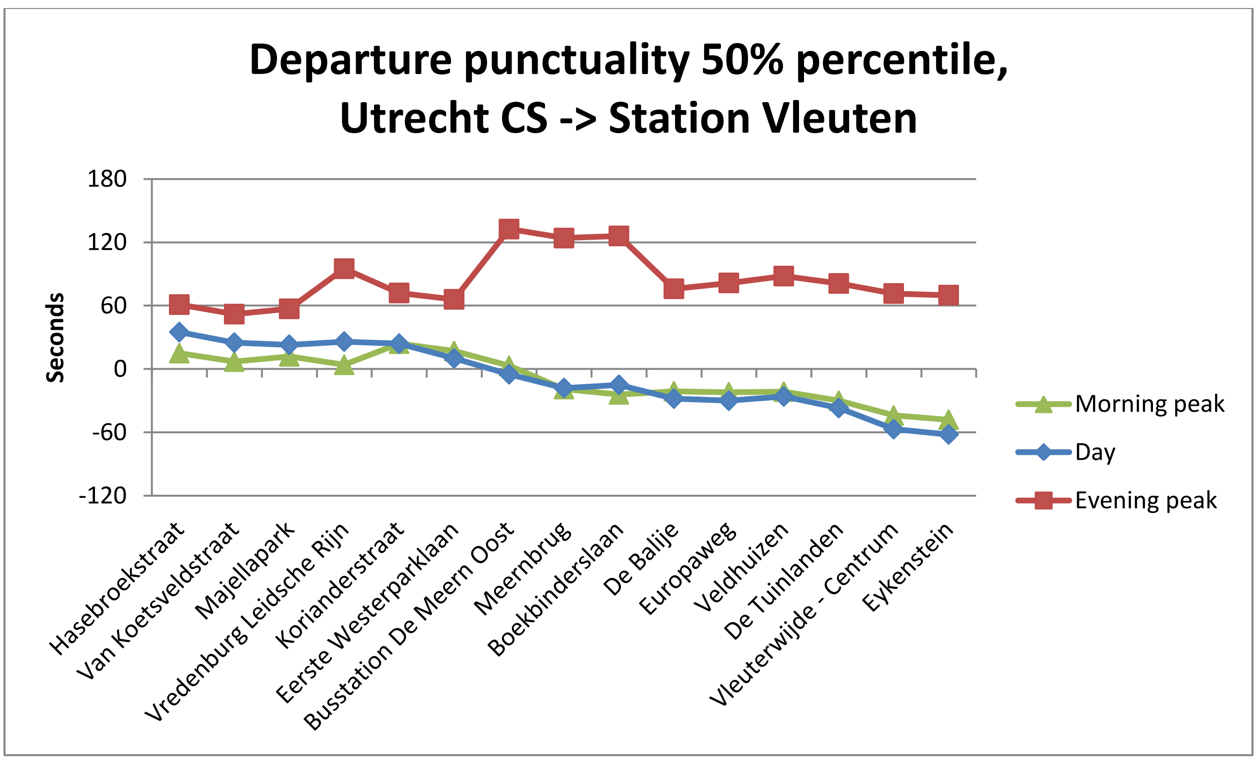


Figure N-12: 50% percentile value indicating the departure punctuality between Utrecht CS and Station Vleuten during different periods of the day

It should be noticed that nearly all trips depart late. Subsequently, this delay is maintained until a sudden drop in the middle section, resulting in early departures. Based on this data it can be concluded that there is apparently a lot of slack in the timetable. During the morning peak, this pattern can be identified best.

N.I.IV Dwell time

Also analyses are performed on data indicating the average dwell times per stop. No clear patterns were identifiable; therefore these figures are not presented in this Appendix. Only one clear outlier was identified, the dwell time at the stop Veldhuizen is very high. This was however only the case for the direction towards Utrecht CS. This difference is explained by the presence of an intersection in front of the bus stop. This results in situations where the bus has to wait on the stop for the intersection to be cleared. This time is subsequently added to the dwell time.

N.II Origin Destination Matrix

Via (Wegewijs, 2014b) also the OD-matrices were obtained for the periods:

- Whole day (0:00-23:25)
- Morning peak (8:00-8:59)
- Evening peak (16:00-16:59)

This numbers are based on OV-chipkaart data for the month March 2014. This is numbers are not consisting bus tickets bought inside the vehicle, QB subscriptions or Park & Ride tickets. Based on an estimate of the BRU (Wegewijs, 2014a), this share of non OV-chipkaart travellers is around 11%. For this effect is corrected by increasing the numbers in OD-matrices by 11%.

