The application of a multi-operator smart card dataset to identify transfer locations with a high potential for transfer time loss minimization

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The application of a multi-operator smart card dataset to identify transfer locations with a high potential for transfer time loss minimization

by

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Preface

In front of you lies my thesis which marks the end of my 8-year journey of being a student at different universities. During these years, I increased my scientific knowledge and I have grown as a person. During high school, I did not know what to study. I started my bachelor's: Spatial Planning and Design at the University of Groningen, but after two and a half years, I already knew I wanted to specialize more in transport and infrastructure. Therefore, after staying in Groningen a little longer and having done a board year for the tennis association in Groningen, I started my master's Transport, Infrastructure and Logistics at the TU Delft with this thesis as my final report.

During my master's, I got very interested in transport modeling. I wanted to do something with this in my thesis and after a discussion with Niels van Oort, I had contact with Goudappel. Together with Arthur Scheltes we decided to start a project by using a multi-operator smart card dataset. Goudappel provided me with the opportunity to do my thesis project at their company in collaboration with the TU Delft. Therefore, I would like to thank my graduation committee. I would like to thank Arthur Scheltes for his ideas, advice and feedback during my process. The second committee member I would like to thank is Niels van Oort for introducing me with Goudappel, detailed feedback, meetings and phone calls. I would also like to thank Jan Anne Annema, for his quick responses, supervision and optimism. The fourth committee member I would like to thank is Chris Tijs for supervision, input and for diving together into the smart card dataset. Lastly, I would like to thank Bart van Arem for his feedback and for chairing this committee.

8 years ago, I never thought I would become an engineer at the TU Delft. I could not have done this without the support of my family, especially my parents. Thank you for supporting me over the past 8 years. I would furthermore like to thank my friends for supporting me, especially during the final months. Lastly, a big thank you to my girlfriend Iris for reading chapters of this thesis, giving me feedback and keeping me motivated.

I hope you will enjoy reading this thesis!

J.H.G. (Jorick) Ensing
Delft, May 2022

Executive summary

Public Transport travelers often need to transfer on their journey. However, travelers dislike transfers; it gives a disutility. Consequently, minimizing this disutility allows for travelers' satisfaction to be increased. In order to do so, the transfers need to be identified first. This is where smart card datasets come in. Smart card datasets can be single-operated as well as multi-operated. From existing literature and conducting interviews, it became clear that single-operator smart card datasets allow for the identification of transfers between the same operators, while multi-operator smart card datasets enable the identification of transfers between different operators as well. However, literature has not yet addressed how a multi-operator smart card dataset can contribute to the minimization of transfer disutility in Public Transport. Therefore this study aims to answer the research question: *In what way can a multi-operator smart card dataset analysis contribute to the minimization of the disutility of transfers for Public Transport journeys?*

To answer the research question, different methods are applied. Firstly, literature research is done to get to know more qualitative information about the factors influencing the disutility of a transfer as well as the design and differences of smart card datasets. Furthermore, this study uses a case study to apply the aforementioned knowledge and answer the research question within this particular context. Within the case study, firstly, a multi-operator smart card dataset is used to identify important transfers with a high potential to minimize its disutility. Then, a measure that reduces the disutility is implemented and tested on the effects on the network in a transport model. Finally, the case study results allow for conclusions on the contribution of such a dataset to the minimization of transfer disutility, both within the case study and generalized beyond the case study.

First of all, current literature sheds light on the various disutility factors of transfers and the current use of smart card datasets. Literature research shows multiple studies mentioning several factors influencing the disutility of a transfer. These are given in table 1. All the discussed papers mention the waiting- and walking time factors. The factors: waiting time, walking time, stairs (the need to level up/down a level), crowding, mode (need to change modes), activity (needing to interrupt an activity) and having difficulties finding the way at the transfer (the ease of wayfinding (EofW)) increase the disutility of a transfer. Having real-time information displays available, having station facilities and the presence of escalators can reduce the disutility of a transfer. This study focused on the factors: waiting time, walking time, stairs, mode, real-time info, station facilities and escalators.

Table 1: Overview of scientific papers that estimates and/or mentions factors that influence the (dis)utility of a transfer

	Wait T	Walk T	Stairs	Crowding	Mode	Real time info	Station fac.	Activity	EofW	Escalators
Garcia-Martinez et al. (2018)	x	x	x	x	x	x		x		
Schakenbos et al. (2016)	x	x			x		x			
Cascajo et al. (2017)	x	x	x	x	x	x	x	x		
Nielsen et al. (2021)	x	x	x				x		x	x
Chowdhury and Ceder (2013)	x	x				x				

Literature also shows that smart card datasets are being used worldwide. Studies from different cities are examined in this study, all of which have applied smart card datasets to identify transfers and examine their Public Transport network. The smart card datasets discussed, used a time interval of 15-60 minutes between check-out of the first trip and the check-in of the second trip to identify transfers and have almost all information about the check-in and out times, check-in and out stops and the smart card ID. Other attributes such as the trip ID, vehicle ID, mode, direction, card type, line number, ride time, operator, distance and fare are sometimes included as well. Especially the studies where the operator attribute is included are interesting, as such an attribute indicates the use of a multi-operator smart card dataset.

From the literature, the design of smart card datasets over the world and which factors influence the disutility of a transfer are known. By having this background knowledge, the study focused on a multi-operator smart card datset for the case study: Haaglanden area. While the (dis)utility factors are known, the transfers in the multi-operator smart card dataset can be analyzed regarding their (dis)utility factors. The case area is located around Den Haag in the Netherlands and is selected because of its high percentage of access and egress Public Transport to several big stations, which indicates a high number of transfers.

The dataset uses a 35-minute time interval to identify transfers and it contains information about the number of travelers using every unique transfer in a specific time interval. Additionally, the average transfer time, the transfer station and which line the traveler is coming from and which line the traveler is going to is included as well.

The multi-operator smart card dataset was analyzed and examined to identify important transfers with a high potential to minimize its disutility. The first dataset analysis shows that four out of the eleven stations have significantly more transferring travelers. These are: Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft. For each of these transfers, the transfer flows and the corresponding average transfer times were visualized and the (dis)utility factors were investigated. The flows were given in chord diagrams, which are especially useful when comparing flow sizes because the flows and sizes can be seen in one glance.

For illustration, for one of the stations, Den Haag Centraal, the chord diagram is visualized in figure 1. The corresponding average transfer time of the transfers at Den Haag Centraal is given in figure 2. The arcs (width) in the chord diagram represent the flows (size) and the color corresponds with the color of the first trip. As can be seen, transfers at Den Haag Centraal are done from/to three different directions by train (track to/from Utrecht (Ut), Amsterdam (Ams) or Rotterdam (Rt)) and from/to the four wind directions. The highest flows are between the Amsterdam track and the West (W) and vice versa. Looking into the average transfer time graph in figure 2, the flow from the Amsterdam track towards the West has an average transfer time slightly above the weighted average of all the transfer times at Den Haag Centraal. The flow from the Amsterdam track towards the North, a large flow, has the third highest average transfer time.

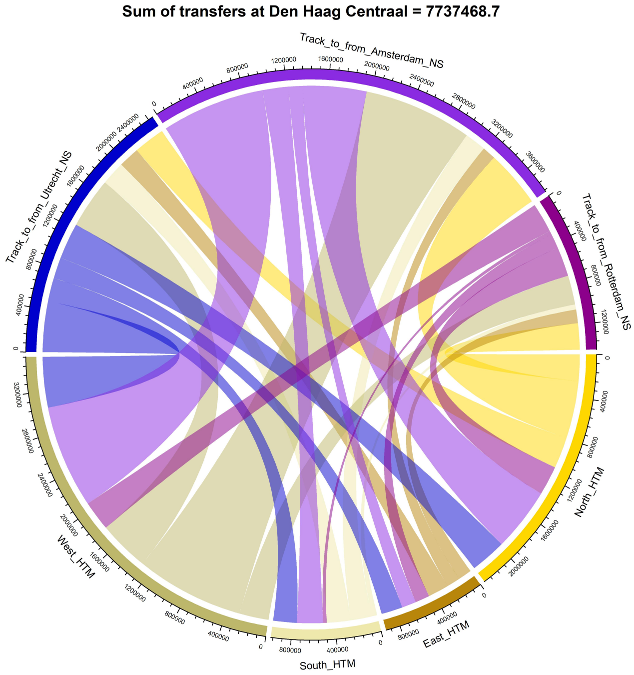

Figure 1: Number of transfers via Den Haag Centraal station between NS (train) and HTM (bus/tram) and their directions

A chord diagram and an average transfer time graph have been made for all four transfer stations. The (dis)utility factors are also examined for each transfer station. For transfers at each transfer station, apart from some transfers at Den Haag Centraal, travelers need to level up or down, increasing the disutility. All transfer stations have real-time information displays for the transfers, reducing the disutility. Den Haag Centraal and Den Haag HS have a very large number of station facilities, Delft a large number and Den Haag Laan van NOI a medium number resulting in a lower disutility for Den Haag Centraal and Den Haag HS and a little lower disutility for Delft station. Apart from transfers at Den Haag Laan van NOI, all transfers at the stations have access to escalators, which reduces the disutility.

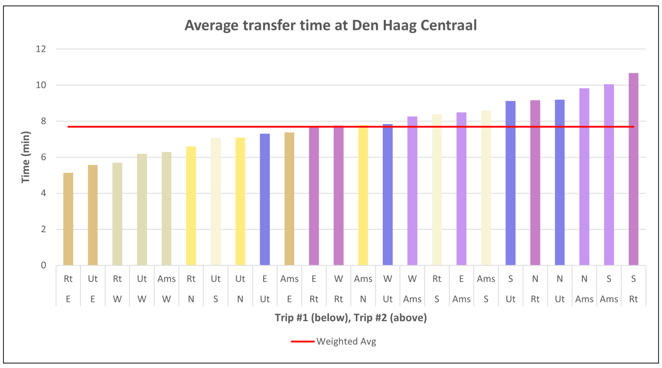

Figure 2: Average transfer time of transfers at Den Haag Centraal between NS (train) and HTM (bus/tram) and their directions

One would expect that higher (lower) average transfer times have a lower (higher) flow, due to the associated disutility. This is sometimes not the case for the transfer stations. Sometimes this can be explained by the other (dis)utility factors, however, while other reasons such as having a high demand (travelers have a reason to go somewhere) and no other (better) alternative available can influence the transfer flow sizes even more, the (dis)utility cannot always explain the flow size.

After examining the most important transfer stations, the individual transfers were examined. Together with the operator HTM, a top 10 transfer with the highest transfer time loss was found to be most interesting to examine further. For the top 10, the (dis)utility factors, including the waiting times and walking times, are examined. For these individual transfers as well, it is found hard to explain the flow sizes by the (dis)utility factors alone.
Now that the most important individual transfers were known, the transfer that has the highest impact on reducing the total transfer time loss was determined when reducing the waiting time by one minute, which can be facilitated by synchronizing the timetables of the concerning lines better. It is found that the transfer from the Train IC from Amsterdam Centraal at Den Haag Centraal towards tram 9 to Zwarte Pad has the highest impact. The share of this particular transfer of the total transfer time loss of all the transfers together (=3577 transfers) decreased by around 0.16 points (from 1.06% to 0.9%) by having a waiting time reduction of one minute. By reducing the waiting- and thus the transfer time of this transfer, this transfer becomes more attractive as the disutility will decrease. Therefore, this measure is implemented and tested in a transport model (OmniTRANS) to examine the effects on traveler flows in the network.
An increase can be found on the measure's implementation line, line 9 to Zwarte Pad. The effects are shown in table 2. The flow increase (371 at Den Haag Centraal) is because travelers from other lines are taking tram 9 to Zwarte Pad instead and because there are new travelers on the network. Therefore, a waiting time reduction to lower the disutility of a transfer can influence travelers' choice behavior of choosing different routes and modes. This furthermore indicates that (dis)utility factors seem to explain (partially) flow sizes.

Table 2: Stops with flow difference on line 9 to Zwarte Pad (working day) after implementation of the measure

Tram stop	**Pass.**	**#1 Board**	**Last Alight**	**Ch. Board**	**Ch. Alight**	**Walk Board**	**Walk Alight**	**Sum Board**	**Sum Alight**
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	-14	0	0	0	-14	0
146,Den Haag, Centraal Station Beneden	-14	371	0	0	0	0	0	371	0
433,Den Haag, Malieveld	357	0	29	-3	0	-27	0	-30	30
434,Den Haag, Dr. Kuyperstraat	298	0	81	0	0	0	0	0	81
435,Den Haag, Javabrug	217	0	38	0	0	0	0	0	38
436,Den Haag, Laan Copes van Cattenburch	179	0	43	0	0	0	0	0	43
437,Den Haag, Riouwstraat	136	0	11	-1	0	0	0	-1	11
461,Den Haag, Madurodam (Noord)	125	0	22	0	0	0	0	0	22
462,Den Haag, Wagenaarweg	103	0	4	0	0	0	0	0	4
464,Den Haag, Nieuwe Duinweg	99	0	15	0	0	0	0	0	15
1088,Den Haag, Circustheater	83	0	24	0	0	0	0	0	24
74,Den Haag, Kurhaus	59	0	50	0	0	0	1	0	51
75,Den Haag, Zwarte Pad Uitstaphalte	8	0	8	0	0	0	0	0	8
Total		**371**	**325**	**-18**	**0**	**-27**	**2**	**327**	**327**

To determine which measures to implement to minimize the disutility of a transfer, it is important to examine the effects of such a measure in the network as it can lead to more crowding, which gives a (high) disutility. Furthermore, a measure such as synchronizing timetables better can lead to more inefficient and unreliable other transfers.

All in all, this study sheds light on how multi-operator smart card datasets can contribute to minimizing the disutility of Public Transport transfers. It concludes that, having implemented particularly valuable data and attributes such as: the transfer station, the trip and line towards the transfer station (which can also be derived from the check-in stop and the operator name), the trip and line after transferring (which can also be derived from the check-out stop and operator name), the number of travelers and the average transfer time (which can also be derived from the check-in- and check-out times and the number of travelers), multi-operator smart card datasets can be used to:

1. Identify most important transfer stations and individual transfers, where minimizing the disutility has the highest impact
2. Illustrate how one particular measure can lower the transfer time disutility

This study therefore concludes that multi-operator smart card datasets are highly valuable for practitioners, such as operators, given their ability to gather information on transfers and their disutility, in order to maximize overall satisfaction of their Public Transport. This, in turn, has a positive effect on operators' reputation as a Public Transport operator and may increase the use of Public Transport. On top of that, this study contributes to the literature as follows. Firstly, it shows which attributes of a multi-operator smart card dataset are required to be able to identify appropriate transfers and consequently minimize the disutility of transfers. Secondly, it adds to the current literature by proposing a method by which a multi-operator smart card dataset can be applied to identify and determine transfer locations with a high potential for disutility minimization. Lastly, it demonstrates the implementation of an example measure and how effects can be examined by means of a transport model.

The results and conclusions of this study gave rise to recommendations for operators, researchers and smart card dataset developers.
It is recommended for the operator to explore possible crowding effects when implementing the measure as crowding gives a disutility. Furthermore, the operator should explore the effects on other lines and transfers as these can become more inefficient by implementing a timetable synchronization. For research, it is advised to test if the method used to identify the most important transfer(s) (stations) results in the same transfer(s) stations as other methods. Furthermore, it is recommended to study the exact (dis)utility values of the city specifically. Then, the (dis)utility of a transfer can be determined with a value and better conclusions can be drawn whether, and to what degree, (dis)utility factors explain the transfer flow sizes. Finally, when a low number of travelers take a transfer in a time interval, privacy regulation can play a role. This can result in bins for the number of travelers that have taken the transfer. If this is the case, it is recommended to aggregate the multi-operator smart card dataset on a high time interval level to avoid these bins. How high the level aggregation level needs to be depends on the aim of the research and on the flow sizes in the network.

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List of abbreviations

PT	Public Transport
NS	Nederlandse Spoorwegen
HS	Hollands Spoor
AVL	Automatic Vehicle Location
APC	Automatic Passenger Counts
AFC	Automatic Fare Collection
Translink	Trans Link Systems
IC	InterCity train
SPR	Sprinter train
NOI	Nieuw-Oost Indië
DHC	Den Haag Centraal
BTM	Bus, Tram, Metro

Contents

1
Introduction

In Public Transport (PT) transfers are common. A transfer is a point where different PT lines intersect within the PT network (Garcia-Martinez et al., 2018). At a transfer travelers can travel with a PT operator and switch to a different PT line of the same PT operator or switch to a different PT line from a completely different PT operator. So, transfers can be done in a network of the same PT operator or in a network between different PT operators. The transfers in a journey are disliked by travelers, it gives a disutility (Garcia-Martinez et al., 2018; Schakenbos et al., 2016; Abrantes and Wardman, 2011; Wardman, 2004; Balcombe et al., 2004; Lu et al., 2018; Guo and Wilson, 2007; Nielsen et al., 2021; Cascajo et al., 2017; Chowdhury and Ceder, 2013). By reducing the disutility of a transfer, journeys with a transfer are liked more by travelers and possibly will be used more often. Reducing the disutility of transfers may lead to a higher use of PT and a lower use of the car mode, which is beneficial for the environment. This is also one of the reasons that governments, such as the government of the Netherlands, strives to have a good connection between all the different Public Transport (Rijksoverheid, 2021).

1.1. Research problem

On nodes (such as a PT station) travelers begin, end or transfer their journey. Often multiple PT operators operate on these nodes (regional and national operator(s)), which may require transferring travelers to switch PT operators during their trip. A transfer, however, has a disutility for traveling with PT (Garcia-Martinez et al., 2018). The disutility of a transfer can be seen as the negative effect on the satisfaction of the travelers as transferring equals, for example, longer waiting and walking times (Balcombe et al., 2004; Wardman, 2004; Abrantes and Wardman, 2011). The transfers between modes are even perceived as the least useful or appreciated part of the journey (Hagen, 2011). To identify the transfers of journeys, an analysis of smart card data is practical. Smart card datasets can be single-operated as well as multi-operated. Operators often have access to single-operator smart card datasets. With single-operator smart card datasets, transfers between the same operator are visible. The most important goal of using these datasets is to develop a substantiated transportation plan where the modifications for the following year will be developed and communicated to the client and to optimize the timetable (Interview HTM, 2022; Interview NS, 2022). Operators do not directly have access to multi-operated smart card datasets. Interviews with operators in the Netherlands revealed that the use of a multi-operator smart card dataset is uncommon as it involves numerous insecurities, while the process to come to a multi-operator smart card dataset costs much time, operators have to deal with company-sensitive information and privacy regulations and need to take competition rules into account (interview HTM, interview NS). However, with multi-operator smart card datasets, or as van Hees (2021) describes, an interoperable dataset, transfers between different operators are visible as well (Interview HTM, 2022; Interview NS, 2022). Therefore, transfers can be identified and developed better with a multi-operator smart card dataset, especially when proper substantiation is desired. A few studies have been done that use such a multi-operator smart card dataset to identify transfers (e.g., Nishiuchi et al., 2015 and Soltani et al., 2015). By identifying and knowing the characteristics of transfers, operators can adjust and improve their network to have better transfers. Although a few studies have been done on this subject, it is not known how a multi-operator smart card dataset can help reduce the disutility of a transfer. Therefore, the problem addressed by this research is that it is currently not known in what way and to what extent an analysis of such a multi-operator smart card dataset can contribute to minimizing the disutility of a transfer between multiple PT operators.

1.2. Research gap and relevance

Transfers between different operators can be identified in a multi-operator smart card dataset (an interoperable system). As said, a few studies have been done using a multi-operator smart dataset to identify transfers and to examine the network and amount of travelers (e.g., Nishiuchi et al., 2015 and Soltani et al., 2015). However, it is currently unknown how an analysis of such a smart card dataset can contribute to minimizing the disutility of a transfer. Therefore this research tries to fill in this gap by analyzing the multi-operator smart card dataset about the usefulness to tackle the disutility of transfers. By knowing how such a smart card dataset is useful, PT operators may adjust according to the outcomes. They may know what and to what extent they are able to adapt and improve their network, which may lead to a lower disutility for their travelers. A lower disutility can lead to higher satisfaction among travellers and it might even result in a higher share of PT users. For this research, a case study will be done. However, the results of this research lead to insights for other (future) research using a multi-operator smart card dataset all over the world as the use of PT data systems is widespread (van Oort and Cats, 2015; Zannat, 2019).

1.3. Research objective

The goal of this study is to explore in what way an analysis of a multi-operator smart card dataset can give insights and contribute to the minimization of the disutility of transfers in PT journeys. This is done by looking into a smart card dataset of two PT operators in the Haaglanden area. In the end, the final deliverable elaborates on the contribution of a multi-operator smart card dataset to minimizing transfer disutility by visualizing travelers' journeys and examining the transfer times and (other) factors that gives a disutility on a transfer. Furthermore, a measure will be implemented that can reduce the disutility of a transfer and the effect on the transfer flows in the network will be examined.

1.4. Research questions

The research objective leads to the following research question:

In what way can a multi-operator smart card dataset analysis contribute to the minimization of the disutility of transfers for Public Transport journeys?

Multiple sub-questions are formulated that contribute to answering the main research question.

Sub-questions

1. What is, according to literature, the impact of transfers on the (dis)utility of traveling with Public Transport and how can the negative impacts be minimized?
2. In what way are smart card datasets designed and how are transfers included?
3. What is missing in single operator smart card data to accomplish having better transfers between different PT operators?
4. What do Public Transport users flows of a multi-operator smart card dataset look like?
5. What can be analyzed about the (dis)utility of the transfers in a multi-operator smartcard dataset?