Analog to the presentation by (van Waveren & Courtz, 2014), Figure N-13 presents distribution of trips over the line for a whole day. How thicker the line in this figure, the higher the number of trips between the respective OD-pair.

It is clear that for each stop the relation with Utrecht CS is very strong. Only in the area around Vleuten there is some significant mutual traffic. Presumably this is because of the presence of two shopping malls (Vleuterwijde Centrum and Veldhuizen) and Station Vleuten. Also the very large demand on the Eerste Westerparklaan and the Korianderstraat is remarkable. The stop spacing is relatively large in this area; this can possibly partly explain this large number.

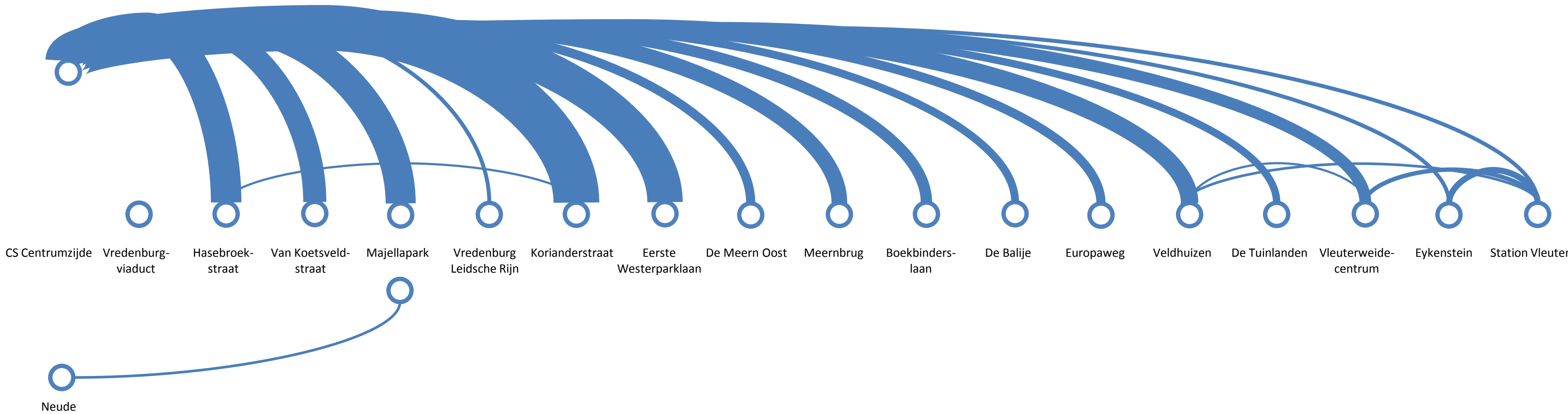


Figure N-13: Representation of OD-relations on trajectory Utrecht CS (left) and Station Vleuten (right). Representation analogue to (van Waveren & Courtz, 2014)

A few comments to clarify the interpretation of the diagram above:

- Only relations serving more than 1000 passengers on a monthly basis are displayed in the diagram.
- Since the stop Vredenburgviaduct is only created around March 2015, it is not associated with any demand.
- The relation Majellapark - Neude is the only significant relation between the stops on the identified trajectory (Vleuten - Utrecht CS) and the remainder of line 28 (Utrecht CS - De Uithof). This OD-pair is included since these people are also traveling on the trajectory that is part of this research (Majellapark-Utrecht CS).

N.III Distribution of trips over the day

The intensities per hour for March 2014 are obtained by (Wegewijs, 2014b) for working days, Saturdays and Sundays. These are corrected for the estimate of 11% of non OV-chipkaart travellers (See Section N.II). These monthly totals are translated to averages per day. March 2014 consists of 21 working days, 5 Saturdays and 5 Sundays. The results are visualized in Figure N-14 below. It should be noted that this figure represents the whole trajectory of line 28 (Vleuten - De Uithof). Therefore, the image only provides an impression of the distribution of trips over the day. The number of travellers on the trajectory Vleuten - Utrecht CS is assessed further on.