1.5. Scope

The spatial scope of this research focuses on the nodes where travelers are transferring as well as the most important transfers of the PT trips done by train, bus or tram, or the other way around in the Haaglanden - Den Haag area in the Netherlands. In figure 1.1 this area is plotted on a map. The central city of the area being discussed is the city of Den Haag, which is the third-largest city in the

Netherlands (Den Haag in cijfers, 2021). Transfer stations and transfers are examined, including the (dis)utility factors. In the end, a measure will be implemented to minimize the transfer time of a specific transfer and the following effects on the transfer flows in the network will be given.
The temporal scope of this research focuses on 2019 as it is seen as a more representative year than the years in which Covid-19 influenced travel behavior. Since the Haaglanden area is popular among tourists due to its beach and is home to many employees and business travelers, the research will not focus on any particular day.

Figure 1.1: Haaglanden - Den Haag area (Imergis, 2021)

1.6. Thesis outline

The next chapter, chapter 2, elaborates on the methods being used. A literature research follows this in chapter 3. After this chapter, the first 2 sub-questions can be answered. Chapter 4 goes in-depth into the data and the analysis approach. The results of this analysis will be given in chapter 5. In chapter 5, sub-questions 4 and 5 will be answered. Chapters 6 and 7 will end this thesis with a discussion, conclusions and recommendations. In figure 1.2 the structure of the thesis, together with the related (sub-) questions that are answered in the chapters, are visualized.

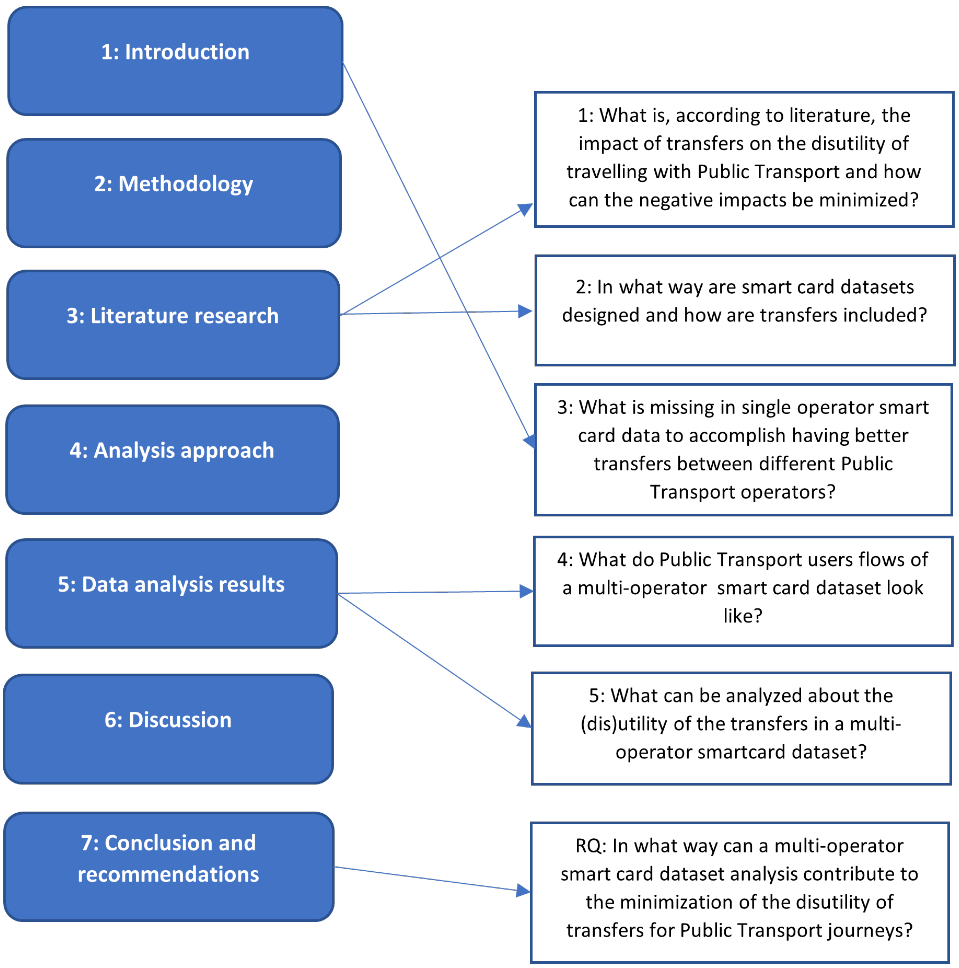


Figure 1.2: Thesis structure

2

Methodology

In order to provide answers to the research questions, different methods are used. This chapter will elaborate on these used methods. In section 2.1 the methodological framework with the linkages of the methods and the research questions is given. First, literature research is done that explains why this research is valuable, gives some important terms, elaborates on the disutility of a transfer and dives into the smart card datasets that are already used in studies all over the world. This is explained further in section 2.2. The study uses a case study which will be explained in section 2.3. In section 2.3.1 an elaboration on the interview method will be given. Section 2.3.2 will elaborate on the data processing including the data source, collection, preparation, analysis and the risks. In the data analysis of this part the programs Microsoft Excel and R are elaborated as well. The last section, section 2.3.3 elaborate on the transport model, OmniTRANS, that is used in this research.

2.1. Methodological framework

In figure 2.1 the methodological framework is given. The blue rectangles represent the sub-questions, the light blue rectangles represent the methods and the yellow shape is a dataset. Sub-questions 1 and 2 will be answered by conducting literature research. Several studies have examined the disutility of transfers and mention several factors influencing the disutility. Furthermore, also several studies all over the world have been done which use smart card datasets. Because there is a wide variety of studies done, a literature study is a useful method to answer these sub-questions. An alternative would be to have interviews, however, then the researcher will not find a wide variety as in the literature. Sub-questions 3 to 5 will be done within a case study. As a case study allows for a more detailed, in-depth investigation of a subject, in this case, transfer stations and transfers (The National Academies Press, 2020). Sub-question 3 will be addressed through interviews with Public Transport operators to understand and get to know more qualitative, in-depth information about what PT operators want to get out of their dataset, what is already possible with their single (or multiple) operator dataset(s) and what not. Sub-question 4 will be answered by analyzing and visualizing a multiple operator smart card dataset. This will mainly be done in Microsoft Excel and R. With R, the flows can be visualised and patterns can be seen. Sub-question 5 will be answered after visualizing the PT user flows and analyzing the transfer times and other disutility factors of specific transfers. Furthermore, a measure for an important transfer in the network will be implemented and tested to see the effects on the transfer flows in the PT network. This will be done in OmniTRANS, which is a transportation model. This program is especially useful to see the effects when changing the network. Finally, all the sub-questions contribute to answering the main research question. In the following sections of this chapter, the methods will be elaborated.

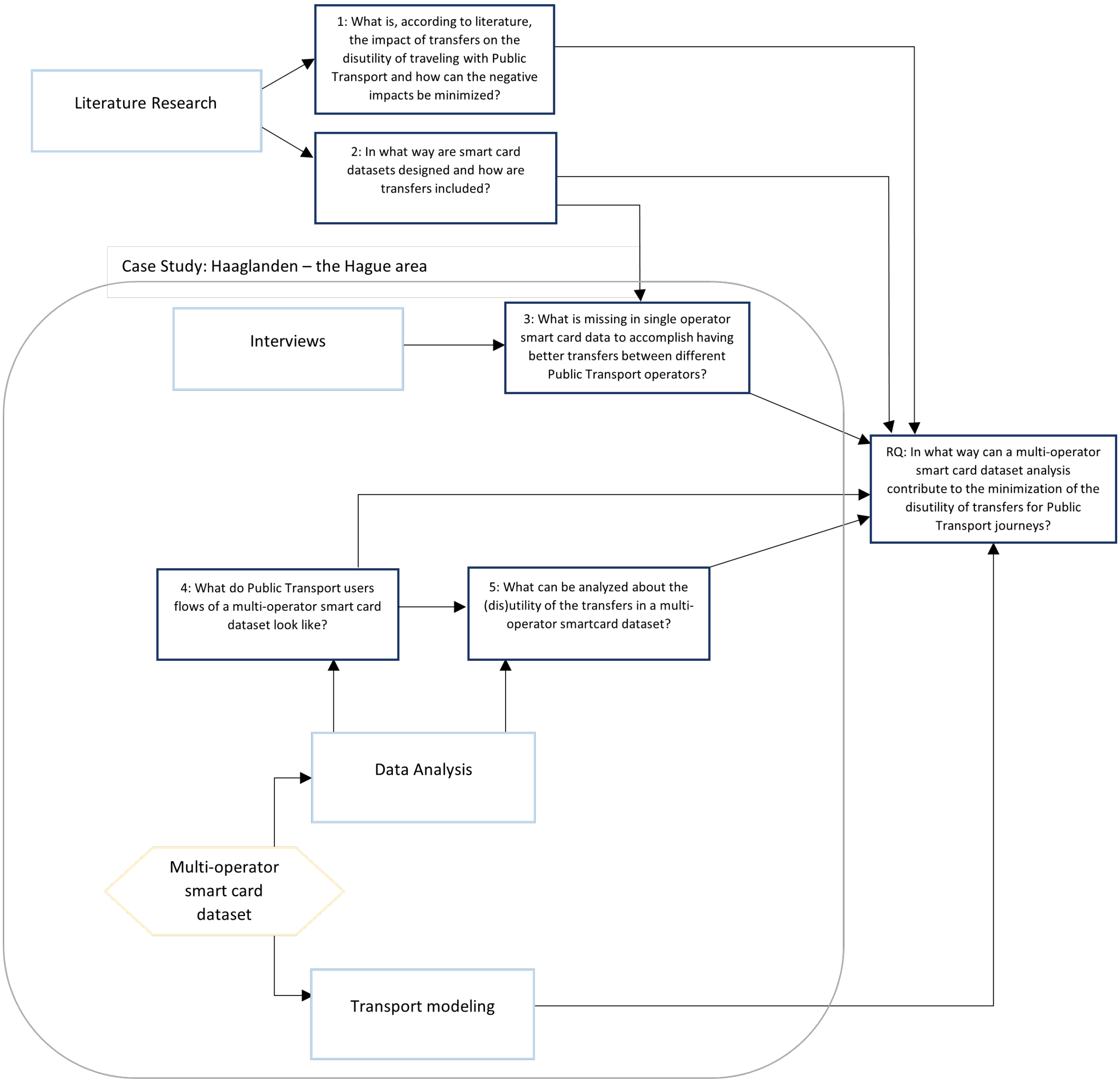


Figure 2.1: Methodological Framework

2.2. Literature research

Literature research is performed to identify the research gap, clarify terminology, elaborate on transfers and their disutility, explain PT data (especially smart card data) and enhance understanding of why transfers need to be optimized. In order to make inferences about what is missing in the current PT data, it is useful to understand how PT data works, what kind of data exists and especially how smart card data works, in what way it can be useful and what its limitations are. After the literature research, the first and second sub-questions will be answered. To collect information for the first two sub-questions many scientific papers, have been researched. Different search engines such as "Scopus", "Google scholar", the TU Delft repository and "Worldtransit research" have been used. The most important keywords used are "public transport", "smart card data", "transfer", "utility" and "transfer penalty". Conclusions from the second sub-question can be used for information to answer the third sub-question.

2.3. Case study: Haaglanden - Den Haag

As previously mentioned in section 1.5, this research focuses on the Haaglanden area in the Netherlands. The main and biggest city in the Haaglanden is Den Haag. The biggest station is "Den Haag Centraal station" followed by the station "Den Haag Holland Spoor" (HS). According to NS, Den Haag Centraal station had a daily average of 98,818 passengers checking in and out in 2019. This brings the station in the top 4 of check-ins and outs of all the stations in the Netherlands. 52% of the access transport from Den Haag Centraal station with NS is done by PT (bus, tram or metro), this share is 33% for the egress transport (NS, 2021). Similarly, Den Haag Holland Spoor has a daily average of 34,892 passengers that checked in and out in 2019. 38% of the access transport to Den Haag Holland Spoor with NS is done by PT (bus, trams or metro), this share is 34% for the egress transport (NS, 2021). Another big station in terms of check-ins and check-outs in the Haaglanden area is Delft. According to NS (2021), Delft facilitated 40,435 check-ins and outs in 2019 on an average day, where 17% is access transport and 21% is egress transport. Because of the high number of check-ins and outs in the Haaglanden region, this area is considered a useful case for this research. Especially because the Hague Central and Holland Spoor have a relatively high percentage of access and egress transport which means a lot of travelers transfer at these stations. In figure 2.2 a visualization of the Haaglanden area can be found. The biggest public transport operator in the city of the Hague (excluding the trains which NS operates) is HTM. Other PT operators are EBS, RET or Arriva (Wiki OV Nederland, 2021).
In this research the focus will be on the connections between the biggest operators in the Haaglanden area; NS and HTM. There exists 11 stations where both NS and HTM operate, these are: Delft, Den Haag Centraal, Den Haag Holland Spoor, Den Haag Laan van NOI, Den Haag Mariahoeve, Den Haag Moerwijk, Den Haag Ypenburg, Lansingerland-Zoetermeer, Rijswijk, Voorburg and Zoetermeer. A few important transfer stations and their transfers will be highlighted and examined in this study.

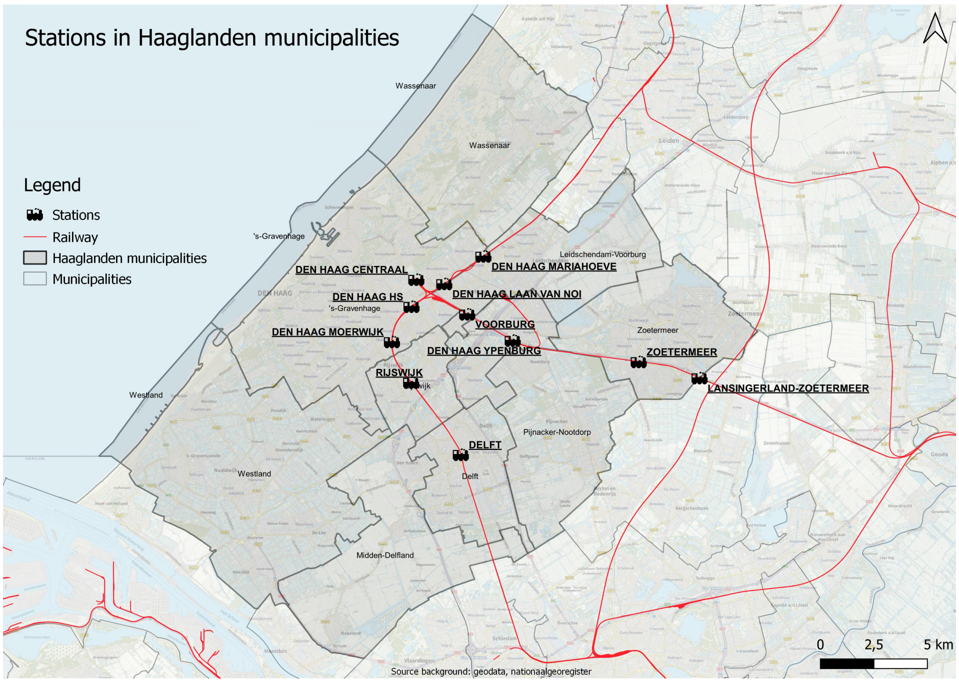


Figure 2.2: Haaglanden area and the stations

2.3.1. Interviews

Interviews with the Public Transport operators HTM and NS as well as Trans Link Systems (Translink) were held to gather more qualitative, in-depth information by getting to know their experience with single- and multi-operator smart card datasets in order to get to know the state of the art and the limits of the smart card datasets better. This will eventually flow into a comparison between single- and multiple operator smart card datasets and what an ideal dataset would look like for PT operators. This contributes to answering the third sub-question.

2.3.2. Data processing

This research uses data and therefore, the steps of the data processing will be elaborated. First, the data source will be explained, followed by data collection, preparation, analysis and the risks that come with data research.

Data source(s)

For this research multi-operator smart card datasets were used from Translink, consisting of data from the operators HTM and NS. Translink is the publisher of the smart card in the Netherlands and they manage a constantly growing dataset that includes information about the use of PT. They help PT operators and agencies improve decisions and solve mobility issues. Translink can build datasets that can see a journey as one single journey when a traveler uses multiple trips from multiple operators, a multi-operator smart card dataset. By doing so, the traveling patterns will become visible. Their goal is to make Public Transport more efficient for the traveler (Translink, 2021). For this study, datasets that include the connections between NS and HTM have been requested. This includes trips from NS and HTM and transferring to one another to see multiple trips as one journey. The data is gathered from smart cards. They are similar datasets as in van Hees (2021) but for different operators and a focus on transfers.

Data collection

Interviews contributed to getting the answer to sub-question 3. Both the NS and HTM are asked to share their experiences and opinions on using multiple-operator datasets and single operator datasets. The last two sub-questions are answered by analyzing and visualizing the datasets and the disutility factors of the transfers. Before examining the data, the correct data needed to be obtained first. HTM and NS gathered their own smart card datasets about multimodal trips via Translink. When access to these datasets was granted, the datasets needed to be thoroughly examined to decide if they were useful enough for this research which took much time. A few limitations were found. There was no information about the personal information of the smart card users, so there were no insights into the different user groups, which meant that this study would not focus on specific user groups. Furthermore, there were some errors in the data. Therefore, not all the information in the datasets was useful. Additionally, some assumptions needed to be made to work with the data.

Data preparation

After gathering all the needed data, the data was adapted for the following stages in the research. Not all the data was useful and some assumptions needed to be made. The data about the amount of transferring travelers were often given in an interval bin. To work with this data, assumptions, based on other datasets and calculations were needed. The data was prepared further for the analysis as well as for the visualizations as the software program R should be able to read the data in order to work.

Data analysis

After collecting and describing the data, the analysis and visualizations were done. The data and its usability is already discussed and assumptions are made. In the first step of the analysis phase, graphs are made that show the number of travelers traveling to or from a specific mode per transfer station. These graphs are made in Microsoft Excel. Microsoft Excel is a data visualization and analysis software of Microsoft. It uses spreadsheets where data can be stored and organized. By having formulas and functions, the data can be analyzed by doing calculations and computations. By means of the graphs, the most important transfer stations are determined. For these most important transfer stations (dis)utility factors are examined and chord diagrams with the flows and directions are made as well as graphs with the average transfer times for the same corresponding directions. The chord diagrams give an idea about the sizes of the number of travelers that are transferring and the graphs give an idea of how long the travelers have to transfer. Together this gives already an idea which transfers are favorable and which are not. The chord diagrams and the graphs are made in the programs R and Microsoft Excel. R is a program and a language for statistical computing and visualizations. One of its features is producing publication-quality plots and diagrams such as chord diagrams. With a chord diagrams flows between nodes can be visualized clearly (The R foundation, 2022). Therefore, R is a program that can be used to visualize the flows of the multi-operator smart card dataset.
In the next step several top 10s transfers are made to analyze the highest average transfer times,

the highest transfer time loss and the highest transfer time loss for line totals. Then together with the PT operator HTM these top10s are discussed and one top10 is determined to analyze these specific transfers further. These top 10s are determined by analyzing the data in Microsoft Excel. One of the main feature of Microsoft Excel that was helpful to determine the top 10s are pivot tables. Pivot tables are tables that can aggregate multiple attributes of a more extensive datasheet. In the next step, the transfers' transfer times are examined more thoroughly to know the share of waiting time and walking time of the total transfer time. The transfer stations of the corresponding transfers are analyzed further by analyzing the (dis)utility factors; presence of facilities, presence of real-time information, if travelers need to level up or down and if there is an escalator present. The share of waiting time and walking time is analyzed further to elaborate what the impact of this share is for the disutility of the transfer. Finally, a measure for one of the transfers is implemented in the network in order to lower the waiting time and the effects can then be given and visualized after running this measure in a transport model (OmniTRANS). For a schematic overview of the analysis and the visualizations, see figure 2.3. The data analysis part of this study will be explained in more detail in chapter 4.

Risks
There are always risks working with data in research. If the researcher needs data from external parties, it may take some time to actually get the data. This was also the case for this research. The researcher was in contact with NS and HTM about the datasets since July 2021 but received them only in October 2021. Contacting Translink, NS and HTM was a time-intensive process. The researcher needed to contact the parties multiple times which cost a lot of time and energy. When the researcher received the data, he analyzed the data for understanding and validity. It contained some striking data which, after discussion with Translink, could either be explained by clarification or by dataset errors. Therefore not all the datasets could be used. Furthermore, some assumptions needed to be made in order to work with all the data in the datasets. A significant weakness in the data that van Hees (2021) faced, is that due to privacy reasons, data about the number of travelers were provided in bins. This may lower the reliability of certain variables. This was also the case in this research's datasets, if only for the low number of transfers. As van Hees (2021) stated in his research, it is challenging to deal with the weaknesses of such a combined PT operator dataset and probably not doable to overcome all the weaknesses. However, in this research this weakness of having bins was solved with a reasonable assumption based on other datasets and calculations. Overall, the data collection and preparation process was a time-intensive task, which took longer than expected despite being taken into account in the research planning. The datasets and assumptions will be further elaborated on in chapter 4.

2.3.3. Transport model

In order to implement and analyze specific measures, data can be linked to a transport model called OmniTRANS (see, e.g., van Oort et al., 2015). OmniTRANS is a transport modeling program developed by Goudappel. It enables the researcher to see effects on mobility by quantifying, presenting and visualizing the data. It is multimodal, it can handle different time periods and is easy to compare specific results. It is especially useful to visualize the total flow on particular links of the network, so the researcher can immediately see where the bottlenecks are and on which links it is not busy at all (Dat.Mobility, 2021). Analyses can be done in the transport model to optimize transfers better by adapting the PT network or changing timetables. Adding, removing or changing a specific transfer, a link or timetable is possible and the transport model can visualize the effects, making it easy to compare. Therefore, in this research, OmniTRANS is used to visualize the impact on the traveler flows by implementing a measure (by having a change in the network).

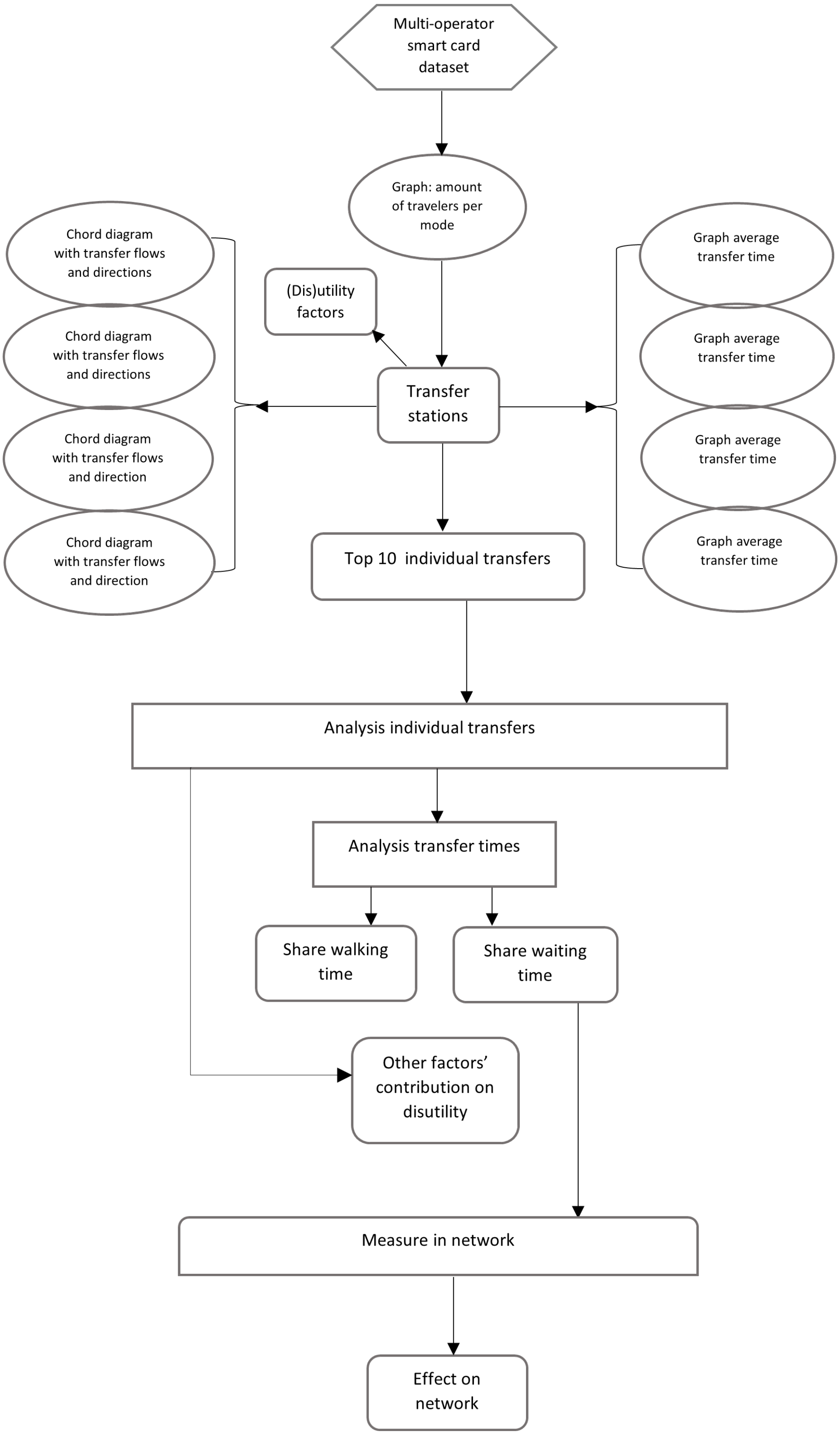


Figure 2.3: Analysis and Visualization steps for the case study

3

Literature research

In this chapter, an in-depth literature study will be done to answer the first and second subquestions: *"What is, according to literature, the impact of transfers on the (dis)utility of traveling with Public Transport and how can the negative impacts be minimized?"* and: *"In what way are smart card datasets designed and how are transfers included?"*. The chapter will begin with explaining the research gap and why this study is done. This is followed by an explanation of the difference between a trip and a journey because these terms will be used a lot in this research and it is important to clarify the difference for understanding the rest of the research. After, transfers in general are explained including different types of transfers. This is followed by an in-depth elaboration on the disutility of transfers and its determinants. The chapter ends with an elaboration on Public Transport data and especially smart card data to understand how smart cards in PT work, in what way the datasets of smart cards appear in the world and which attributes of smart cards the datasets have information of.

3.1. Filling in the gap

A few studies have been done identifying transfers between different PT operators by using a multi-operator smart card dataset (e.g., Nishiuchi et al., 2015 and Soltani et al., 2015). These studies identify transfers and examine the travelers on the networks to comprehend the use of the PT system. The studies state that their outcomes can help PT operators to adapt their network but they do not go into the transfers' disutility and its factors. Therefore it is unknown how and in what way a multi-operator smart card dataset can contribute to analyzing the disutility of a transfer. If a multi-operator smart card dataset can help understand why specific transfers have high transfer times or why many travelers use specific transfers, it can be of more value for the PT operators instead of only knowing where the travelers are transferring. The reason behind the "why" a transfer is used and it has a certain transfer time and disutility is also important. By knowing the reasons behind the transfers, the PT operators can adjust their network or stations according to these outcomes, to make a journey for a traveler more pleasant. This can lead to a higher share of PT users, which may also lead to a lower share of car users, which is beneficial for the environment; one of the reasons why governments want to have good connections between the different PT modes (Rijksoverheid, 2021). That is why this study tries to examine in what way an analysis of a multiple-operator smart card dataset can contribute to minimizing the disutility of a transfer between multiple PT operators.

3.2. Trip and journey

A journey is defined as traveling from origin to the destination stop including transfers. A trip is defined as a part of a journey, the links between transfers (Almlöf et al., 2021). So in figure 3.1, when traveling from A to B, links a and b are considered as trips and links a+b and link c are considered journeys.
A unimodal trip is a trip that uses one mode only. A multimodal trip is a trip where the traveler uses different vehicular travel modes. These vehicular travel modes can be a combination of PT (e.g., train, bus, tram, metro) and private modes (e.g., bike and car) or a combination of multiple PT modes (Bovy and Hoogendoorn-Lanser, 2005).

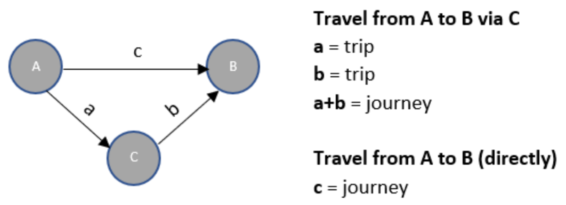


Figure 3.1: Trip and journey

3.3. Transfers

A transfer in PT is a point where different PT lines intersect within the PT network (Garcia-Martinez et al., 2018). At a transfer, travelers can choose to step out and have the option to transfer to another line on the PT network. This can also be a different PT mode. It is also possible that a traveler needs to transfer to a different PT operator. Transfers can be classified into three different categories; (a) adjacent transfer points, (b) nonadjacent transfer points and (c) shared road segments transfer points, which are illustrated in figure 3.2. Type a, an adjacent transfer point, is where passengers need to walk across a street to catch their next vehicle. Type b, a nonadjacent transfer point, is where passengers need to walk a certain distance to catch their next vehicle. Type c, the shared road segments transfer, is where passengers do not have to walk out of the station but wait to catch their next vehicle (T. Liu et al., 2014). These different transfers do have different transfer times. When transferring at a transfer point of type (b), travelers probably need to walk longer than transfer types of (a) and (c). This can lead to higher transfer times and can also affect travelers' satisfaction.
Several studies investigated the perception of travelers on transfers between different modes of transport (e.g. Garcia-Martinez et al., 2018; or Guo and Wilson, 2007). Hagen (2011) concludes that transfers between modes are the least useful or appreciated part of the journey. It takes walking and waiting time and people value their time.

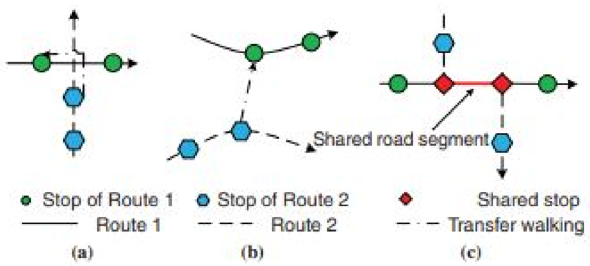


Figure 3.2: Types of Transfers (T. Liu et al., 2014)

3.4. Disutility of transfers

Travelers are trying to maximize their utility by choosing the alternative that has the highest utility (McFadden, 1974). The utility of an alternative consists of a systematic utility (V) and an error term (epsilon). The systematic utility consists of the observable factors (e.g., travel time, travel costs, age) and the error term consists of all the unobserved factors (i.e., everything that governs the individual choice) (van Nes, R, 2021). For the utility function see equation 3.1.

$$U_i = V_i + \epsilon_i \tag{3.1}$$

A transfer in a journey with PT affects the total utility. There are several factors related to a transfer that gives traveling with a transfer a disutility.
The main factors that give a disutility are the waiting time and walking time (Garcia-Martinez et al., 2018) which, together, can be seen as the total transfer time (e.g., Schakenbos et al., 2016). These are the main factors because people value their time. From the research of Abrantes and Wardman

(2011), it became clear that the waiting time is experienced as 1.7 times the in-vehicle times. This number is even higher in Wardman (2004). Balcombe et al. (2004) and Wardman (2004) add to this that the waiting time is disliked more than the in-vehicle time. According to Abrantes and Wardman (2011), the walking time is experienced 1.65 times the in-vehicle time. This number is again even higher in Wardman (2004). According to Schakenbos et al. (2016) not only long transfer times are disliked, but short travel times of less than 5 minutes are also disliked, as these can be perceived as stressful to travelers, especially for older people. The most optimal transfer time they found is 8 minutes. Besides walking time and waiting time, the disutility also exists of a pure transfer penalty related to several factors like comfort or the availability of adequate information. According to Garcia-Martinez et al. (2018) the pure transfer penalty is comparable to a 15.2 (for one transfer) equivalent increase in in-vehicle minutes, meaning that longer trips may be preferred to alternative trips that include a transfer(s).
There are differences in the exact experience rates due to, for instance, differences between countries, cities and people's characteristics (which can also explain the different numbers in Abrantes and Wardman (2011) and Wardman (2004)) (Iseki and Taylor, 2009). People that travel for commuting, education or personal business purposes value their in-vehicle time higher than people who travel for leisure (Lu et al., 2018). Therefore, different user groups are expected to value their transfer time differently as well. It also depends on what mode people are transferring (Schakenbos et al., 2016; Guo and Wilson, 2007). According to Guo and Wilson (2007) travelers that do change modes in a transfer are more bothered than those who stick with the same transport mode. In other words, all other things being equal, people traveling by train and transferring to the bus, metro or tram would be less satisfied than when they transfer from train to a different train. A difference in level (stairs) gives a disutility as well, as the travelers need to level up or down, which costs more effort (Garcia-Martinez et al., 2018; Nielsen et al., 2021). Crowding also has a negative impact on the disutility as a large number of people together in a limited space can influence the travelers' transfer perception (Garcia-Martinez et al., 2018; Cascajo et al., 2017).
Besides factors increasing the disutility of a transfer, there are also several factors that can reduce the disutility of a transfer. Having displays with dynamic arrival and departure times (real-time info), having station facilities (St. fac.) are factors that can reduce this disutility of a transfer (Garcia-Martinez et al., 2018; Nielsen et al., 2021; Schakenbos et al., 2016; Cascajo et al., 2017; Chowdhury and Ceder, 2013). The ease of wayfinding (EofW) is also of importance since travelers dislike a transfer more when it is difficult to find their way (Nielsen et al., 2021). All the mentioned factors and the several papers are summarized in an overview in table 3.1.
It is important to realize that most of all the mentioned factors have different effects when the number of transfers changes, e.g. when having one transfer, the waiting time is disliked more than the walking time, however, when having two transfers, the walking time is disliked more (Garcia-Martinez et al., 2018).

Table 3.1: Overview of scientific papers that estimates and/or mention factors that influence the (dis)utility of a transfer

Scientific paper	Wait T	Walk T	Stairs	Crowding	Mode	Real-time info	St. fac.	Act.	EofW	Escalators
Garcia-Martinez et al. (2018)	x	x	x	x	x	x		x		
Schakenbos et al. (2016)	x	x			x		x			
Cascajo et al. (2017)	x	x	x	x	x	x	x	x		
Nielsen et al. (2021)	x	x	x				x		x	x
Chowdhury and Ceder (2013)	x	x				x				

Factors between each other in the same studies, which are given in table 3.1, can be compared; however, because the papers do not have the same reference levels and do not always have the same network, it is hard to compare the rates of the factors between the papers. Besides, for one paper, the rate can say something about the willingness to travel a particular time longer instead of transferring, while for the other it is related to the in-vehicle minutes. Not having the same reference level and network could also explain different rates for equal factors. However, as said, the factors in a specific paper can be compared to each other as these have the same reference levels and the same network. Then one will get an idea of the importance of the factors related to each other. In table 3.2 the rates of the factors that are found are given.

Table 3.2: Overview of the scientific papers and their factor rates that influence the (dis)utility of a transfer. * = not significant

Scientific paper	Wait T	Walk T	Stairs	Crowding	Mode	Real-time info	St. fac.	Act.	EofW	Es.
Garcia-Martinez et al. (2018)	-1.141	-0.785	-0.715*	-3.638	-2.185	0.413*		-0.004*		
Schakenbos et al. (2016)	4.1-15.9	-			-		-0.8			
Cascajo et al. (2017)	-0.3320	-0.3407	-0.7*	-1.0272	-	0.7*	-	-		
Nielsen et al. (2021) work	-	0.83	-				-0.71*		0.8-3.93	-1.26
Nielsen et al. (2021) leisure	-	0.97	-				-1.19		-0.31-0.82*	-1.39
Chowdhury and Ceder (2013)	-	-				-				

Garcia-Martinez et al. (2018) states their rates in equivalent in vehicle minutes. A rate of -1.141 means that this is comparable with a 1.141-minute increase in equivalent in-vehicle minutes. Rates are given for one transfer (for two transfers, the rates are different). What can be seen is that the waiting time gives a higher disutility than the walking time. Crowding, however, gives by far the highest disutility, followed by changing mode. Giving real-time information can reduce the disutility; however the rate is not significant.

Schakenbos et al. (2016) are giving their rates in the form of generalized travel time. A rate of 4.1 means that a traveler is willing to spend 4.1 minutes more travel time instead of making a transfer. The transfer time is used for the waiting time and the walking time is assumed at 3 minutes (this number is used for reduction, which means total transfer time is waiting time + 3 minutes). The station facility rate is only used for very large stations with at least ten shops. This rate is different for recreational/other trip motives, i.e., -4 min generalized travel time. So these travelers are willing to spend 4 minutes more travel time to have a transfer at such a station. So, station facilities can reduce the disutility of a transfer (for specific travel motives).

Cascajo et al. (2017) provide their results only as parameters. The rates are given for one transfer. What can be seen in this paper is that there is almost no difference between the disutility of waiting time and walking time (which is different as opposed to (Garcia-Martinez et al., 2018)). The factor stairs (having a difference in level) has a higher disutility than the waiting or walking times factors. However, this rate is not significant. The highest giving disutility relates to crowding. Similarly as Garcia-Martinez et al. (2018), real-time information can reduce the disutility; however, again, this is not found significant.

Nielsen et al. (2021) are giving their rates in the form of a substitution to bus in-vehicle time. A -1 means a reduction of the disutility of a trip by about one minute of bus in-vehicle time. Their research distinguishes between working trip motive and leisure trip motive. Again walking time gives a disutility and station facilities can reduce this disutility. Escalators can also help reduce the disutility, as it costs less effort to change levels at a station. Just as Schakenbos et al. (2016) said, travelers for leisure purposes value station facilities more to the reduction of the disutility of a transfer.

Chowdhury and Ceder (2013) do not have specific rates and thus cannot be included numerically.

3.5. Public Transport data

Public Transport systems are equipped with a lot of automated data collection systems. On the one hand, there is data on the vehicle side and on the other hand, there is data on the passenger side of the PT system. The main vehicle data is traditionally Automatic Vehicle Location (AVL). Passenger data traditionally is gathered by Automatic Passenger Counts (APC) or Automatic Fare Collection (AFC).

AVL systems are often used for analyzing the speed and service reliability of the PT and are either time- or event based, meaning that vehicles transmit data about the vehicle over a certain time interval or when something occurs (e.g., braking, doors open) (van Oort and Cats, 2015). APC and AFC data can help the PT system optimize. Especially AFC data (e.g. smart card data) allows for a lot of (personal) travel data to be obtained, which is valuable for this research. A new form of AFC data is data from travelers paying with their face-ID, which is now in use in Moscow, Russia. Travelers using this system need to upload a photo of themselves together with their bank- and PT card that needs to be linked in the public transport app. Travelers only need to look into the camera to enter the vehicles (German Press Agency - DPA, 2021). This is a rather new system that may be used in the future more frequently. For this research however, this is out of scope.

3.6. Smart card data

Smart card data is collected by automated fare collection systems in PT (Fu and Gu, 2018). Travelers use these smart cards to check-in and/or to check-out in PT systems. In doing so, they automatically pay the ticket price either by having put money on their smart card beforehand or are debited automat-

ically. Smart card data comes in large quantities and is very accurate. It comes in different designs; there are systems that have implemented smart cards where the traveler only check-in but there are also systems where the traveler has to check-in and check-out (Zannat, 2019; Hussain, Bhaskar, et al., 2021). The advantage of the latter is the possibility to track travelers' exact destinations, which can be valuable, for instance, in analyzing overcrowding (Wang et al., 2015), to see gaps in demand and supply of transit services (Hussain, Behara, et al., 2021) and where travelers transfer. The usage of smart cards is increasing rapidly and already many countries and cities are using smart cards in their PT, e.g., London, New York, Boston, Beijing, Stockholm or the Netherlands (Zannat, 2019; van Oort and Cats, 2015).
In the Netherlands, smart cards have been equipped in the whole country since 2012. Travelers must check-in and check-out and all PT services are accessible with the same smart card. Therefore, it is possible to have valuable information about the travelers' trips and journeys, including the origin and destination. Checking-in and checking-out are done either on the platforms (train and metros) or in the vehicle itself (bus and trams). The advantage of this latter one is that it gives more detailed information because all the trips are tracked (it is possible to see journeys including transfers), whereas the check-in check-out system in the train or metro information will only be gathered from the first and last station (van Oort and Cats, 2015). In this case, transfers are not visible when using the same operator.
When switching operators at a transfer during the travelers' journey, the traveler will have to check-out of operator A and check-in with the following operator B. This will mean that transfers are visible in the smart card data; however, the data will be stored in two different datasets, one dataset for operator A and one dataset for operator B. Operator A will have access to data from the origin to the transfer and operator B will have access to data from the transfer to the destination. Two different datasets from two different operators will complicate the analysis of the journeys and thus the identification of transfers. An interoperable system would make it easier to give better insights into the Public Transport journeys and it is also more convenient for the travelers (Yoh et al., 2006). In an interoperable system, all data is combined in one dataset: a multiple-operator dataset. However, it is not easy to reach a consensus among the different operators with an interoperable system. Not all operators have the same goals or want the same fares for their travelers because each can have their focus on different user groups. Besides, operators do not want to hand over control over their fare collection and policies and thus are reluctant to share their plans and agreements with other operators (Yoh et al., 2006). All in all, this explains why limited research is done on interoperable systems that use smart cards. It is, however, interesting to study this more in detail as an interoperable system gives new and better insights into the journeys of travelers using multiple operators (van Hees, 2021).

3.6.1. Smart card datasets studies over the world

In order to know in what way smart card datasets appear, several papers with case studies all over the world are being examined. All the elaborated papers use smart card data and examine transfers. In this section, the papers will briefly be discussed in terms of the geographical location where the smart card data are collected (which city/region is focused in the paper), how trips are combined to journeys, what the papers are actually examining and which attributes of the smart card data are used and especially which of these attributes are remarkable or, if comparing with other papers, which attributes are missing. For an overview of the different papers and their attributes, see table 3.3.

London, United Kingdom

In the research by Seaborn et al. (2009) multimodal journeys are being identified and assessed by using smart card fare payment data in London, United Kingdom. The goal was to identify transfer behavior to, from and within the bus network. Travelers using the (Tfl) bus network only need to check in with their smart card, whereas for the Underground network, they need to check-in and out. The bus and Underground trips derived from the smart cards were combined into journeys by means of informed maximum elapsed time assumptions to identify the transfers. While the trips by bus do not have alighting location and time, it is hard to make an assumption. However, this was possible by looking into the bus travel times and walking time to the Underground station (for bus-Underground transfers) or by looking into the bus travel times and wait time for the following bus (for bus-bus transfers). For Underground to bus transfers, this was rather easy by looking at the checking out time and location from their Underground trip and the check in time and check-in location for their bus trip. Therefore the most important attributes of the data from the smart cards were the check-in and out times and the check-in and check-out stops.

Seoul, South-Korea
Whereas in London a traveler do not need to check-in and out for every PT mode, in Seoul, South Korea, the traveler does (Ali et al., 2016). Therefore, knowing the check-in and out time and location makes it easy to see where travelers start their trip and where they end their trip. Ali et al. (2016) analyzed transfers, especially between subway to subway trips, with smart card data. In order to determine if a traveler is transferring at a specific station or if the traveler is doing an activity in between two trips, they decided to work with a maximum of 30 minutes transfer time. This means, if the time between the check-out of the first trip and the check-in time of the second trip is less than 30 minutes, the traveler is transferring, otherwise this is inferred as an activity. After identifying the transfers between two trips, the journeys were determined and analysis was done. An attribute that was useful for the analysis of determining the activities of people that they do in between journeys, is the card type attribute. Knowing the card type (adult, youth, children) and external facility data makes it easier to analyze what kind of activity is near the destination of the travelers' journeys. A remarkable attribute that the smart card dataset had, was the fare of trips, none of the other papers elaborated on in this research have information about the fare.