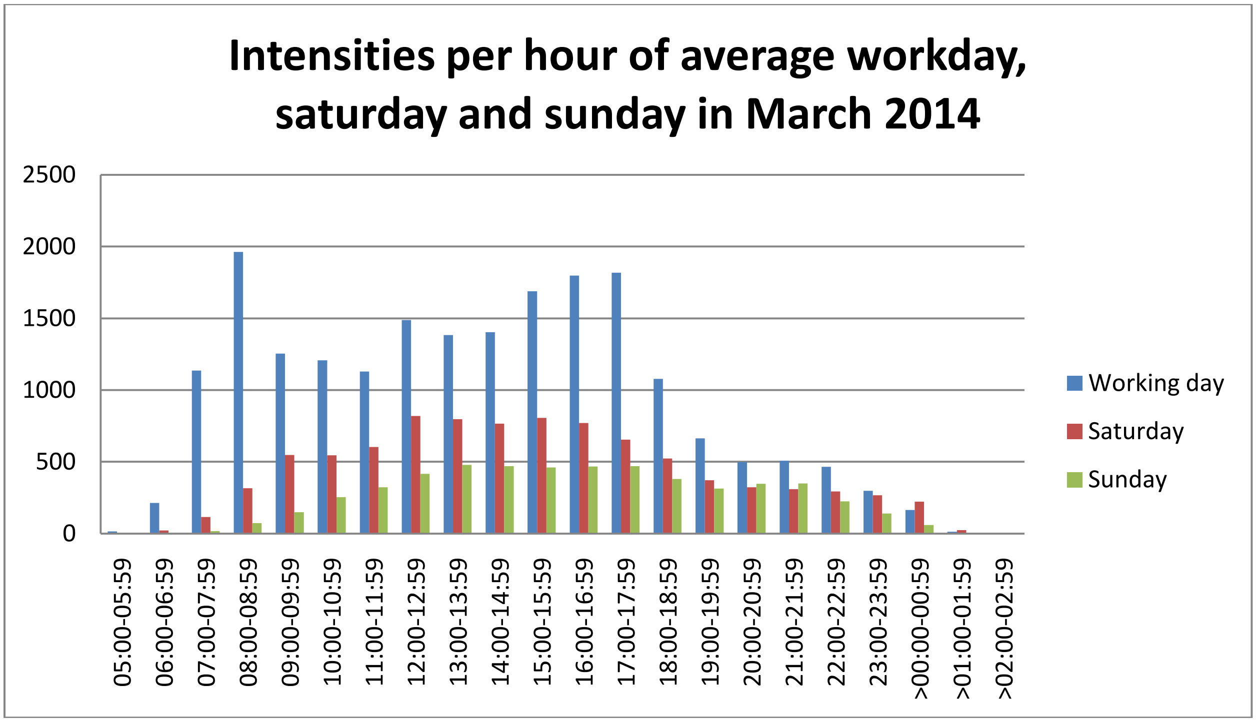


Figure N-14: Travel intensities spread over the day for an average working day, Saturday and Sunday

The ratio between peak and non-peak is roughly 1,5. Also the Saturday and Sunday are quite well represented compared to an average working day.

From the three OD-matrices (see Section N.II) the numbers of passengers on the trajectory Vleuten - Utrecht CS for the month of March are extracted. Table N-3 below presents these values. Since Leidsche Rijn is mainly a residential area it is expected that in the morning peak people are travelling towards the city centre, and in the evening in the opposite direction. From the numbers this hypothesis can be confirmed. It can be seen that the morning peak hour (8:00-8:59) is associated with a larger demand that the evening peak (16:00-16:59), this phenomenon could also be deduced from Figure N-14.

Table N-4 presents the ratio's used for the analysis in Section 6.5.

Table N-3: Identification of peak hour intensities per direction

	Vleuten -> Utrecht CS		Utrecht CS -> Vleuten	
	Absolute	%	Absolute	%
Day	103947		106066	
8:00-8:59	12630	12,15%	5887	5,55%
16:00-16:59	6113	5,88%	11560	10,90%

Table N-4: Distribution of the demand per hour, compared to a working day between 8:00-8:59 (both directions together)