Brisbane, Australia
To identify the time between two trips as an activity or a transfer Ali et al. (2016) used a 30-minute time interval. In Alsger et al. (2015) different assumed transfer time intervals were examined and tested with smart card data in Brisbane, Queensland, Australia, to research if different intervals have a significant impact on the number of transfer journeys. They analyzed transfer times from 15 to 90 minutes in 15-minutes intervals. For the PT system, boarding and alighting times and locations were known, just as in Ali et al. (2016), which made it easier to combine trips into journeys. The final conclusion about the impact of the different intervals on the total transfer journeys was a minor increase of 15% to 23% more transfer journeys when increasing the interval from 15 minutes to 90 minutes. So, changing the interval between two trips to determine journeys from trips does not have a significant impact when assuming a 15 to 90 minutes interval. Another study in Brisbane, Australia, was conducted by Soltani et al. (2015) where the focus laid on identifying the travel patterns of urban linear ferry passengers by using smart card data. They did not focus specifically on transfers; however they concluded that transferring between bus or rail and the ferry system is significant, which means that travelers are combining their urban ferry trips with other PT modes. An attribute that the smart card dataset they used had, while other smart card datasets in the world often do not, is the operator name. This indicates that the data came from an interoperable system, or this is at least an indication that a multiple-operator dataset is used.

Singapore
The study of X. Liu et al. (2019) also had information about the whole journey including the origin and destination, because in their study area, Singapore, travelers need to check-in and check-out with their smart cards as well. They tried to replicate the Public Transport network of Singapore with smart card data analysis. They used a 45-minute interval to identify the transfers in the travelers' journey. The replication was reliable in terms of coverage while approximately 96% of travel demand on the PT system of Singapore was replicated, which can support, e.g., decision making. In table 3.3, it is notable that this paper did not have the attribute check out time. This is because this check-out time was included in the ride time attribute, which is the difference between the check-out time and the check-in time. Just as in Ali et al. (2016) the card type and thus the passenger type were known.

Nanjing, China
Zhao et al. (2019) explored in their study a method to recognize transfers between metro and bus using smart card data in Nanjing, China. They successfully identified these transfers by rule learning and a cluster analysis (how this works is irrelevant for this research). For identifying a transfer, they used a 20-minute interval between travelers' trips. In the smart card data, only the check-in time of the bus and the check-out time of the metro were recorded. Therefore the focus laid on the metro to bus transfers. While it was not of importance for their research where the people are coming from or going to but only purely the transfer between metro and bus is of importance, the check-in and out stops were not of

importance and thus not included in the smart card data. The personal smart card data number and the check-out time of the metro and the check-in time of the bus were sufficient to identify the transfers.

Kochi City, Japan
Nishiuchi et al. (2015) studied and evaluated transfer nodes in Kochi City, Japan, by using smart card data. The authors used a 60-minute transfer time to get to know the total number of people making transfers. The efficiency of transfers was evaluated in terms of transfer efficiency, stabilization and dependency, where efficiency was measured as the average of transfer time at the transfer point, stabilization was measured as the variance of the transfer time at the transfer and dependency was measured in the number of bus or tram stops used for departure or destination. So this study focused specifically on the transfer and did not look in detail at the origin and destination of the travelers and thus, just as in Zhao et al. (2019) the check-in and out stops were not necessary. Furthermore, for the analysis, the different card types were used as well (passenger type). One of the other remarkable attributes the smart card data had, is the operator name which indicates that the smart card dataset consisted of multiple operators and thus, indicates an interoperable system or at least an indication that a multiple-operator dataset was used, similar to Soltani et al. (2015). Going forward, they recommend to consider factors such as origin-destination properties, seasons or weather conditions to get a more comprehensive method of evaluating Public Transportation system transfer nodes.

Den Haag, The Netherlands
Yap et al. (2019) introduced a methodology in order to determine significant transfer stations in the PT network and to identify subsets of specific network lines going via these hubs that need to be prioritized to minimize the transfer times for travelers. This is done for one operator, HTM, in Den Haag, the Netherlands and with the help of smart card data. Just as in Seoul, Brisbane and Singapore in the Netherlands, travelers need to check-in and check-out, which again makes it easier to see travelers' origin and destinations of their journey. The most important transfer stations were determined by determining the spatial boundaries of the transfer stations first and second, by looking into the transfer flows between stations by using the Herfindahl-Hirschman Index. The larger the flows, the more important the transfer. The subset of lines within these most important stations was identified by using a detection technique.

Table 3.3: Smart card datasets over the world

Scientific Paper	Check In Time	Check Out Time	Check In Stop	Check Out Stop	Trip ID	Veh. ID	Card ID	Mode	Direct-ion	Card type	Line No	Ride Time	Oper-ator	Dist-ance	Fare
Ali et al. (2016)	x	x	x	x			x	x		x	x			x	x
Alsger et al. (2015)	x	x	x	x			x		x						
Liu et al. (2019)	x		x	x	x		x	x	x	x	x	x		x	
Nishiuchi et al. (2015)	x	x					x			x			x		
Seaborn et al. (2009)	x	x	x	x	x		x	x							
Soltani et al. (2015)	x	x	x	x	x		x		x		x		x		
Yap et al. (2019)	x	x	x	x	x	x	x				x				
Zhao et al. (2019)	x*	x*				x*	x			x	x*				
*only for either bus or metro															

Smart cards are in use in many countries and cities worldwide. Several studies have worked with and examined smart card datasets to identify multimodal journeys. Table 3.4 summarizes the most important aspects of the literature studies discussed. To identify transfers, many studies use a different transfer interval. The check-in and out time, the check-in and out stops and the Card ID are observed as attributes in nearly all the smart card datasets. In the studies in Asian cities, the card types (passenger type) are also known, while this is not the case for the studies in Europe or Australia. Privacy regulations may explain this. Furthermore, what is interesting is that the studies in Brisbane and Kochi City do have information about the operators, which indicates a smart card dataset from multiple operators. For the other studies, apart from Yap et al. (2019), it is unknown if they use a single- or a multi-operator smart card dataset. The studies and their findings are helpful in understanding which attributes are necessary in smart card data in order to examine transfers in journeys with trips from different operators. Lastly, all the studies use two or three modes and the bus mode is examined in all of them.

3.6.2. Privacy

The use of smart card data raises privacy concerns. Smart card data uses personal information of travelers and can be compared with credit card data, cell phone communication or other tracking technologies (Clarke, 2001). The users are also not likely to accept having their demographic or socioeconomic information linked to smart card use. Therefore no personal data should be available or shared with the researcher. This could form a limitation of the data, namely that the data is less detailed (e.g., the number of travelers can be given in bins instead of specific numbers when there are low numbers of travelers) (van Hees, 2021).

Table 3.4: Overview table of existing literature using smart card data

Scientific Paper	City	Main goal	Attributes	Transfer time interval (min)	Type smart card dataset	Mode
Seaborn et al. (2009)	London	Identifying transfer behavior	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, mode	15-60	-	Bus, Underground
Ali et al. (2016)	Seoul	Public Transport simulation	Check-in time, check-out time, check-in stop, check-out stop, card ID, mode, card type, line no., distance and fare	30	-	Bus, Metro
Alsger et el. (2015)	Brisbane	Study impact of different transfer time intervals	Check-in time, check-out time, check-in stop, check-out stop, card ID, direction	15-90	-	Bus, train, ferry
Soltani et al. (2015)	Brisbane	Identifying travel behavior	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, direction, line no., operator	-	multi-operator	Bus, rail, ferry
Liu et al. (2019)	Singapore	Replication of PT network	Check-in time, check-in stop, check-out stop, trip ID, card ID, mode, direction, card type, line no., ride time, distance	45	-	Bus, metro
Zhao et al. (2019)	Nanjing	Exploring transfer recognition method	Check-in time, check-out time, vehicle ID, card ID, card type, line no.	20	-	Bus, metro
Nishiuchi et al. (2015)	Kochi City	Better comprehending PT system	Check-in time, check-out time, card ID, card type, operator	60	multi-operator	Bus, tram
Yap et al. (2019)	Den Haag	Introducing methodology to find significant transfer stations	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, line no.	-	single-operator	Bus, tram

3.7. Conclusions

A literature study has been done to get information and answers to the first and second sub-questions. The factors that increase or reduce the disutilities of a transfer are examined and provide an answer to the first sub-question: *"What is, according to literature, the impact of transfers on the (dis)utility of traveling with Public Transport and how can the negative impacts be minimized?"*. After an elaboration on smart card datasets over the world, the second sub-question *"In what way are smart card datasets designed and how are transfers included?"* can be answered as well.

Several factors influence the disutility of a transfer. The two main factors that give disutility are the waiting and walking times. This is important for travelers as they value their time. According to Abrantes and Wardman (2011) and Wardman (2004) the waiting time is experienced at least 1.7 times the in-vehicle time and the walking time is experienced at least 1.65 times the in-vehicle time. Crowding and a difference in level on the transfer station are giving a disutility as well (Garcia-Martinez et al., 2018; Cascajo et al., 2017; Nielsen et al., 2021). Crowding has even the highest impact on the disutility. Furthermore, travelers that do change modes in a transfer are dissatisfied more than those who stick to the same transport mode (Guo and Wilson, 2007). Lastly, the ease of wayfinding and disruption of an activity can influence the disutility as well (Garcia-Martinez et al., 2018; Cascajo et al., 2017 and Nielsen et al., 2021.
There are also several factors that can help reduce this disutility. Factors that can reduce the disutility of a transfer are; having real-time info by having displays with dynamic, real-time arrival and departure times, giving travelers the opportunity to shop or having other facilities and having escalators (Garcia-Martinez et al., 2018; Cascajo et al., 2017; Nielsen et al., 2021; Schakenbos et al., 2016; Chowdhury and Ceder, 2013).
The aforementioned factors do not have the same impact on every individual's own (dis)utility. The exact numbers vary due to differences in personal characteristics and between different user groups, but it also varies for different geographical places (Iseki and Taylor, 2009). Therefore, exact factor rates on a transfer's (dis)utility are hard to generalize.

To answer the second sub-question, smart card datasets over the world are examined and elaborated. Smart card data is collected by an automated fare collection system in PT (Fu and Gu, 2018). The travelers use these smart cards to check-in and/or to check out in the PT systems. The implementation of smart cards is increasing rapidly as well as the number of research directed at this topic. Several studies have been done looking into the transfers in the PT network. Studies in Seoul, Singapore, Brisbane, Kochi City, Nanjing, London and Den Haag have used smart card datasets in order to identify transfers in the PT system and to identify multimodal journeys (Seaborn et al., 2009; Ali et al., 2016;

Alsger et al., 2015; Soltani et al., 2015; X. Liu et al., 2019; Zhao et al., 2019; Nishiuchi et al., 2015; Yap et al., 2019). To identify the transfers, the studies use a time interval between the check-out time and check-in time. Studies use a time interval of 15-60 minutes; however, changing the interval between a range of 15-90 minutes does not have a big impact on the number of transfers being done (Alsger et al., 2015). In some cities, travelers only need to check-in in the vehicles or gates, while in other cities, travelers need to check-in and check-out. This latter system has the advantage that it is easier to find the transfers and the origin and destinations of travelers' journeys. This system is also used in the Netherlands (van Oort and Cats, 2015). As can be seen in table 3.3, almost all the smart card datasets in the world have information about the check-in and check-out time, the check-in and check-out stop, as well as the smart card ID. Furthermore, especially for the Asian cities; Kochi city, Singapore, Nanjing and Seoul, the card types and thus the passenger types are given in the smart card datasets as well. This is not the case for the non-Asian cities; London, Den Haag and Brisbane. It could be the case that different privacy regulations play a role in this. Two studies also have information about the operator name, which indicates that the dataset is already a multi-operator dataset. Other attributes that are present in some but not in all of the datasets are Trip ID, Vehicle ID, Mode, Direction, Line number, Ride Time, Distance traveled and the Fare.

4

Analysis approach

Until this part, the (dis)utility factors of a transfer and to what extent they give a (dis)utility and how smart card datasets are shaped are known from the literature. By means of interviews, it is clear what is missing in single-operator smart card datasets to get to better transfers between different PT operators and what the added value of a multi-operator smart card dataset is. More information on this can be found in the results of the interviews in Appendix D.

From this chapter onwards, the study will dive into the case study's multi-operator smart card dataset. In this and the next chapter, a multi-operator smart card dataset will be analyzed for the Haaglanden (Den Haag) case to see what the data from a multi-operator smart card dataset consists of and how it can be analyzed and which results can be derived. As it is known from previous chapters that multi-operator smart card datasets give more information on the transfers between different operators, it would be possible to identify important transfers. From literature research it is known which factors have an influence on the disutility of a transfer. The important transfers can therefore be analyzed further regarding their (dis)utility factors. Then, disutility factors may be minimized. Therefore a measure will be implemented that lowers one of the disutility factors (i.e., the waiting time) of an important transfer and the effects on the network load will be examined in a transport model.

This chapter begins with an elaboration and explanation of the multi-operator smart card datasets being used. The second part discussed the data's usability and a few assumptions. In the third part, the analysis of the data is explained. The approach to come to the most important transfer stations and most important transfers and how to analyze the flows, average transfer times and (dis)utility factors are given. An approach is given how a measure will be implemented for one of the most important transfers to lower the disutility factor: the waiting time. The effects of this measure will be analyzed. All the results of the analysis are given in the next chapter, chapter 5.

4.1. The multi-operator smart card datasets

The multi-operator data of NS and HTM from Translink consists of 6 different datasets. These six datasets were analyzed and examined how useful they are. After an extensive examination and multiple meetings with Translink, the conclusion could be drawn that three of these datasets had errors that could not be fixed anymore. The process to understand the datasets and examining them for validity and errors was very long and took more time than expected. Therefore this needs to be taken into account in other research working with multi-operator datasets. Eventually, this whole process resulted in 3 useable datasets:

- Dataset 1a: transfers on average days
- Dataset 1b: transfers on summer days
- Dataset 2: origin-destination patterns

All datasets consist of transfer information between the operators HTM and NS. Dataset 1a is given in 10-minute intervals aggregated for the whole year, which exists from the 1st of October 2018 until the 30th of September 2019, but also separately specific for September 2018 and September 2019. Dataset 2 consists of origin-destination patterns and is aggregated for the same time periods (whole year, September 2018 and 2019). A transfer time interval has been set at 35 minutes for the datasets. So if the time between the check-out time of the first trip and the check-in time of the following second trip is less than 35 minutes, it is considered a transfer. This time interval is in line with the scientific papers discussed in chapter 3. To couple transfers with the right PT line, translation tables are used. Of the three usable datasets, dataset 1b will eventually not be used in this research as this research does not focus on a particular day or does not compare certain days. However, dataset 1b can be used in further research that focuses on summer days.

4.1.1. Transfers on average days

Dataset 1a consists of information per every unique transfer taken for the periods discussed in the section before. Ten festive days, however, are excluded. These dates can be found in table 4.1.

Table 4.1: Festive Days

December 2018	January 2019	April 2019	May 2019	June 2019
25, 26	1	21, 22, 27	5, 30	9, 10

While only transfers between HTM and NS and vice versa are given, only tram/bus to train or train to tram/bus transfers are included. No transfers between tram and bus and vice versa or between the same modes are given, i.e. no transfers between the same operator are included. Every row in the dataset covers a unique transfer and has information on the period, the kind of day (average workday or average weekend day), the transfer station, the line towards the transfer station (trip #1), the line successive from the transfer station (trip #2), the sum of transfers, the standard deviation of the sum of transfers, the average transfer time in minutes, the standard deviation of the average transfer time in minutes and the number of days that the transfer is used. For an example of the dataset, see tables 4.2 and 4.3. As can be seen, for the sum number of transfers, smaller than 30 or 40 values are given as a ”lower” sign (where <30 corresponds with weekend days and <40 with working days). These cannot be given an exact value due to the information management rules (”informatiehuishouding”), which have rules to protect travelers’ privacy. For the same reason, the standard deviation is given as a ”NULL” value.

As not all multi-operator smart card datasets are the same, for other multi-operator smart card dataset designs, the trip #1 attribute could also be derived from the check-in stop or line including the operator name and the trip #2 could also be derived from the check-out stop or line including the operator name. Furthermore, the average transfer time could be derived from the difference between the trip #1 check-out time and the trip #2 check-in time together with the sum of transferring travelers.

Table 4.2: Dataset 1a

Period	Kind of day	Transfer station	Trip #1	Trip #2	Time check-out
sep-18	avg working day	Delft	Bus 18 to Laan van Clingendael	Train IC to Den Haag Central	07:50-08:00
year	avg weekend day	Den Haag Central	Bus 23 to Colijnplein	Train IC to Amsterdam Central	15:50-16:00
sep-19	avg working day	Den Haag HS	Train IC from Amsterdam Central	Tram 1 to Zwarte Pad	12:20-12:30
year	avg working day	Rijswijk	Train SPR from Den Haag Central	Bus 23 to Kijkduin	19:30-19:40

Table 4.3: Dataset 1a continued

Sum Number Transfers	Stdev Number Transfers	Avg transfer time (min)	Stdev transfer time (min)	Number of days
45	4.02	8.12	2.56	14
<30	NULL	25.01	NULL	1
86	5.68	7.45	4.45	16
<40	NULL	4.40	NULL	10

4.1.2. Origin-Destination patterns

Dataset 2 consists of origin-destination patterns between HTM stops and NS stations. As can be seen in table 4.4 this dataset looks different than datasets 1a. It consists of data for every unique transfer with at least a sum of transfers of 50 (this minimum is due to privacy regulations). The HTM stops and the directions of NS lines are given. Line numbers and specific trains are not provided anymore and that is also why there is no transfer time data. The NS stations outside of the Haaglanden area are given as directions; ”Gouda and further”, ”Schiedam and further”, ”Leiden Centraal”, ”further than Leiden Centraal to Schiphol”, ”further than Leiden Centraal to Alphen aan de Rijn” and ”further than Leiden Centraal to Haarlem”. The period, kind of day, transfer station, the sum number of transfers and the number of days are the same as in dataset 1a.

Table 4.4: Dataset 2

Period	Kind of day	Origin	Transfer station	Destination	Sum Number Transfers	Number of days
sep-18	avg working day	Abtswoudsepark	Delft	Schiedam and further	246	15
year	avg weekend day	De Dreef	Den Haag Central	Gouda en verder	800	56
year	avg working day	Gouda en verder	Den Haag HS	Delftselaan	52	168
sep-19	avg weekend day	Leidschenveen	Den Haag Laan van NOI	Leiden Centraal	56	9

4.2. Usability and assumptions of the datasets

In order to work with the datasets and perform analyses, the data need to be evaluated on its flaws and the subsequent assumptions need to be made.
The data will be examined on the share of the <30 and <40 bins and the other values of the sum of transfers. It will be unfavorable if the <30 and <40 transfers bins have a high share as it is unclear which precise value the bin actually indicates for this transfer. This means that the data will consist largely of assumptions. However, if the weighted share of the <30 and <40 bins are low and thus the weighted share of all the other values are high, the data is accurate and fewer assumptions have to be made.

4.2.1. Usability of the datasets

Uncommon transfers

In the data several transfers are found from and/or to a specific Public Transport line that normally does not cross the transfer station. For example, a transfer at Delft station between bus line 18 to the Schilp and the Intercity train to Vlissingen. Bus line 18 does not have Delft station on its line. This may be due to one of the following reasons. Firstly, it can be the case that this bus line needed to follow a different route due to a disruption(s) and thus may stop at different stops. Secondly, the traveler did not check-in and/or out correctly. Thirdly, as the maximum time between a check-out and check-in is 35 minutes, it can be the case that someone is going with a different type of travel mode in between the two lines but within 35 minutes. Lastly, it is also possible that a traveler is walking in between the two trips and thus is walking to the stop where the second trip is departing from. These ”errors” in the data will not be removed as this can also provide valuable information. For instance, if it is plausible that someone is walking in between two trips, connections between lines could be poor.

Interpretation and usability of the data

First, the share of the sum of transfers of the <30 and <40 bins together and the share of the sum of the transfers of the other values of dataset 1a will be calculated.
In dataset 1a, there are 381,667 unique transfers made between the 1st of September 2018 and the 30th of September 2019. Of these 381,667 rows, 316,266 unique transfers have a sum of transfers lower than 30 or 40. This means that 82.9% of the unique transfers that are made have a sum of transfers lower than 30 or 40. This also means that 17.1% of the unique transfers that are made have a sum of transfers larger than 30 or 40.

Secondly, the weighted shares of the transfers of the bins and the weighted share of the transfers above 30 and 40 can be calculated with the help of dataset 2. From dataset 2 it is possible to get the total sum of transfers for the same time period. This sum is 13,363,108.32. By deducting the sum of transfers above 30 and 40 of dataset 1a from this number, the number of transfers for all the unique transfers that has a sum of transfers below 30 and 40 can be calculated. The sum of transfers above 30 or 40 is 12,202,820. Deducting this number from 13,363,108.32 results in a sum of 1,160,288.32. This leads to a weighted share of the transfer below 30 and 40 of 8.7% and a weighted share of transfers above 30 and 40 of 91.3%. This number is totally different from the shares before, which were 82.9% and 17.1% respectively. The weighted share of above 30 and 40 is high and thus, the vast majority of the data consists of exact, numerical values for the sum of transfers.

4.2.2. Assumptions

To get a more complete analysis, it will be helpful to allocate the lower than 30 and 40 bins a more precise value as working with bins is not useful. By dividing the sum of the unique transfers of the <30 and <40 bins together by the number of unique transfers below 30 or 40, an average sum of transfers of this bin per unique transfer can be calculated. This results in a division of the sum of 1,160,288.32 by the number of unique transfers; 316,266, which results in 3.7.
This number will be used for every unique transfer with the <30 or <40 bin. This does not mean that for every unique transfer this is indeed the precise value; it can be the case that this number is lower or higher. Especially if the number of days that a specific transfer is used is more than 3, it is already certain that the number is in fact higher. Besides, in the calculation, dataset 2 is used for the total sum of transfers. This dataset only consists of unique transfers done 50 times or more; thus, no sums below 50 are given. This can have an influence on the precise value of the total sum of transfers. However, the number of 3.7 is the closest average value possible with the available data. Nonetheless, it should thus be noted that this value is still an assumption.

4.3. Data analysis steps

In this section, the analysis is described. For the analysis, dataset 1a has been used including the 3.7 assumption for every value lower than 30 or 40. Furthermore, to prevent double-counting September, September 2019 separately has not been included as this month is already included for the ”year” period. The analysis starts with identifying and examining the most important transfer stations. For these transfer stations, the (dis)utility factors will be examined, the flows will be visualized and the average transfer times will be plotted. First indications can already be made from these and further explanations for the flow size by (dis)utility factors may already be given. Then, the individual transfers are examined in order to find the transfers that are effective for measure implementation to lower the disutility. Top10s of important transfers are made and one of these top10s will be chosen to examine in further detail. Lastly, the (dis)utility factor waiting time of one of these most important transfers will be lowered by implementing this as a measure in a transport model to examine the effects on the flows in the network.

4.3.1. The most important transfer stations

First, the study focuses on the most important transfer stations in order to visualize the flows and average transfer times of the transfers and to explore to what extent the (dis)utility factors explain the different flow size.

To get a first overview where travelers are transferring, a graph is created showing the number of transferring travelers going from a specific mode and towards a specific mode. The distinguished modes are ”Sprinter” (SPR) trains which are trains that stop more often (yellow), ”Intercity (IC) and High-Speed Network (HSN)” trains which are trains that stop less often and cover a longer distance (red), trams (blue) and the bus (black). See figure 4.1 for this overview. As can be seen in the figure, few transfers are made at the stations Den Haag Mariahoeve, Den Haag Moerwijk, Den Haag Ypenburg, Lansingerland-Zoetermeer, Rijswijk, Voorburg and Zoetermeer. Therefore, the focus will be on the stations Delft, Den Haag Centraal, Den Haag Holland Spoor (HS) and Den Haag Laan van NOI. In figure 4.2 these four stations and their number of transferring travelers per specific mode are highlighted and zoomed in. The first thing that stands out is the high peak of Den Haag Centraal station. There is a high number of travelers that transfer with the IC/HSN and tram modes for this station. Den Haag HS station follows in the second place, with Den Haag Laan van NOI and Delft in the third and fourth places.

For these four important transfer stations the (dis)utility factors whether the traveler need to level up or down (stairs), if real-time information is available, how many facilities are present at the station and if there are escalators available are examined.

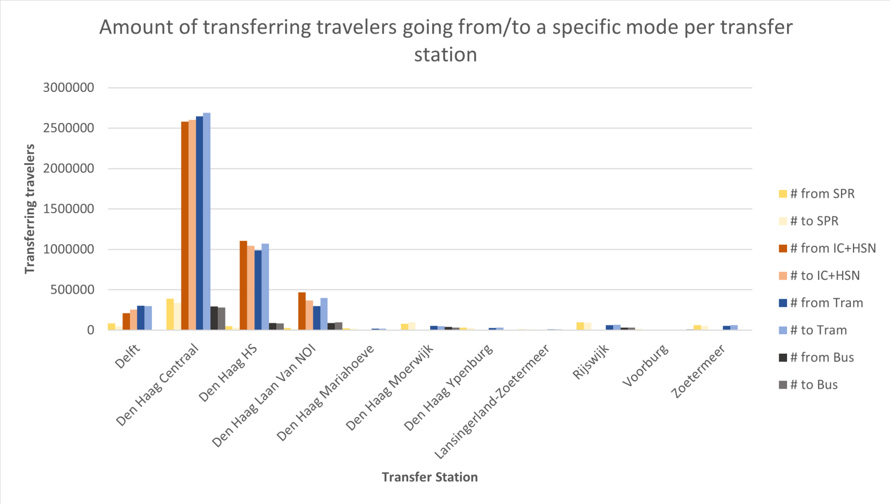


Figure 4.1: Number of travelers per mode for the stations

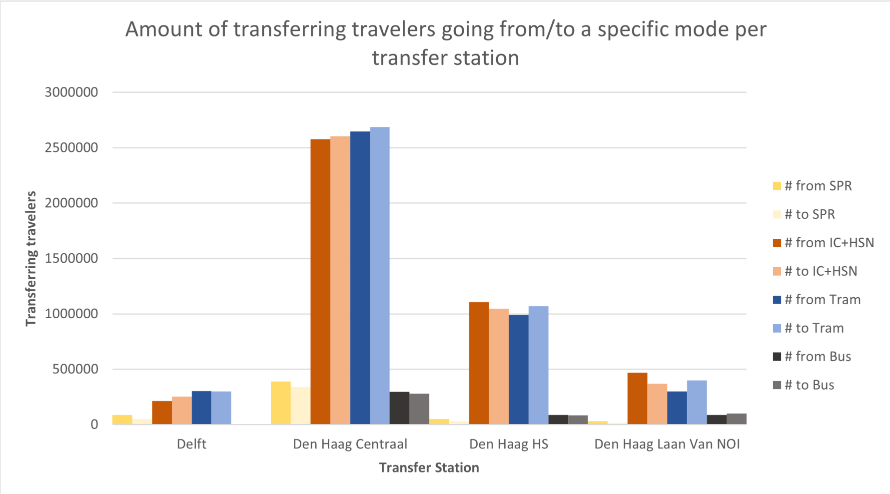


Figure 4.2: Number of travelers per mode for the stations Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft

4.3.2. Visualising the transfer flows

For each of the four transfer stations, this section zooms into the number of transfers and their directions by means of visualizations. These visualizations provide an answer to the fourth sub-question: *What do Public Transport users flows of a combined smart card dataset look like?*. The number of transfers and the directions of the travelers will be calculated and visualized by dividing each PT line to the corresponding wind directions (for the HTM lines) and track directions (for the NS lines) regarding the transfer station. However, to better compare the flows, for the stations Den Haag Centraal, Den Haag HS and Den Haag Laan van NOI the HTM lines are given the same wind direction as the three stations are close to each other. So, for the HTM lines, the reference station will be Den Haag Centraal, as this station is in the middle of these three. Delft, however, has its own frame of reference. It could be the case that some PT lines are given a different wind direction for the Den Haag HS and Den Haag Laan van NOI stations as these transfer stations are slightly more to the South-West and East respectively, compared to Den Haag Centraal. Furthermore, sometimes a PT line is in between two wind directions, then the begin or end of the line is taken to determine the wind direction. The reference tables on which PT lines are given which wind- and station direction regarding each transfer station can be found in Appendix B.1.
After determining which line corresponds to which wind and track direction, the sums of each wind direction towards the track direction and vice versa are determined. The wind (track) direction towards a track (wind) direction can be seen as a direction pair. The analysis was done in Microsoft Excel and

dataset 1a was used. When the sum of transferring travelers for each direction pair is known, these flows are visualized in a chord diagram for each of the four transfer stations. With a chord diagram, one can study flows between a set of nodes (R Graph Gallery, 2018). This chord diagram has been made in the program R. The sum of transferring travelers for every direction pair for every transfer station separately are imported as datasets in R. With these datasets, a code has been built to visualize the flows for each transfer station. The code and the corresponding color codes used to visualize each direction flow can be found in Appendix B.2. Figure 4.3 shows the process of the analysis and visualizations of the flows.

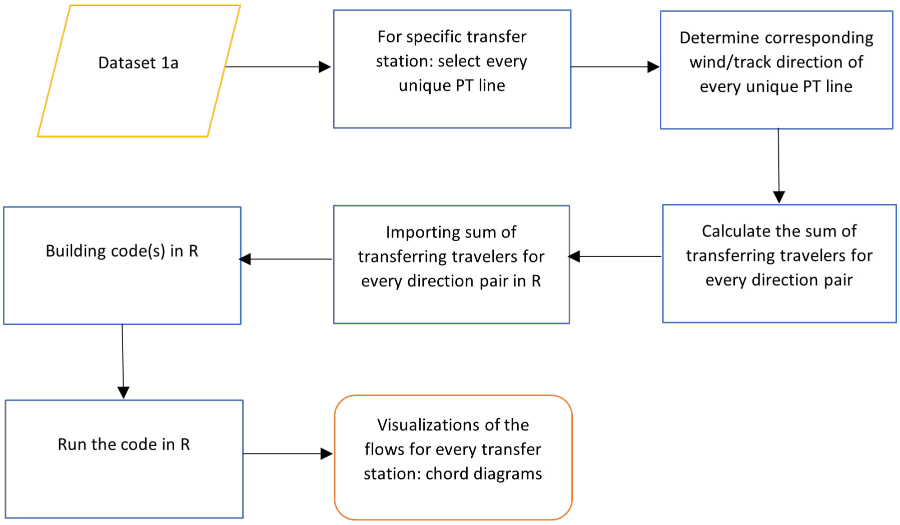


Figure 4.3: Method of visualizing the transferring travelers (flows) for each specific transfer station

4.3.3. Plotting the average transfer times

Based on previous analysis of the transfer flows, directions pairs are found for every four transfer stations separately. As the visualization only gives the sum of travelers per pair, an analysis of the average transfer times for each corresponding pair is performed. A visualization of the flows and the average transfer times can show at which transfers, and at which stations, a relatively high number of transfers and average transfer time take place. If a pair has a very high sum of transfer flow but has a very low average transfer time, this is a transfer used often and does not costs the traveler much time. The other way around, if a pair has a very low sum of transfer flow but has a very high average transfer time, this is a transfer that costs the traveler much time and is rarely used by travelers. The method to get the average transfer times for each corresponding direction pair is similar to the previous analysis' first steps of visualizing the transfer flows. This step is performed in Microsoft Excel. For an overview of the method, see figure 4.4.

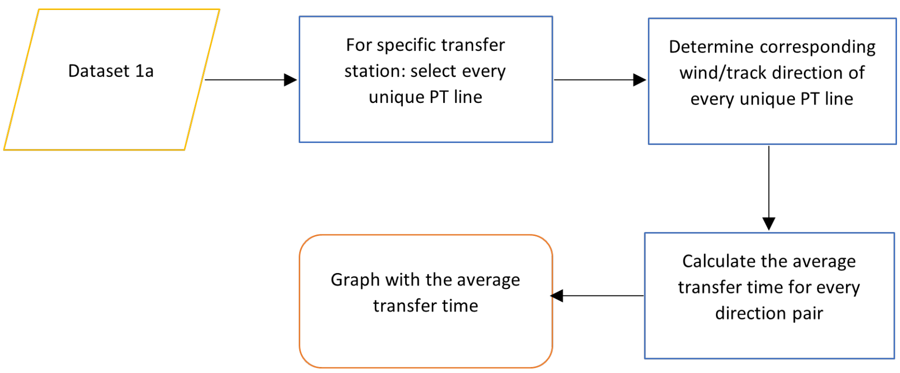


Figure 4.4: Method of visualizing graphs with the average transfer times

4.3.4. Top 10s of individual transfers

From this part onwards, the individual transfers are examined in order to explore which transfer could potentially be the most suitable transfer to implement a measure to lower the disutility.

After visualizing the transfer flows and the average transfer times per every direction pair for the transfer stations Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft, a first indication is made about transfers. In the following analysis phase, top 10s are made to identify the transfers in more detail. These top10s are not made for every direction pair but for each unique transfer (from a PT line to a PT line). Rankings are limited to 10 rows as it is not doable to examine all of them in detail, considering there are more than 380,000 unique transfers (in 10-minute intervals) or more than 3500 transfers between HTM and NS and vice versa. Therefore, three different top 10s have been calculated: a top 10 transfers with the highest average transfer time, a top 10 transfers with the highest transfer time loss and a top 10 line total transfers with the highest transfer time loss.
For these analyses, the ”NULL” average transfer time values (=0.15% of the data) are neglected as these would give errors.

Top 10 transfers with the highest average transfer time
The first top 10 consists of the top 10 transfers with the highest average transfer time. For this, the values below 30 and 40 are not considered, as this will lead to many high averages considering these values often only indicate a few transfers in total. These values are often caused by one that is doing an activity in between (but still has a time interval of less than 35 minutes) the two trips or one of the reasons mentioned in section 4.2.1. The consequence is that a very low number of transfers would get a very high average transfer time. This is not reliable and thus, these are not taken into account for this specific top 10. This analysis is done in Excel with the use of pivot tables.

Top 10 transfers with the highest transfer time loss
With the first top 10 transfers with the highest average transfer time, the number of travelers is not considered. Therefore another top 10 is made with the ten transfers with the highest transfer time loss. To compose this top 10, first, in dataset 1a, an extra column with the transfer time loss is added. This transfer time loss in minutes is calculated by multiplying the sum of transfers with the average transfer time in minutes for every unique transfer. Then, the sum of this transfer time loss is calculated. Following, a division of the transfer time loss with the sum of the transfer time loss to get shares. From this division, percentages are made and the top 10 transfers with the highest percentages were chosen. This method can be found in figure 4.5 and the analysis is done in Microsoft Excel. Again pivot tables are used.

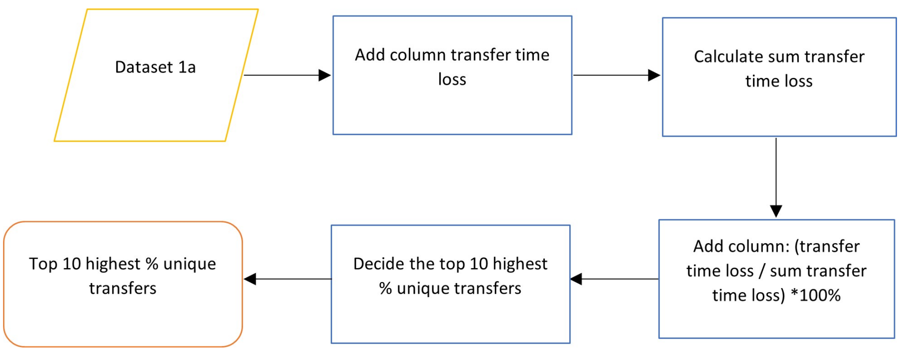


Figure 4.5: Method top 10 transfers with the highest transfer time loss percentages

Top 10 transfers with the highest transfer time loss for line totals
The third top 10 refers to the total shares of the lines. This top 10 is almost the same as the previous top 10. The only difference is that the highest line totals are identified and analyzed for this top 10 instead of looking at every possible transfer. For example: when having a total ”trip #1” to tram 9 Zwarte Pad, all the transfers (the share) from the other lines that are transferring to this line will be added together. There are more than 3500 transfers, however, there are (only) 240 total lines. The method is the same as the top 10 transfers with the highest transfer time loss for every unique transfer apart from deciding the top 10 highest; now, the top 10 is decided from the line totals instead of the individual transfers. Figure 4.6 shows the method to get to this top 10. This analysis is done in Microsoft Excel and again, pivot tables are used.

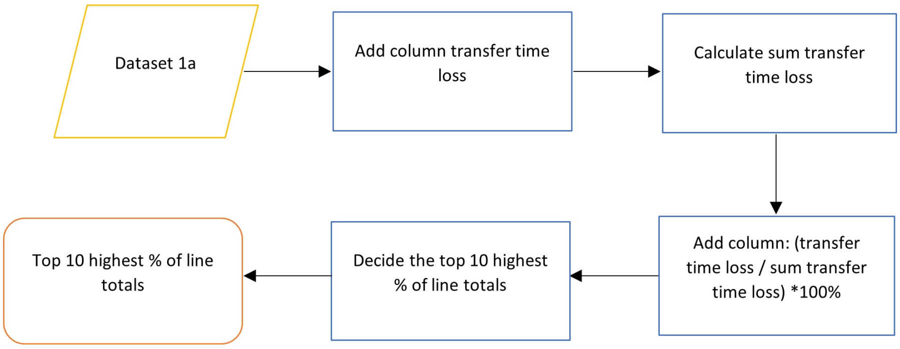


Figure 4.6: Method top 10 transfers with the highest transfer time loss percentages for line totals

4.3.5. Diving into the top10
In the following analysis step, one top 10 is chosen to analyze these transfers in more detail. Together with the operator HTM, a top 10 is chosen. Then, for the transfers, the disutility factors are examined. The following disutility factors will be examined: waiting time, walking time, if the traveler needs to level up or down, if there is real-time information available, if there are facilities and if there are escalators. The disutility factors that will not be examined, as these require more detailed research, are crowding, if travelers are doing an activity and the ease of wayfinding. Furthermore, the mode is known: a traveler changes modes between bus/tram to train or vice versa. The main focus however is on the waiting and walking times. These are examined in more detail. The transfer time is divided in the walking time and waiting times for the transfers. The average walking time (the time travelers, on average, need to walk from alighting one vehicle to their connection vehicle) is measured by using a stopwatch and walking the corresponding transfer by the author himself. The average waiting time is calculated by subtracting the walking time from the average transfer time.

4.3.6. Measure implementation
After having the most important results from the most important transfers, a measure on the network will be determined to lower the transfer time of a specific transfer. Reducing the waiting time has been chosen as this is one of the measures that can be implemented relatively fast and easy in practice and while changing the walking times would soon lead to transfer stations design changes. The transfer that has the highest impact on the total transfer time by reducing the transfer time by one minute will be chosen as this transfer will lead to the highest reduction of the total transfer time minutes. In Excel, the total reduced transfer time in minutes can be calculated when having a reduced transfer time of one minute. This can be done by taking the sum of transferring travelers times the reduction of time of one minute.
However, reducing a specific transfer time could increase the traveler flow using this transfer as the transfer time for this specific transfer will be lower and thus become more attractive. Therefore, to see this effect on the traveler flow, the measure will be implemented in a transport model of HTM in Den Haag in the program OmniTRANS. The data in the model is based on single-operator smart card data (HTM) only and all the PT lines from the operator HTM are included. These lines are visualized in figures 4.8 and 4.9. For visualizing and analyzing the effects of the measure on the flows it is not an issue that the transport model is based on single-operator smart card data of HTM, while the concern-

ing transfer is based on the multi-operator smart card dataset. This is because the transport model consists of the number of travelers of HTM including the transferring travelers coming from other operators. Furthermore, the transport model does only have information about HTM traveler flows and not for NS, however, travelers coming from a HTM line and transferring towards a NS train have a relatively lower transfer time due to the ability to check-in at the NS platform before the train arrives. This is not the case for the other way around (from NS to HTM) as the traveler need to check-in inside the HTM vehicle. Therefore, the transfer time loss for transfers from HTM to NS is assumed to be lower and thus will not take place in the top 10s. This means the transport model can be used for visualizing and analyzing the effects of the implementation of the measure on the network.

To examine the effects on the flows in the network, a reference model level in OmniTRANS will be made with the specific transfer line at one stop and the destination of the train at a centroid next to this stop. Getting from the centroid to the stop with the transfer line will cost the traveler a certain amount of minute(s) and second(s). By reducing this amount with 60 seconds in a new model level, the effects can be visualized by comparing the new model level with the reference model level. Then, the change of traveler flow can be visualized and the differences in exact flow numbers can be given. Possible other PT lines operating at the same stop are given a different stop to prevent transfers to these lines from getting a one minute decrease of waiting time as well. These steps, to get from the top 10 transfers towards visualizing the flow effects on the network by implementing the measure, are shown in figure 4.7.