Hour block	Working day	Saturday	Sunday
05:00-05:59	0,01	0,00	0,00
06:00-06:59	0,11	0,01	0,00
07:00-07:59	0,58	0,06	0,01
08:00-08:59	1,00	0,16	0,04
09:00-09:59	0,64	0,28	0,08
10:00-10:59	0,62	0,28	0,13
11:00-11:59	0,58	0,31	0,16
12:00-12:59	0,76	0,42	0,21
13:00-13:59	0,71	0,41	0,24
14:00-14:59	0,72	0,39	0,24
15:00-15:59	0,86	0,41	0,23
16:00-16:59	0,92	0,39	0,24
17:00-17:59	0,93	0,33	0,24
18:00-18:59	0,55	0,27	0,19
19:00-19:59	0,34	0,19	0,16
20:00-20:59	0,25	0,16	0,18
21:00-21:59	0,26	0,16	0,18
22:00-22:59	0,24	0,15	0,11
23:00-23:59	0,15	0,14	0,07
>00:00-00:59	0,08	0,11	0,03
>01:00-01:59	0,01	0,01	0,00
>02:00-02:59	0,00	0,00	0,00

Appendix O Interview R. J. Roos

This Appendix presents the summary of an interview with Robert Jan Roos. R. J. Roos is a public transport consultant at Arcadis. He has been closely involved in the design of the 'Zuidtangent'.

Attendees: Patrick van der Meijs, Robert Jan Roos
Location: Office Arcadis, Piet Mondriaanlaan 26, Amersfoort
Date: 01-09-2014
Time: 15:00-16:00

Shuttle

Doel: Nieuwe reizigers in het openbaar vervoer te trekken. Initiatief vanuit Vervoerbedrijf Centraal Nederland. Project in de omgeving van Amsterdam Zuidoost (destijds de Zuidas van Amsterdam). Het doel was werknemers die reizen per auto een alternatief te bieden in de vorm van collectief vervoer. Jan Fijn van Draat deed onderzoeken om erachter te komen waar de reiziger echt "warm" van wordt. Vanuit deze onderzoeken en het maken van een echt marktproduct is de shuttle formule ontstaan.

Vanuit andere vervoerbedrijven is gekeken om deze formule te kopiëren. Bleek geen succes, moet worden aangepast aan de behoeften per regio (deze ervaring is opgedaan in Zwolle).

Zuidtangent

Zuidtangent is destijds beredeneerd vanuit kwaliteit van rijden. Voorwaarde hiervoor was het hebben van 'vlotte' route met een hoog comfort. Het zgn. "Rijden als een tram". Hierdoor zijn bijvoorbeeld de bogen ruim ontworpen. Vanuit de politiek (provincie Noord-Holland), is vlak voor de aanleg aangegeven dat de infrastructuur eenvoudig omgebouwd moet kunnen worden naar tram. Om dit mogelijk te maken is de betonnen busbaan 20 cm dikker aangelegd om t.z.t. de rails in de bovenste laag in te frezen. Het lijkt nu technisch en praktisch nagenoeg onhaalbaar om meer dan 300 km tramrails in te frezen (hinder omwonenden, buiten gebruik van de Zuidtangent gedurende een lange periode). Daarnaast zal na de ombouw een zeker niet sneller product worden geboden met een (veel) lagere frequentie

Afgesloten haltes zijn nooit overwogen. Wel de gelijkvloerse instap is een belangrijk kernpunt geweest om de kwaliteit van de reis te waarborgen. Het "knielen" van de voertuigen bij elke halte werd als negatief ervaren, zodat er gekozen is de perronhoogte op 28 cm te brengen (binnen de randvoorwaarden geboden toegang)

Het traject Schiphol - Haarlem stuk hoogwaardiger dan Schiphol - Amsterdam Zuid en Schiphol - Bijlmer Arena. Deze beide routen hebben op belangrijke trajecten (A9, A10) geen eigen infrastructuur en daardoor hinder van het overige verkeer (onbetrouwbaarheid). Daarnaast bevatten deze trajecten veel haakse bochten (minder comfortabel) en een lagere prioriteit op kruisingen (lagere reissnelheid). Het gevolg hiervan is dat de vervoerontwikkeling op deze stukken ver achter blijft t.o.v. het kerntraject Haarlem - Schiphol (Noord). Ook uit de jaarverslagen van de Zuidtangent blijkt dit.

Een van de redenen hiervan is dat je te maken hebt met verschillende gemeentes die allemaal hun eigen ideeën hebben (o.a. Haarlem, Amstelveen, Amsterdam). Dit resulteert in verschillende verschijningsvormen en bijbehorende kwaliteitsniveaus. In Frankrijk zijn deze problemen vaak nog groter wanneer er soms wel 24 verschillende gemeenten bij betrokken zijn.