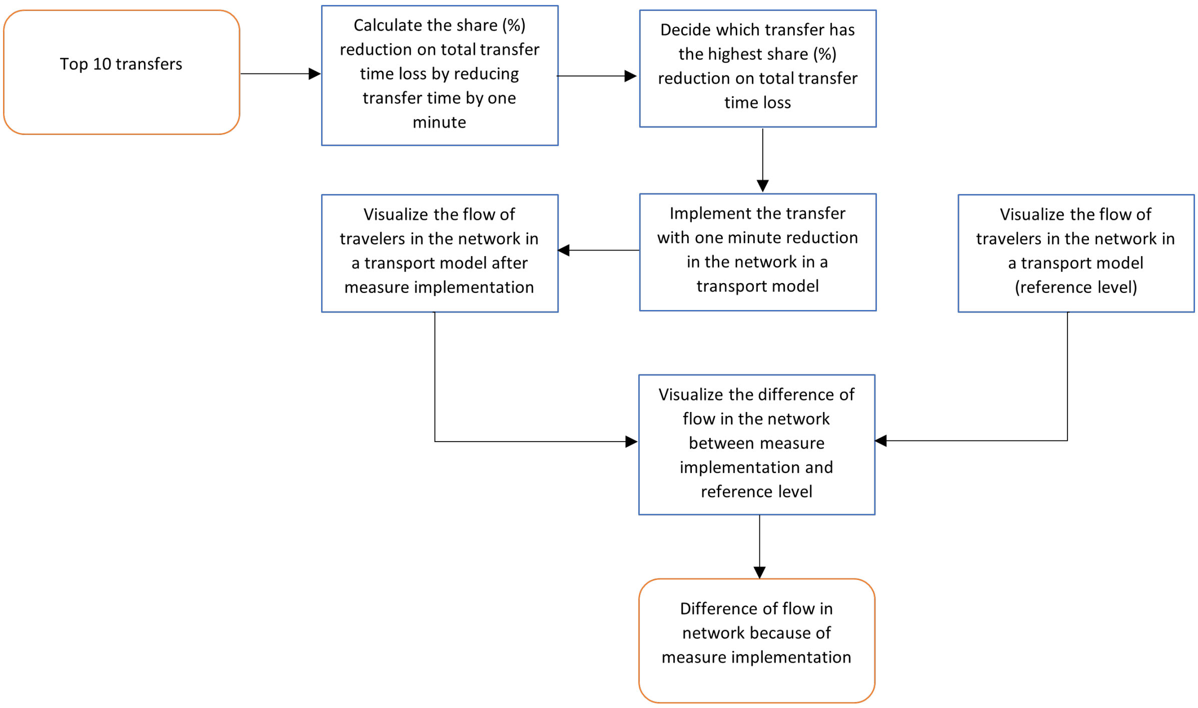


Figure 4.7: Method of visualizing the effects of the measure implementation

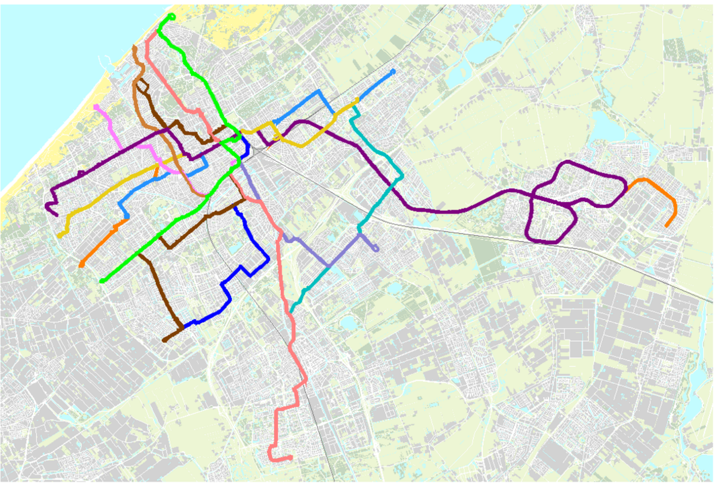


Figure 4.8: HTM tram lines (each color is a different line)

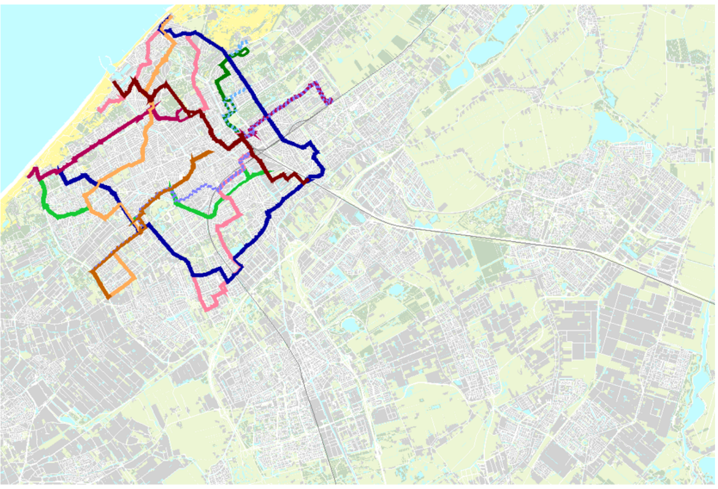


Figure 4.9: HTM bus lines (each color is a different line)

5

Data analysis results

In this chapter, the results of the analysis will be discussed. First, the (dis)utility factors level up or down (stairs), availability to real-time information, the number of station facilities and escalators presence for the four most important stations are elaborated. Second, the transfer flows with the corresponding average transfer times are visualized for the four stations. After this section, the fourth sub-question: *What do Public Transport users flows of a multiple-operator smart card dataset look like?* can be answered. The flows and transfer times (waiting + walking times) will be compared to each other to examine if the transfer time and other (dis)utility factors can explain the flow size. This is followed by the results of the three different top 10s of the individual transfers: a top 10 transfers with the highest average transfer time, a top 10 transfers with the highest transfer time loss and a top 10 transfers with the highest transfer time loss for line totals. After that, together with one of the two operators, a specific top 10 is chosen to analyze further. For this top 10, the (dis)utility factors will be examined, emphasizing the walking and especially the waiting times. Then, a specific measure will be chosen for one of the transfers to lower the waiting time. The effects of this measure on the network will be shown. All in all, the fifth sub-question: *What can be said about the (dis)utility of the transfers in a multiple-operator smartcard dataset* can be answered.

5.1. (Dis)utility factors of the four transfer stations

The (dis)utility factors whether you need to level up or down (stairs), if real-time information is available, how many facilities on the station are present and if there are escalators available are shown for the four stations in table 5.1. The size level of station facilities is based on the same levels as in Schakenbos et al. (2016); stations with one or two shops are given a medium level, stations with three to nine shops are given a large level and ten or more are given a very large level.

Table 5.1: The four stations and their (dis)utility factors

	Stairs	Real-time info	Station fac.	Escalators
Den Haag Centraal	Yes/No	Yes	very large	Yes
Den Haag HS	Yes	Yes	very large	Yes
Den Haag Laan van NOI	Yes	Yes	medium	No
Delft	Yes	Yes	large	Yes

The need to level up or down gives a disutility to the transfer (Garcia-Martinez et al., 2018; Cascajo et al., 2017 and Nielsen et al., 2021). As can be seen in table 5.1 the four stations are quite similar for this factor. For some transfers at Den Haag Centraal travelers do not need to level up or down but for other transfers travelers need to level up or down. For all other transfers at the other stations, you do need to level up or down. Therefore all the transfers, apart from some transfers at Den Haag Centraal, the need to level up or down factor is giving a disutility.

Having real-time information can reduce the disutility of a transfer (Garcia-Martinez et al., 2018; Cascajo et al., 2017 and Chowdhury and Ceder, 2013). All the transfer stations have real-time information displays on their platforms that shows how long it takes for the vehicle to arrive/depart. Therefore all of the transfers can get a reduction on the disutility.

Station facilities (shops) reduce the disutility of a transfer (Schakenbos et al., 2016, Cascajo et al., 2017 and Nielsen et al., 2021). Den Haag Centraal has the most shops, followed by Den Haag HS, both having at least more than nine shops (very large), Delft has seven shops (large) and Den Haag Laan van NOI is a medium transfer station in terms of facilities as it has only one shop. Therefore, Den Haag Centraal and Den Haag HS get a higher reduction on the disutility of the transfers than transfers at Delft and Den Haag Laan van NOI. Den Haag Laan van NOI gets on its turn a lower reduction on the disutility than transfers at Delft because of a lower number of station facilities.
The presence of escalators at the transfer reduces the disutility of a transfer as well (Nielsen et al., 2021). Den Haag Laan van NOI is the only station where travelers do not have access to escalators. This means that the transfers on Den Haag Centraal, Den Haag HS and Delft are getting a reduction on the disutility of their transfers because of the presence of escalators, whereas transfers at Den Haag Laan van NOI do not get a reduction.

All in all, Den Haag Centraal would have the lowest and Den Haag Laan van NOI would have the highest disutility for these four factors. However, at Den Haag Centraal, different transfers occur which may lead to different values for the disutility because for some transfers travelers need to move up/down a level while for some transfers, travelers do not. The latter transfers have a lower disutility. As a disutility of a transfer is not favorable for travelers, transfers with a higher disutility is assumed to have a lower flow. In this case, transfers at Den Haag Laan van NOI is then assumed to have lower loads then Den Haag Centraal. However, more disutility factors have an influence on the disutility. Two other disutility factors: waiting times and walking times are more transfer dependent and therefore will be examined further in later sections in this study.

5.2. The transfer flows and their average travel times for the four transfer stations

For the four transfer stations: Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft the number of transfers (the flows) are given per direction pair in a chord diagram. These are visualized in figures: 5.1; 5.3; 5.5 and 5.7. For the corresponding direction pair, the average transfer times are also visualized for each transfer station. These are visualized in a graph which can be seen in figures: 5.2; 5.4; 5.6 and 5.8.

The chord diagrams visualize the flow direction for every traveler that transfers at the specific transfer station. The wind direction corresponds to the direction of the HTM lines (tram or bus) and the track directions corresponds to the NS lines' direction (train). For example: for the chord diagram of Den Haag Centraal (figure 5.1), the line between the track to/from Amsterdam and the West indicates that travelers are departing from the Amsterdam track by train (NS) and transfer at Den Haag Centraal towards a tram or bus (HTM) in a western direction. The arc's color corresponds with the color of the first trip, i.e., the trip towards the transfer station. It is important to keep in mind that the chord diagrams can not be compared to each other as the different stations have a different total sum of transfers, which are given above the chord diagrams.
From the average transfer time graphs, it can be seen that the transfer between a wind direction towards a NS direction is lower than the other way around. This is because the traveler needs to check-in and check-out inside the tram/bus (HTM) and check-in and check-out at the platform for the NS trains. This means that when checking-in at NS, travelers can already check-in before the train departs and one can wait after the check-in poles, while tram and bus users have to wait for the tram/bus to arrive to check-in. This explains why transfer's travel times from a HTM line to a NS line are, on average, lower.

For each transfer station, some flows are highlighted and tried to be explained by the (dis)utility factors by comparing it with the average transfer times (which consists of the waiting- and walking time) and other (dis)utility factors.

5.2.1. Den Haag Centraal

As can be seen in figure 5.1 transfers at Den Haag Centraal are done from/to three different directions by train (via the track to/from Utrecht, Amsterdam or Rotterdam) and from/to the four wind directions

North, East, South and West. In total over 7.7 million travelers are transferring between NS and HTM and vice versa at Den Haag Centraal (in the period between the 1st of September 2018 and the 30th of September 2019). Most travelers transferring at Den Haag Centraal come from the Amsterdam track and continue their journey towards the West or North and vice versa, and from the Utrecht track towards the West and vice versa, with the largest flows between the West towards the Amsterdam track and vice versa. Looking into the average transfer time graph in figure 5.2, the flow from the Amsterdam track towards the West has an average transfer time slightly above the weighted average of all the transfer times at Den Haag Centraal: 8.3 over 7.7 minutes. Of the largest flows, the flow from the Amsterdam track towards the North has the highest average transfer time; 9.8 minutes. The transfers with the lowest average transfer times are the transfers coming from the East towards the Rotterdam track.

Sum of transfers at Den Haag Centraal = 7737468.7

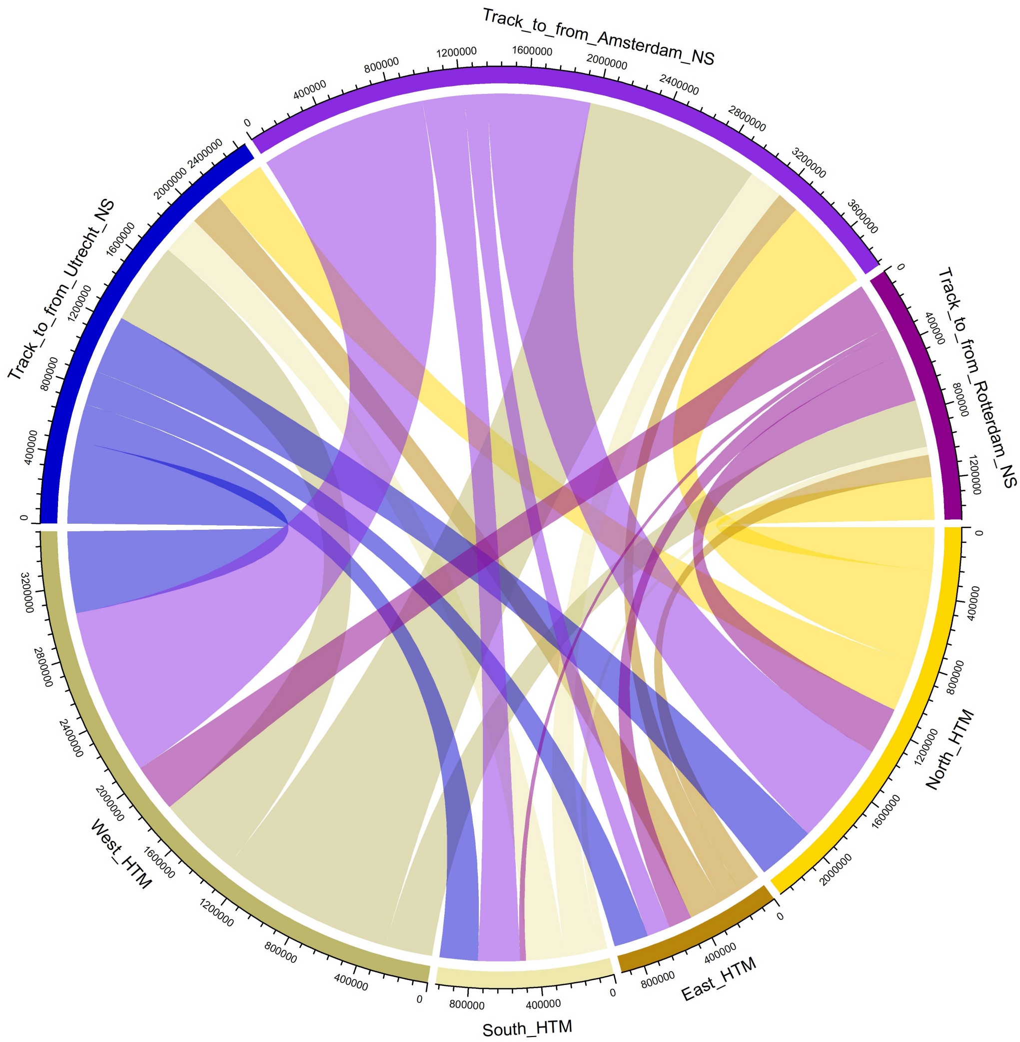
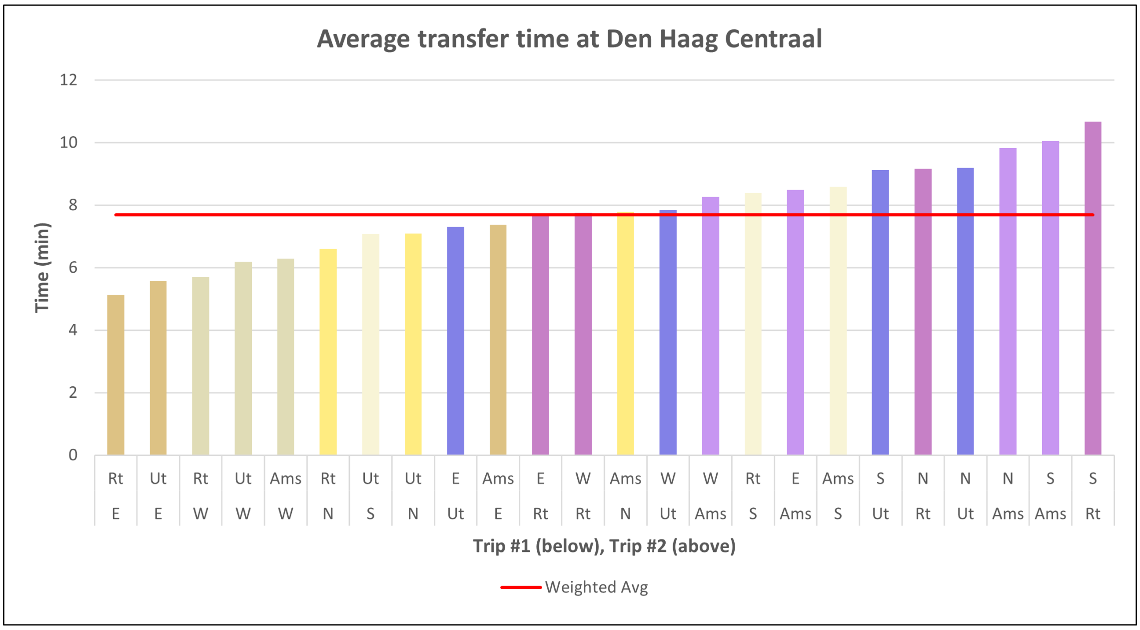


Figure 5.1: Number of transfers via Den Haag Centraal station between NS (train) and HTM (bus/tram) and their directions



Abbreviation	Direction
Ut	Track_to_Utrecht_NS
Ams	Track_to_Amsterdam_NS
Rt	Track_to_Rotterdam_NS
N	North_HTM
E	East_HTM
S	South_HTM
W	West_HTM

Figure 5.2: Average transfer time of the transfers at Den Haag Centraal between NS (train) and HTM (bus/tram) and their directions

5.2.2. Den Haag HS

As can be seen in figure 5.3, transfers at Den Haag HS are done from/to three different directions by train (via the track to/from Amsterdam, Rotterdam and Den Haag Centraal) and from/to the four wind directions North, East, South and West. The transfers to/from the East direction are almost negligible. In total almost 2.9 million travelers are transferring between NS and HTM and vice versa at Den Haag HS (in the period between the 1st of September 2018 and the 30th of September 2019). Most travelers transferring at Den Haag HS are coming from the Rotterdam track towards the North (the largest flow) and vice versa and from the Amsterdam track towards the South and vice versa. Looking into the average transfer time graph in figure 5.4, the largest flow, the flow from the Rotterdam track to the North has an average transfer time of around 8.6 minutes which is slightly above the weighted average of all the transfers at Den Haag HS. The graph shows a significant difference between the average travel time for the highest six transfers and the other transfers. This is because these six transfers with the highest average transfer times have a very low number of transfers, implying that these transfers are not common. Plausible reasons are given in section 4.2.1. However, by taking a closer look, the specific transfers are mostly not possible at HS. This means travelers are walking to/from a different stop and thus automatically have a higher transfer time, or the specific transfers are not logical to make as it would be more efficient to stay in a vehicle and transfer at a different station/stop. This leads to high transfer times for only a few travelers, resulting in high average transfer times. The weighted average transfer time (the red line) is however representative, as it is a weighted average. It is shown that the high transfer times (around 20 minutes) do not have a big impact on the weighted average, which is 7.8 minutes.

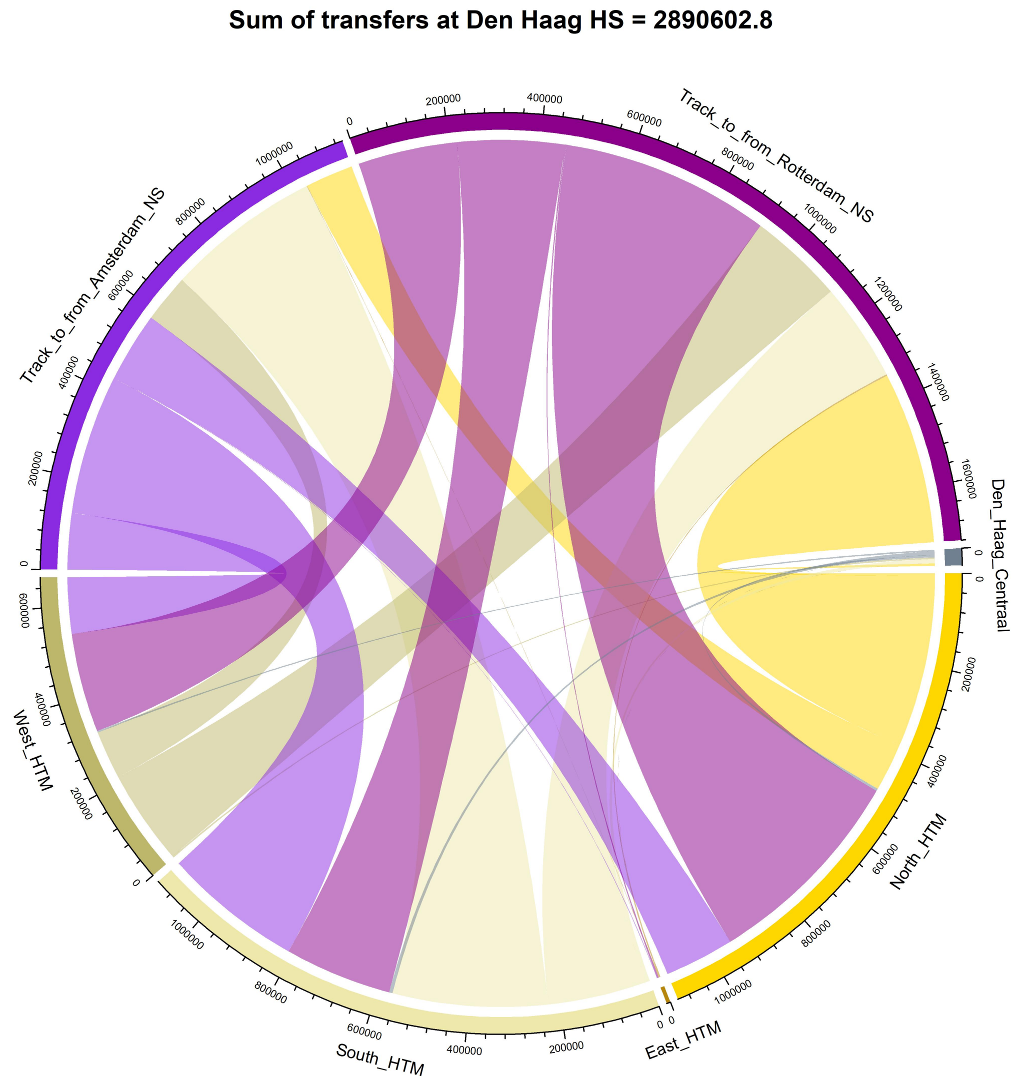
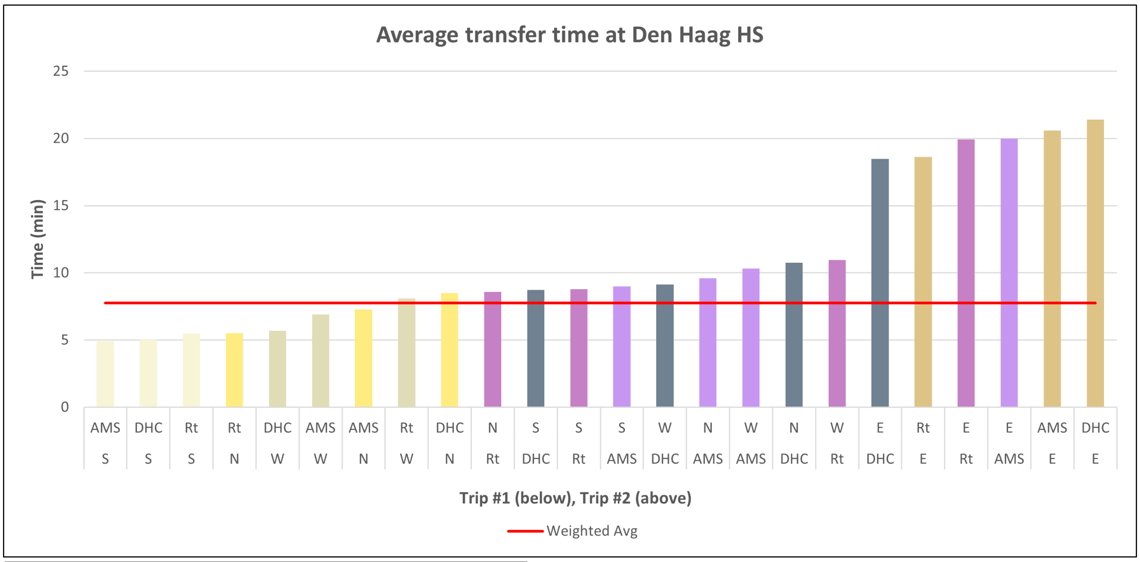


Figure 5.3: Number of transfers via Den Haag HS station between NS (train) and HTM (bus/tram) and their directions.
*Direction to/from Utrecht track is not taken into account as this consists of 0.03% of the total only



Abbreviation	Direction
Ams	Track_to_from_Amsterdam_NS
Rt	Track_to_from_Rotterdam_NS
DHC	Den_Haag_Centraal
N	North_HTM
E	East_HTM
S	South_HTM
W	West_HTM

Figure 5.4: Average transfer time of the transfers at Den Haag HS between NS (train) and HTM (bus/tram) and their directions. *Direction to/from Utrecht track is not taken into account as this consists of 0.03% of the total only

5.2.3. Den Haag Laan van NOI

As can be seen in figure 5.5 transfers at Den Haag Laan van NOI are done from/to three different directions by train (via the track to/from Amsterdam, Rotterdam and Den Haag Centraal (DHC)) and from/to the four wind directions North, East, South and West. In total over 1.1 million travelers are transferring between NS and HTM and vice versa at Den Haag Laan van NOI (in the period between the 1st of September 2018 and the 30th of September 2019). Most travelers that are transferring at Den Haag Laan van NOI are coming from the Amsterdam track and are transferring to the East and the West and are coming from the East and transferring towards the Amsterdam track. What is remarkable is the difference between the flow from the Amsterdam track towards the West and vice versa: 197,584 transfers and 107,486 transfers. So far, at the Den Haag Centraal and Den Haag HS stations, the flows were always similar in size for both ways. However, at Den Haag Laan van NOI this is thus not always the case. Overall, 503,016 travelers are transferring towards the train while 637,705 travelers are transferring towards the tram or bus. This gap can probably be explained by a higher flow of travelers traveling further into the city and taking a train at a different transfer station on the way back.
Looking into the average transfer time graph in figure 5.6, the directions from the Amsterdam track towards the East and West have an average transfer time of around 6.7 and 8.7 minutes respectively. The average transfer time of travelers coming from the East and transferring towards the Amsterdam track has the lowest average transfer time of (only) 4.8 minutes.

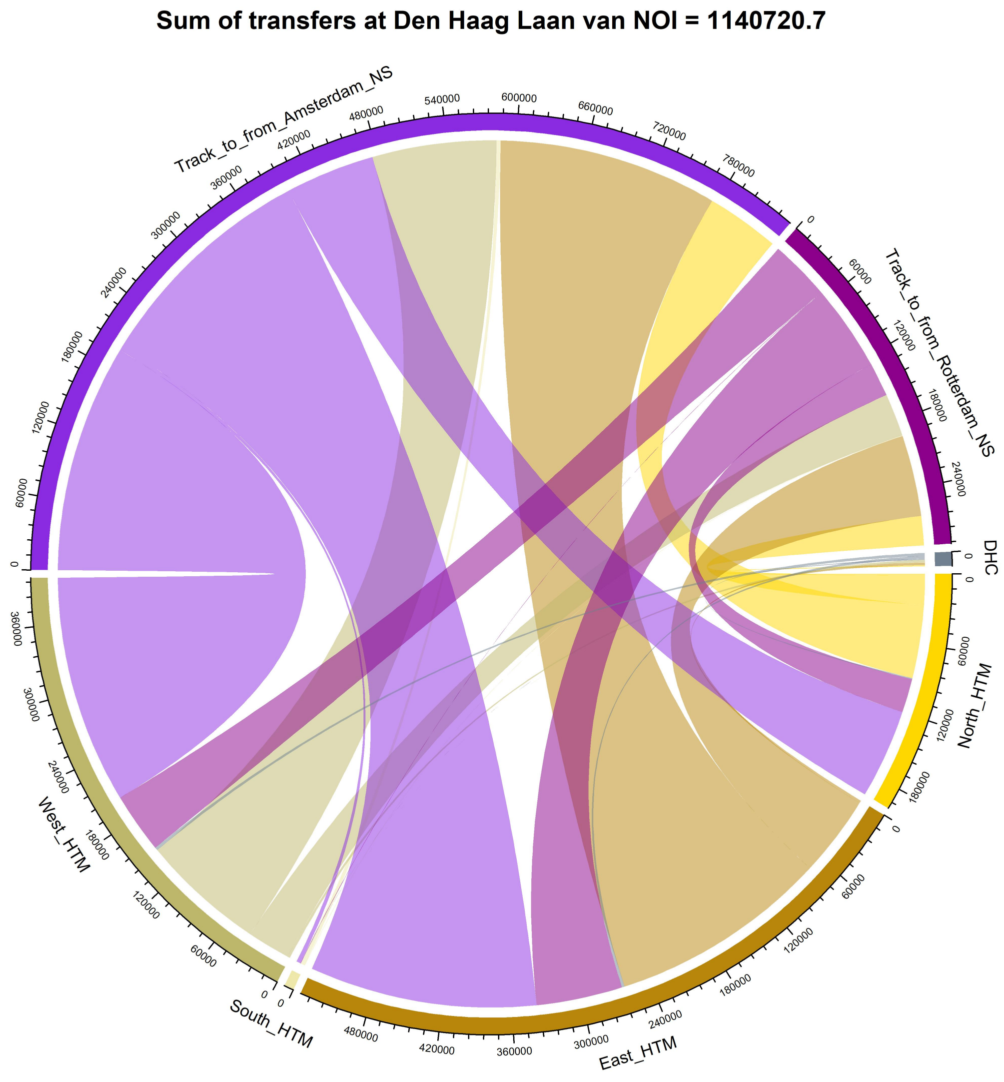
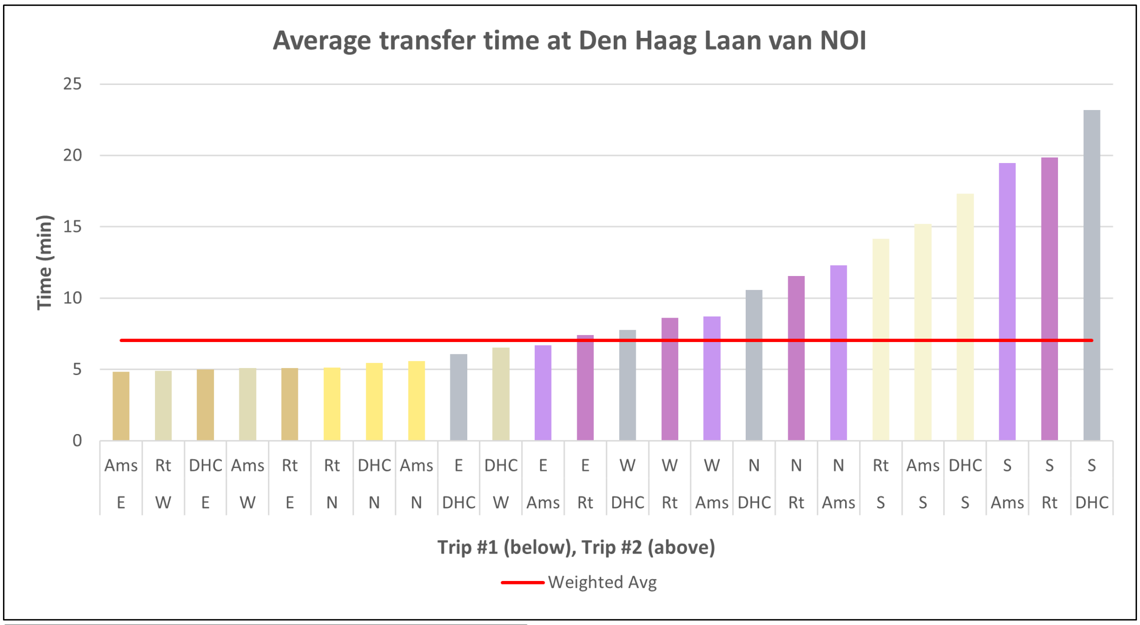


Figure 5.5: Number of transfers via Den Haag Laan van NOI station between NS (train) and HTM (bus/tram) and their directions



Abbreviation	Direction
Ams	Track_to_from_Amsterdam_NS
Rt	Track_to_from_Rotterdam_NS
DHC	Den_Haag_Centraal
N	North_HTM
E	East_HTM
S	South_HTM
W	West_HTM

Figure 5.6: Average transfer time of the transfers at Den Haag Laan van NOI between NS (train) and HTM (bus/tram) and their directions

5.2.4. Delft

As can be seen in figure 5.7 transfers at Delft are done from/to two different directions by train (via the track to/from HS and Rotterdam) and from/to two wind directions North and South. In total almost 750,000 travelers are transferring between NS and HTM and vice versa at Delft (in the period between the 1st of September 2018 and the 30th of September 2019). Most travelers that are transferring at Delft are coming from the HS track and transferring towards the South and vice versa and are coming from the North and going to the Rotterdam track and vice versa. Looking into the average transfer time graph in figure 5.8, the flows from the Rotterdam track towards the North and from the HS track towards the South are the highest, around 7.6 and 7.4 minutes respectively. So, the transfers with the highest average transfer time have a large flow as well.

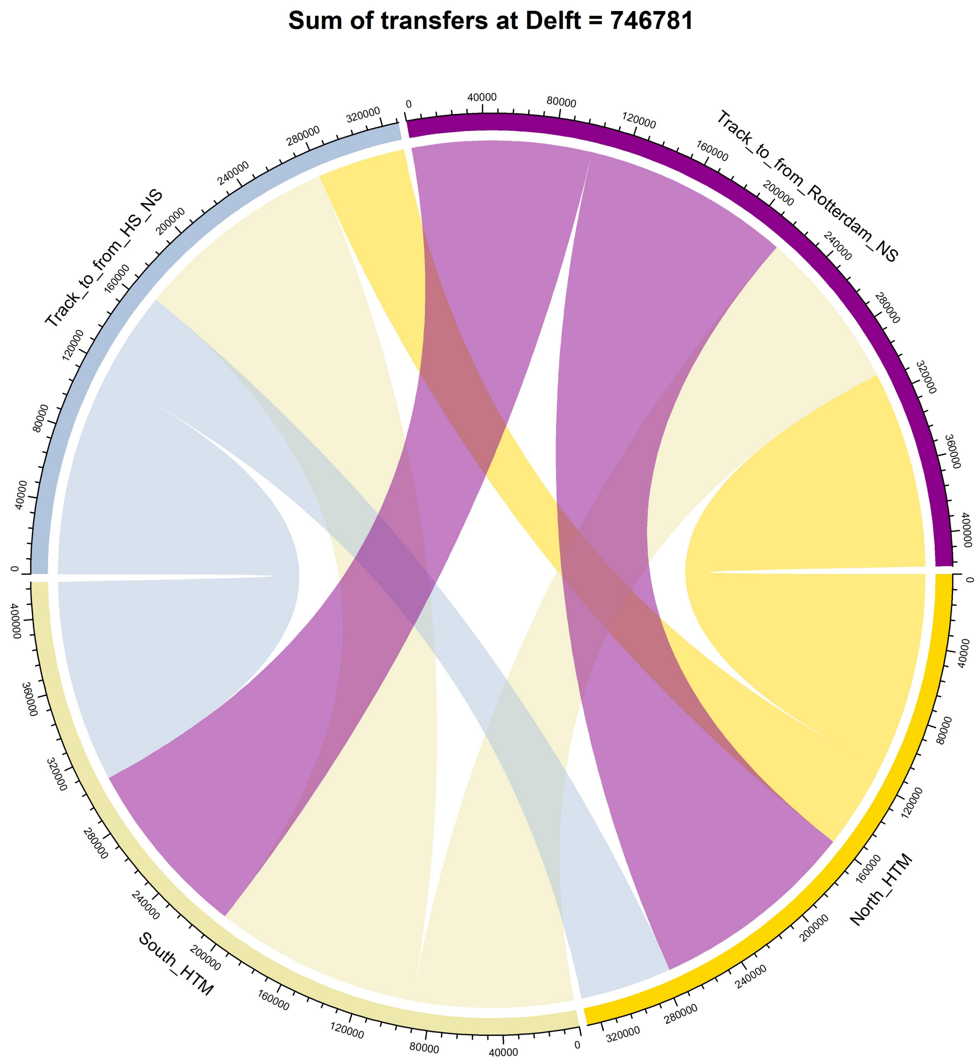
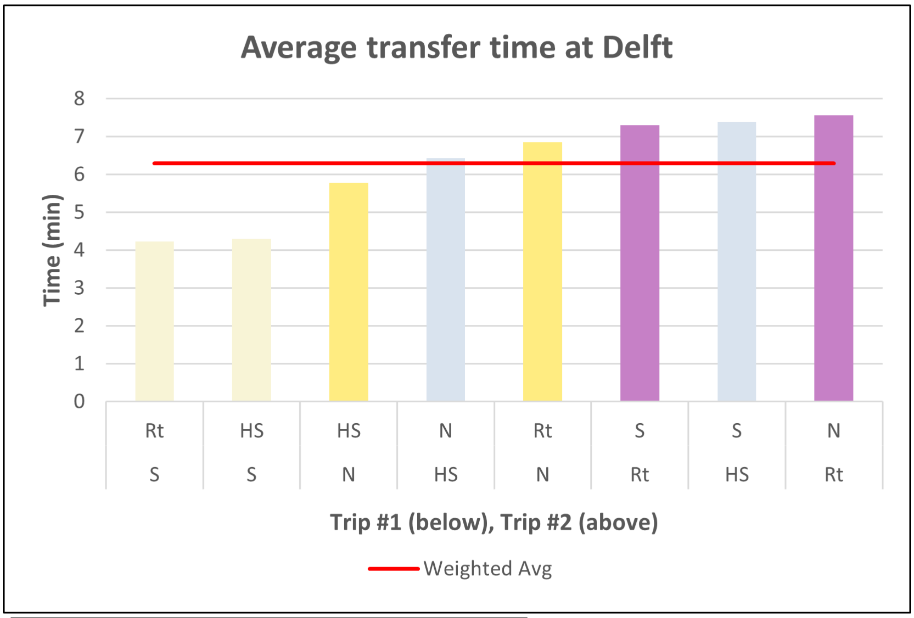


Figure 5.7: Number of transfers via Delft station between NS (train) and HTM (bus/tram) and their directions



Abbreviation	Direction
HS	Track_to_from_HS_NS
Rt	Track_to_from_Rotterdam_NS
N	North_HTM
S	South_HTM

Figure 5.8: Average transfer time of the transfers at Delft between NS (train) and HTM (bus/tram) and their directions

5.2.5. Explanatory (dis)utility factors

In this section the flows of the transfer stations will be discussed and tried to be explained by the average transfer time (waiting time and walking time) and the four (dis)utility factors discussed in section 5.1.

Explanatory (dis)utility factors Den Haag Centraal

The flow from the Amsterdam track towards the North mainly consists of transfers between the IC trains coming from Leiden and/or Amsterdam direction towards tram lines 9 and 16. These transfers have a relatively high transfer time which is not favorable for taking a transfer as explained in section 3.4. Therefore it is unusual that one of the higher flows at Den Haag Centraal has one of the highest average transfer times. However, part of this can be explained by the other (dis)utility factors. As said in section 5.1, at Den Haag Centraal, travelers have access to many facilities (very large) and have access to real-time information that can reduce the disutility of the transfer(s). For the transfers to and from lines 9 and 16, travelers furthermore do not need to level up or down which could decrease the disutility of the transfer even more (Garcia-Martinez et al., 2018 and Cascajo et al., 2017). Therefore this can be part of the reasons why still a high number of travelers are using these transfers with a relatively high transfer time.

One would expect relatively higher (lower) flows for the transfers with a low (high) average transfer time. This is not the case for the lowest average transfer times. The lowest average transfer time, transfers from the East direction towards the Rotterdam track are mainly transfers between tram lines 2,3,4,6 or bus 24 towards the IC train to Dordrecht or Eindhoven or the SPR train to Dordrecht. At these transfers, the traveler needs to level up which could increase the disutility of the transfer (Cascajo et al., 2017). The need to level up can be part of the reason why the flow is low.

Explanatory (dis)utility factors Den Haag HS

One would expect that the higher (lower) average transfer times have a lower (higher) flow as higher transfer times are not favorable for travelers because they give the transfer a disutility. Not taking into account the first six highest average transfer times, as these are uncommon transfers, the transfer from the Rotterdam track towards the West has the next highest average transfer time of 11 minutes. This transfer has the sixth-highest flow. This means it is a relatively high flow with a relatively high average transfer time. This can partially be explained because there is the availability of escalators, real-time information and many facilities that reduces the disutility of the transfer. The transfers from the South have the lowest average transfer times. The flows from the South have a relative high flow which can be explained by a lower transfer disutility because of low transfer times.

Explanatory (dis)utility factors Den Haag Laan van NOI
Transfers from the East to the Amsterdam track have the lowest average transfer time and have one of the highest flows. The other high flows have, however, a higher average transfer time. This could be explained because there is the availability of real-time information. However, transferring travelers need to level up or down, have almost no facilities and do not have escalators, which does not reduce the disutility of these transfers at Den Haag Laan van NOI. Therefore this cannot be explained by the (dis)utility factors and thus, there are probably different reasons why these relatively high transfer times have a higher flow.

Explanatory (dis)utility factors Delft
The highest flows at Delft have the highest average transfer times as well. This can be explained by the availability of real-time information, some facilities and escalators at Delft station which reduce the disutility of transfers.

Other reasons
There are, however, (more) other reasons explaining the flow sizes. A higher demand and no other better alternative available, meaning travelers have to take the route and thus the transfer, because they have a reason to go somewhere, or other (dis)utility factors not taken into account in this study such as crowding, disruption of an activity or the ease of wayfinding have an influence as well. Therefore, to be able to draw conclusions to this, more research is necessary. Also research into the exact (dis)utility values for this case is necessary to study whether the (dis)utility factors are explaining the flow sizes. Now, it is uncertain if the flow sizes can be explained by (dis)utility factors. If exact values are known, it is possible to calculate and model whether travelers use the transfer or if they prefer a different route and transfer. Perhaps the travelers will even choose a completely different mode of transport if the disutility of a transfer is too high for them and no better route is available.

5.2.6. Conclusions

The user flows from this study's multi-operator smart card dataset are visualized per transfer station in chord diagrams. It consists of an arc that differs in width. The width differs according to the number of travelers between a direction from the first trip to the direction of the second trip. The lines are divided into directions to prevent the diagrams from becoming illegible. This and figures 5.1; 5.3; 5.5 and 5.7 give an answer to the fourth sub-question: *What do Public Transport users flows of a multi-operator smart card dataset look like?*.

The fifth subquestion: *What can be said about the (dis)utility of the transfers in a multi-operator smart-card dataset* can be answered based on the transfer station level as well. This section visualizes the transfer flows and the corresponding average transfer times for the four transfer stations. The flow size is compared with the corresponding average transfer time and the (dis)utility factors to see if these could explain the flow size. The transfer time can directly be derived from the multi-operator smart card dataset. However, the transfer time by itself consists of both walking and waiting time disutilities, which both cannot be determined directly from the dataset. Other (dis)utility factors: the need to level up or down (stairs), availability of real-time information, level of station facilities and the presence of escalators are examined as well to see if these could explain the flow size. These can neither directly be derived from the multi-operator smart card dataset. However, because transfer stations can be identified, these factors can be examined, manually, in following steps. The walking time as well. By knowing the transfer time and the walking time, the waiting time can be derived by subtracting the walking time from the transfer time.

Overall, it is hard to explain the flow size by transfer stations' (dis)utility factors. Assumptions can be made, but it is not directly possible from a multi-operator smart card dataset to explain the flow size by (dis)utility factors. Because transfer stations are known, further manual examination of the (dis)utility factors can be done in following steps. However, it is not precisely known how strong the (dis)utility values are for this case. Therefore, research needs to be done into the values of the (dis)utility factors for this specific case. After that, it may be possible to explain the flow size by the (dis)utility factors. However, it might still be hard because it could also be that there is a certain demand and no other better alternative(s) possible which could mean that the traveler is taking this transfer also with a higher disutility.

In the next section, a closer look will be taken into the individual transfers to explore if the fifth subquestion: *What can be said about the (dis)utility of the transfers in a multiple-operator smartcard dataset* will be answered differently and to identify the most suitable transfer to implement a measure for minimizing the disutility.