Het idee was oorspronkelijk bij Schiphol de infrastructuur één niveau boven maaiveld aan te leggen. Op deze manier kon het kruisen met voetgangersstromen worden vermeden. Dit is uiteindelijk niet doorgegaan omdat de Zuidtangent een bussysteem is, en door de nieuwe vervoerder gesteld is dat deze kwaliteiten alleen bij tramsystemen horen.

Bij de instructie van het personeel voor de opening van de Zuidtangent is sterk gefocust op kwalitatief hoogwaardig rijden. Door het kwalitatief hoogwaardig rijden:

- Worden halteertijden sterk verkort (mensen lopen al naar de deur voordat ze aankomen bij een halte wanneer ze weten dat de chauffeur langzaam zal remmen
- Wordt een hoop brandstof bespaard (+-15%).

HOV/BRT zonder focus op de Zuidtangent
We kunnen stellen dat Nederland het, ten opzichte van de rest van Europa goed doet op het gebied van HOV/BRT. Dit blijkt ook uit het COST rapport, geschreven door (Finn et al., 2011). De ervaring leert echter dat in Nederland vaak wordt gefocust op wat er niet goed gaat, en de vele dingen die wel goed gaan uit het oog worden verloren.

Het OV wordt vaak ontwikkeld vanuit allerlei standpunten/drijfveren: beschikbare subsidies, nieuwe technieken, enz. Het belangrijkste, het ontwerp van het OV naar wens van de reiziger, wordt in veel gevallen onderbelicht.

Afstudeerwerk Josh Bennink: framing carrousel waarin verschillende denkbeelden gerelateerd aan HOV worden weergegeven. De ervaring leert dat veel technisch onderlegden het HOV maar benaderen vanuit één oogpunt. De vraag is echter hoe je van OV, HOV maakt zodanig dat je een groter bereik krijgt dan de vaste reiziger.

BRT in Curitiba is ontwikkeld volgens het vingerstad model. Het kent een aanbestedingssysteem waar een goede aanbesteder mag blijven. Duidelijke bandbreedtes zijn afgesproken voor aantal prestatie indicatoren, pas wanneer men hierbuiten opereert wordt er opnieuw aanbesteed. Hier vind dus concurrentie plaats op basis van de werkelijke prestatie. In Nederland is dit tegenstrijdig. Hoe je ook functioneert na verloop van tijd wordt er opnieuw aanbesteed op basis van je prestatie op papier en niet in het echt.

Trambonus internationaal niet echt vindbaar. Je moet het eerder zien als kwaliteitsbonus.

Betreft het betalen op halte. BRU heeft er heel bewust voor gekozen om bij de tram te betalen buiten het voertuig. Kan ook voor de bus een mogelijkheid bieden tot kortere halteertijden.

Bij het ontwerp van het OV-chipkaart systeem is er veel te weinig gekeken naar het gebruiksgemak van de klant. Het is een subsidie gedreven systeem. In Taiwan een systeem met één pas waar alle betalingen mee gedaan kunnen worden, werkt hier perfect. In Nederland was het OV-chipkaart systeem voorheen al geïntegreerd in de betaalpassen. Er werd echter, gedreven door subsidies, zelf een systeem ontwikkeld. Uiteindelijk is een systeem overgenomen uit Hong Kong. Dit systeem is gebaseerd op 320 haltes, hier zijn het er veel meer. Indien TLS meer omzet gaat genereren door andere betaaldiensten aan het product te koppelen bestaat de kans dat het volume aan geld te groot wordt en een bankvergunning te komen.

Eigenlijk zijn alle OV systemen wereldwijd subsidie behoevend, op twee na:

- London Docklands Railway. Dit is echter omdat de voorganger failliet is gegaan, en een groot deel van het systeem al was afgeschreven.
- Singapore metro. Hier mag de operator zelf de locatie van de haltes bepalen in combinatie met hele sterke 'Transit Oriented Development'

Amsterdam - Purmerent: heel snel van Amsterdam naar Purmerent maar hier uiteindelijk kris kras door de stad. Resultaat van een beleidsbeslissing die niet uit het oogpunt van reiziger is genomen.

Betreft mijn onderzoek: Kijk echt waar de reiziger in geïnteresseerd is. De meerwaarde ligt erin te kijken naar de matrix wat en waar hebben ze iets gedaan en kijk of het functioneert of niet functioneert.

HOV bus in Huizen: je kan allerlei maatregelen om te versnellen in de stad teniet doen, door één halte op een onhandige manier vorm te geven (onderaan de afrit Eemnes is hiervan een voorbeeld). Dergelijke zaken als in Huizen is in veel systemen aan de hand. Wanneer je de service van een tram wil benaderen, waarom gebruik je dan haltekommen? Leg je gemakkelijk te mijden haakse bochten op het traject? Laat je een bus een ronde over plein rijden (Enschede)?

HOV systeem in Madrid is echt een mooi product geworden. Voorbeeld van de wil er iets goeds en moois van te maken.

HOV in Frankrijk over het algemeen zeer mooi. Twee straten buiten de corridor is er echter vaak weinig te merken van de verbeteringen.

Het gaat erom dat je een visie hebt, en de wil hebt er iets moois en goed van wil maken. Of het dan 'light' of 'heavy' BRT is maakt veel minder uit, een visie is veel belangrijker.

Appendix P Survey of Leidsche Rijn

This appendix presents the most important findings of a survey of the area of Leidsche Rijn. The survey is executed on 07-05-2014 together with R. Tiemersma. The numbers in the text below refer to the numbers indicated in Figure P-1.

- Ontsluiting Castellum in toekomst niet optimaal. Dit gebied zal bezoekers gaan trekken uit Leidsche Rijn, Utrecht en misschien zelfs uit de regio. Het kan daarom wenselijk zijn de bereikbaarheid per OV te verbeteren. (1)
- De kwaliteit van de fietsenstallingen bij de haltes kan beter. Soms is er een tekort. Verder kunnen overdekte stallingplaatsen de aantrekkelijkheid verhogen.
- Het knooppunt De Meern-Oost stelt weinig voor, het ligt zeer afgelegen (2). De koppeling met het nabijgelegen bedrijventerrein en kantorenlocatie Ouderijn Zuid is er niet (3). Mogelijk kan de aantrekkelijkheid verbeterd worden door het beschikbaar stellen van bedrijfsfietsen.
- Er gaan ook stemmen op het knooppunt de Meern-Oost een stuk naar het noorden te verplaatsen (t.h.v Langerakbaan). Dit om zo ook lijn 26 erbij te betrekken (4). Dit is een logischere plek gezien het grotere aantal bestemmingen en hogere dichtheden in de omgeving.
- Een deel van Veldhuizen is relatief slecht bereikbaar met het OV (loopafstand van +- 1200 m). Dit gebied wordt echter voornamelijk bevolkt door gezinnen met een of meerdere auto’s waarvoor dit een relatief klein probleem is (5).
- Op een aantal locaties moet de busbaan van lijn 28 onnodig vaak gekruist worden door fietsers. Dit levert onnodig gevaarlijke situaties op (locaties eventueel later specificeren).
- Vleuterweide beschikt over een groot winkelcentrum dat veel bezoekers trekt (6). De organisatie van de stromen fietsers, auto’s en de bus is echter verre van optimaal. Vooral op zaterdagochtend levert dit chaos en bijbehorende gevaarlijke situaties op. Een van de oplossingen die nu wordt onderzocht is auto's te laten meerijden op de busbaan. Dit kan de kwaliteit van het OV beïnvloeden.
- Mogelijk idee voor uitbreiding van het netwerk: bij station Vleuten een doorsteek richting Maarsen (7). Dit om een snellere verbinding tussen Vleuten/De Meern en Maarssen, Breukelen en Amsterdam (Zuid Oost) te creëren. De haalbaarheid hiervan is twijfelachtig gezien de doorkruising van het centrum van Vleuten. Ook de vervoersvraag kan tegenvallen, onder meer vanwege het hoge autobezit in Vleuten.
- Een andere mogelijke uitbreiding van het netwerk is Vleuten en Terwijde met elkaar verbinden(8). Hiervoor is een nieuwe aansluiting (voor de bus) nodig van Vleuten op de Haarrijnse Rading. Op deze wijze zouden ook de recreatieplassen (Haarrijnse Plas (9)) ten noorden van Vleuten (in de zomer populaire recreatieplekken) ontsloten kunnen worden. Dit betekent wel een doorkruising van het noordelijke lint.
- De haltedichtheid van lijn 28 is binnen Leidsche Rijn misschien te laag. Vooral in vergelijking met het deel door Utrecht ‘voor de brug’.
- Het deel van lijn 28 dat in De Meern over de Rijksstraatweg loopt en hier geen geheel eigen infrastructuur heeft lijkt weinig invloed te hebben op het kwaliteitsniveau van de lijn (10).

Figure P-1: Overview of study area of Leidsche Rijn