5.3. Top 10s of individual transfers

A first indication has been made about the highest (lowest) flows and the highest (lowest) average transfer times of direction pairs at the four transfer stations, including some (dis)utility factors. In this section, the individual transfers are analyzed in more detail. Three top 10s are made: a top 10 of transfers with the highest average transfer time, a top 10 of transfers with the highest transfer time loss and a top 10 transfers with the highest transfer time loss for line totals. These will be discussed individually in the following paragraphs.

5.3.1. Top 10 transfers with the highest average transfer time

The transfers with the highest average transfer times are shown in table 5.2. The two highest average transfer times are transfers coming from the IC train from Utrecht Centraal. A plausible reason these transfer times are high is while they are done in the night/early in the morning (night train) and for ”Trip #2” the tram 12 to Markenseplein and tram 11 to Strandweg are not yet in operation at these times. The third highest transfer, the IC train from Duivendrecht towards bus 26 to Kijkduin, likely has a high average transfer time because bus 26 only departs every 30 minutes and thus, this transfer is not optimal as its average transfer time is more than 20 minutes. The numbers 4,7,8,9 and 10 are all transfers from a specific train towards tram 1 to Zwarte Pad. These all have a relatively high transfer time because tram 1 to Zwarte Pad does not stop at the transfer station Den Haag Centraal. This means that travelers are probably walking from Den Haag Centraal towards the nearest stop at line 1, which is in the city center, to take this particular tram 1 to Zwarte Pad. Then finally the numbers 5 and 6 are transfers at Den Haag Laan van NOI from the IC train from Lelystad Centrum and Amsterdam Centraal towards tram 19 to Delft station. These have a high average transfer time because tram 19 does not stop nearby Den Haag Laan van NOI and travelers are probably using the nearby metro towards Leidschenveen to where tram 19 does stop. The metro is managed by a different operator (RET). A RET transfer is not included in the dataset. However, this transfer via RET is feasible within 35 minutes and therefore shown as a transfer in the dataset. This explains why these transfers have a high average transfer time. All in all, these top transfers have a high average transfer time. However, while these transfers are either impossible at the given transfer station to transfer directly or are done at specific times (early morning), the transfer sums are relatively low. Therefore a new top 10 has been made that includes the sum of transfers; a top 10 transfers with the highest transfer time loss.

Table 5.2: Top 10 transfers with the highest average transfer time

Top	Trip #1	Transfer station	Trip #2	Average Time (min)
1	Train IC from Utrecht Centraal	Den Haag HS	Tram 12 to Markenseplein	24.97
2	Train IC from Utrecht Centraal	Den Haag HS	Tram 11 to Strandweg	22.01
3	Train IC from Duivendrecht	Den Haag HS	Bus 26 to Kijkduin	20.3033
4	Train SPR from Amsterdam Centraal	Den Haag Centraal	Tram 1 to Zwarte Pad	19.62
5	Train IC from Lelystad Centrum	Den Haag Laan van NOI	Tram 19 to Delft station	19.25
6	Train IC from Amsterdam Centraal	Den Haag Laan van NOI	Tram 19 to Delft station	18.66
7	Train IC from Enschede	Den Haag Centraal	Tram 1 to Zwarte Pad	18.2483
8	Train IC from Amersfoort Schothorst	Den Haag Centraal	Tram 1 to Zwarte Pad	17.9025
9	Train IC from Zwolle	Den Haag Centraal	Tram 1 to Zwarte Pad	17.62
10	Train IC from Utrecht Centraal	Den Haag Centraal	Tram 1 to Zwarte Pad	17.256

5.3.2. Top 10 transfers with the highest transfer time loss

Table 5.3 shows the ten transfers with the highest transfer times loss. What can be noted immediately is that the six highest all concern IC trains coming from Amsterdam Centraal. Tram 3 to Arnold Spoelplein appears the most often for "Trip #2" in this top10, followed by tram 9 to Zwarte Pad. There are 3577 unique transfers done in the dataset, but this top 10 unique transfers have a share of 9.08% of the total transfer time loss. The top 6 transfers with the highest transfer time loss, the transfers coming with the IC from Amsterdam Centraal, already have a transfer time loss percentage of 6.22%. This means that these six transfers have a transfer time loss of 6.22% of the total transfer time loss (which consists of 3577 transfers). Reflecting on the previous section, section 5.2, this is not remarkable. The flows from the Amsterdam Centraal direction are for the most important transfer stations high and the average transfer times of these flows are not particularly low, resulting in high transfer time loss. In the next top 10 the total share of transfer times loss of the IC coming from Amsterdam Centraal line including other lines are given.

Table 5.3: Top 10 transfers with the highest transfer time loss in percentages of total transfer time loss (=3577 transfers)

Top	Trip #1	Trip #2	Percentage (%)
1	Train IC from Amsterdam Centraal	Tram 3 to Arnold Spoelplein	1.3384
2	Train IC from Amsterdam Centraal	Tram 16 to Van Boetzelaerlaan	1.2127
3	Train IC from Amsterdam Centraal	Tram 9 to Zwarte Pad	1.1927
4	Train IC from Amsterdam Centraal	Tram 2 to Kraayensteinlaan	0.8420
5	Train IC from Amsterdam Centraal	Tram 4 to De Uithof	0.8206
6	Train IC from Amsterdam Centraal	Tram 9 to De Dreef	0.8127
7	Train IC from Groningen	Tram 3 to Arnold Spoelplein	0.7435
8	Train IC from Leeuwarden	Tram 3 to Arnold Spoelplein	0.7117
9	Train IC from Groningen	Tram 9 to Zwarte Pad	0.7040
10	Train IC from Amsterdam Centraal	Tram 1 to Abtswoudsepark	0.6987

5.3.3. Top 10 transfers with the highest transfer time loss for line totals

The top 10 line total transfers with the highest transfer time loss are given in table 5.4. There are 128 total lines in total. However, the top 10 total lines with the highest transfer time loss already have a share of 63.6%, which is nearly 2/3th of the total transfer time loss. The table shows that the IC train from Amsterdam Centraal has a total percentage of 12.8%. This percentage implies that the total transfer time of the train IC towards all the different PT lines of HTM has a share of 12.8% of the total transfer time loss of the all the total lines together. The total "Trip #2 line" to Amsterdam Centraal has not the same share, something that one would expect. The plausible reason is that the transfer time from a HTM line to a NS train is lower than the other way around, as the traveler does not need to check-in on the NS train. It is possible to check-in already at the station entrance, before the platform and before the train even arrives resulting in lower average transfer times. Therefore the total of lines to Amsterdam has "only" a share of 6.6% and thereby finds itself in third place. The total of lines towards the tram 9 to the Zwarte Pad has a share of 7% and finds itself in second place. In the fourth place is the total of lines towards tram 3 to Arnold Spoelplein, which has a share of 6.3%.

Table 5.4: Top 10 line totals with the highest transfer time loss in percentages of total transfer time loss (=128 lines)

Top	(Total) Trip #1 line	(Total) Trip #2 line	Percentage (%)
1	Train IC from Amsterdam Centraal	-	12.8022
2	-	Tram 9 to Zwarte Pad	6.9998
3	-	Train IC to Amsterdam Centraal	6.6387
4	-	Tram 3 to Arnold Spoelplein	6.2724
5	-	Tram 16 to Van Boetzelaerlaan	5.6164
6	Train IC from Vlissingen	-	5.4745
7	Train SPR from Dordrecht	-	5.0515
8	Train IC from Dordrecht	-	4.9920
9	Train IC from Groningen	-	4.9052
10	Train IC from Leeuwarden	-	4.8202

5.4. The transfers with the highest transfer times loss

After consultation with HTM, the conclusion is drawn that the top 10 transfers with the highest transfer time loss is the most interesting to examine in further detail. As in table 5.3, each transfer could be done at different transfer stations, the specific transfer station with the corresponding percentage, sum and the average travel time is added in table 5.5. Looking into the specific transfer station's percentages, each transfer is mainly done at one specific transfer station. The transfer from the Train IC from Amsterdam Centraal at Den Haag Centraal towards tram 16 to Van Boetzelaerlaan has the highest share (1.0808%). This transfer is followed by the transfer from the Train IC from Amsterdam Centraal at Den Haag Centraal towards tram 9 to Zwarte pad (1.0594%) and the transfer from the train IC from Amsterdam Centraal at Den Haag Centraal towards tram 3 to Arnold Spoelplein (1.0316%). In the next section, only the transfer stations with the highest percentage for each transfer from the top 10 will be examined further to examine the (dis)utility factors (given in bold in table 5.5). In the next section, the walking and waiting times are examined, which are followed by the other four (dis)utility factors: need to level up or down (stairs), availability of real-time information, number of facilities and if there are escalators.

Table 5.5: Top transfers with the highest transfer time loss in percentages of total transfer time loss - per transfer station*
* Very low shares are not included

Top	Trip #1	Transfer station	Trip #2	Share (%)	Sum	Avg tr. time (min)
1	Train IC from Amsterdam Centraal	All	Tram 3 to Arnold Spoelplein	1.3384	138633	6:49
		Den Haag Centraal		**1.0316**	101659.7	7:09
		Den Haag Laan van NOI		0.2990	36740.2	5:44
2	Train IC from Amsterdam Centraal	All	Tram 16 to Van Boetzelaerlaan	1.2127	123218.8	6:56
		Den Haag Centraal		**1.0808**	111097.5	6:52
		Den Haag HS		0.1235	11766.1	7:24
3	Train IC from Amsterdam Centraal	All	Tram 9 to Zwarte Pad	1.1927	124605.5	6:45
		Den Haag Centraal		**1.0594**	113650	6:34
		Den Haag HS		0.1256	10622.5	8:20
4	Train IC from Amsterdam Centraal	All	Tram 2 to Kraayensteinlaan	0.8420	107097	5:33
		Den Haag Centraal		**0.7367**	97484.9	5:20
		Den Haag Laan van NOI		0.0959	9179.2	7:22
5	Train IC from Amsterdam Centraal	All	Tram 4 to De Uithof	0.8206	110321.7	5:15
		Den Haag Centraal		**0.5856**	76321	5:25
		Den Haag Laan van NOI		0.2286	33752.8	4:46
6	Train IC from Amsterdam Centraal	All	Tram 9 to De Dreef	0.8127	84372.4	6:47
		Den Haag HS		**0.5531**	56558.5	6:39
		Den Haag Centraal		0.2742	27628.9	7:00
7	Train IC from Groningen	All	Tram 3 to Arnold Spoelplein	0.7435	80561	6:31
		Den Haag Centraal		**0.7293**	78999	6:31
8	Train IC from Leeuwarden	All	Tram 3 to Arnold Spoelplein	0.7117	74435.9	6:44
		Den Haag Centraal		**0.6990**	72887.2	6:46
9	Train IC from Groningen	All	Tram 9 to Zwarte Pad	0.7040	66190.5	7:30
		Den Haag Centraal		**0.7028**	66146.1	7:30
10	Train IC from Amsterdam Centraal	All	Tram 1 to Abtswoudsepark	0.6987	65939.2	7:28
		Delft		**0.4273**	42456	7:06
		Den Haag HS		0.2491	22741	7:43

5.4.1. Disutility factors

Walking- and waiting time

The total transfer times are divided into walking- and waiting times. These are given in table 5.6. Of these transfers, the transfer times fluctuate between 5 minutes and 20 seconds for the transfer at Den Haag Centraal from the IC from Amsterdam Centraal towards Tram 2 to Kraayensteinlaan and 7 minutes and 30 seconds for the transfer at Den Haag Centraal from the IC from Groningen towards tram 9 to Zwarte Pad. The walking times fluctuate between 2 minutes and 50 seconds for multiple transfers at Den Haag Centraal and 3 minutes and 20 seconds for the transfer at Delft from the IC from Amsterdam Centraal towards tram 1 to Abtswoudsepark. The transfers at Den Haag Centraal have a lower walking time than at Den Haag HS and Delft. The waiting times fluctuate between 2 minutes and 25 seconds for the transfer at Den Haag Centraal from the IC from Amsterdam Centraal towards tram 2 to Kraayensteinlaan and 4 minutes and 40 seconds for the transfer at Den Haag Centraal from the IC from Groningen towards tram 9 to Zwarte Pad.

As walking and waiting times give the traveler a disutility, the transfers with a higher walking and waiting times would have a higher disutility (when all other factors are equal). In that case, for the top 10, the transfer at Den Haag Centraal between the train IC from Groningen towards the tram 9 to Zwarte Pad has the highest disutility and the transfer at Den Haag Centraal between the train IC from Amsterdam Centraal towards tram 2 to Kraayensteinlaan has the lowest disutility. Purely based on the transfer time, the latter transfer is assumed to have a higher flow than the transfer between the train IC from Groningen towards tram 9 to Zwarte Pad. According to Garcia-Martinez et al. (2018) waiting times give a higher disutility than walking times (with one transfer in the journey). This would mean, when two transfers have the same transfer time (waiting- + walking times), but have different walking and waiting times, the transfer with the highest waiting time would have a higher disutility. However, it is not certain that the waiting time is giving a higher disutility than the walking time because Cascajo et al. (2017) found almost identical parameters for the waiting and walking times. Besides, the values of the (dis)utility factors can be different between cities (Iseki and Taylor, 2009). Thus, city-specific studies require a separate study into the identification of the variables of disutility factors. Furthermore, it is unclear if someone is taking more than one transfer in the same trip from the dataset. From section 3.4 it became clear that (dis)utility factors differ when transferring twice instead of once. Therefore the dataset should be designed where it is visible if one person is taking more transfers in the same journey or not.

Table 5.6: Division walking and waiting times* for the top transfers with the highest transfer time loss in percentages of total transfer time loss - per transfer station
*Walking times are measured by hand and might fluctuate due to crowding, individual walking speed, platform changes and alighting position at the platform

Top	Transfer Station	Transfer time (min)	avg Walking time (min)	avg Waiting time (min)	Percentage waiting (%)
1	Den Haag Centraal	7:09	2:55	4:14	59.2
2	Den Haag Centraal	6:52	2:50	4:02	58.8
3	Den Haag Centraal	6:34	2:50	3:44	56.9
4	Den Haag Centraal	5:20	2:55	2:25	45.2
5	Den Haag Centraal	5:25	2:55	2:30	47.8
6	Den Haag HS	6:39	3:05	3:34	53.7
7	Den Haag Centraal	6:31	2:55	3:36	55.2
8	Den Haag Centraal	6:46	2:55	3:51	58.2
9	Den Haag Centraal	7:30	2:50	4:40	62.3
10	Delft	7:06	3:20	3:46	53.1

Other disutility factors

The four other (dis)utility factors discussed in this research: need to level up or down (stairs), availability of real-time information, number of facilities present and the presence of escalators for these transfers are examined as well and are shown in table 5.7.

As already said in section 5.1 all the stations and their transfers have the availability of real-time information, which reduces the disutility for all the transfers. The facilities at Delft are categorized as large and Den Haag Centraal and Den Haag HS are categorized as very large, according to Schakenbos et al. (2016). As a higher number of facilities at a transfer station reduces the disutility of a transfer, the transfers at Delft reduces the disutility less than the transfers at Den Haag Centraal and Den Haag HS when all other factors are equal. As leveling up or down gives a disutility, this can explain, for Den Haag Centraal, the first and the second place transfers with the highest transfer time loss: the Train IC from Amsterdam Centraal towards tram 16 to van Boetzelaerlaan (1.0808%) and to tram 9 to Zwarte Pad (1.0594%). For these transfers the travelers do not need to level up or down to get to their following vehicle, which lead to a lower disutility and can lead to a higher flow. While the transfer times of these transfers are not the highest, but they have the highest transfer time losses, their flow is high. However, it cannot be said with certainty that this higher flow is because of the (dis)utility factors studied. Other reasons such as a high demand an no other better alternative available or other (dis)utility factors not taken into account in this study have an influence as well. Therefore, more research needs to be done in order to be sure about this and to draw conclusions. Furthermore, by knowing the exact values of the disutility factors a better research can be done whether the (dis)utility factors can explain the flow sizes.

Table 5.7: Other disutility factors for the top transfers with the highest transfer time loss in percentage of total transfer time loss - per transfer station

Top	Trip #1	Transfer station	Trip #2	Level up/down	Real-time info	Facilities	Escala-tors
1	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 3 to Arnold Spoelplein	Yes	Yes	very large	Yes
2	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 16 to van Boetzelaerlaan	No	Yes	very large	No
3	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 9 to Zwarte Pad	No	Yes	very large	No
4	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 2 to Kraayensteinlaan	Yes	Yes	very large	Yes
5	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 4 to De Uithof	Yes	Yes	very large	Yes
6	Train IC from Amsterdam Centraal	Den Haag HS	Tram 9 to De Dreef	Yes	Yes	very large	Yes
7	Train IC from Groningen	Den Haag Centraal	Tram 3 to Arnold Spoelplein	Yes	Yes	very large	Yes
8	Train IC from Leeuwarden	Den Haag Centraal	Tram 3 to Arnold Spoelplein	Yes	Yes	very large	Yes
9	Train IC from Groningen	Den Haag Centraal	Tram 9 to Zwarte Pad	No	Yes	very large	No
10	Train IC from Amsterdam Centraal	Delft	Tram 1 to Abtswoudsepark	Yes	Yes	large	Yes

5.4.2. Conclusion

It is not possible to get the (dis)utility factors of the transfers directly from the multi-operator smart card dataset. However, a multi-operator smart card dataset can identify the most important transfers. Therefore, more research can be done in the following steps to examine these transfers' (dis)utility factors. For the most important transfers, the (dis)utility factors waiting time, walking time, need to level up or down, availability of real-time information, the number of facilities present and the presence of escalators are examined manually and results are given in tables 5.6 and 5.7. Therefore, this is the same conclusion to the fifth sub-question: *What can be said about the (dis)utility of the transfers in a multi-operator smart card dataset?* as was given in section 5.2.6.

5.5. Measure implementation

Now that the details of the most important transfers and their transfer stations are known, the transfer that has the highest impact on the total transfer time loss can be determined when reducing the waiting time by one minute, which can be facilitated by synchronizing the timetables of the concerning lines better. In table 5.8 the most important transfers for the specific transfer stations are given including the percentage difference when the waiting time is reduced by one minute. This "difference" column gives the highest impact on the total transfer time loss. Not the first transfer with the highest transfer time loss has the highest impact, but the second (with a share of around 1.06%): the train IC from Amsterdam Centraal transferring at Den Haag Centraal towards tram 9 to Zwarte Pad has the highest impact on the transfer time loss (given in bold in table 5.8). A one-minute decrease in waiting time reduces the total transfer time loss by around 0.16 percentage points. This means the share of the transfer from the train IC from Amsterdam at Den Haag Centraal towards Tram 9 to Zwarte Pad of the total transfer time loss of all the transfers together decreased with around 0.16 points by having a waiting time reduction of one minute. The share of this transfer on the total transfer time loss without a waiting time reduction was around 1.06% and when implementing a one minute reduction of waiting time, this will decrease to a share of around 0.9%, which brings itself from the second to the third place of the highest transfer time loss.

Table 5.8: Top transfers with the highest transfer time loss in percentages of total transfer time loss - including share difference on transfer time loss when implementing the measure

Top	Trip #1	Transfer station	Trip #2	Share transfer time loss (%)	Share transfer time loss when -1 min waiting time (%)	Difference (% points)
1	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 3 to Arnold Spoelplein	1.0316	0.8875	0.1441
2	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 16 to Van Boetzelaerlaan	1.0808	0.9233	0.1575
3	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 9 to Zwarte Pad	1.0594	0.8982	**0.1612**
4	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 2 to Kraayensteinlaan	0.7367	0.5985	0.1382
5	Train IC from Amsterdam Centraal	Den Haag Centaal	Tram 4 to De Uithof	0.5856	0.4774	0.1082
6	Train IC from Amsterdam Centraal	Den Haag HS	Tram 9 to De Dreef	0.5531	0.4529	0.1002
7	Train IC from Groningen	Den Haag Centraal	Tram 3 to Arnold Spoelplein	0.7293	0.6173	0.1120
8	Train IC from Leeuwarden	Den Haag Centraal	Tram 3 to Arnold Spoelplein	0.6990	0.5957	0.1034
9	Train IC from Groningen	Den Haag Centraal	Tram 9 to Zwarte Pad	0.7028	0.6090	0.0938
10	Train IC from Amsterdam Centraal	Delft	Tram 1 to Abtswoudsepark	0.4273	0.3671	0.0602

5.5.1. Effects of the measure

If reducing the waiting time for the train IC from Amsterdam Centraal at Den Haag Centraal towards Tram 9 to Zwarte Pad by one minute, this transfer will get more attractive as the disutility will decrease. Therefore, this measure will be implemented and tested in a PT model in OmniTRANS to see and visualize its effect on traveler flows. First a reference model level will be made and the loads on the network will be visualized. In the model a walk link exists between Den Haag Centraal and the stop of tram 9 to Zwarte Pad with a certain walking speed. To measure the effects of the implementation of the measure of one minute less waiting time, the walking speed on this link from Den Haag Centraal towards the tram stop of tram 9 to Zwarte Pad is increased in a new model level in order that the transfer time has decreased by 60 seconds. In order to get the effects on the flow in the network it does not matter for the model that the walking time is decreased while in this study a waiting time reduction is used. While it is not possible to change waiting times that easy and while the outcome of the effect in the transport model would be the same when changing the walking time, this is seen as a representative way of implementing the measure and showing the effects.
The load on the network of the reference model level, so without the measure, can be seen in figure 5.9. This load is given for an average working day for the whole city of Den Haag. The highest loads are in the center of Den Haag, especially around Den Haag Centraal station. A similar load on the network will be seen on this scale when implementing the measure. However, if taking a closer look at the Den Haag Centraal station area, small changes can be seen (see Appendix C.1). From Den Haag Centraal towards the North-West, a small increase of load can be seen, while in the South-West of Den Haag Centraal a little less load is observed. An overview of the tram lines and stops, including the location of Den Haag Centraal are given in figure C.3 in Appendix C.2.

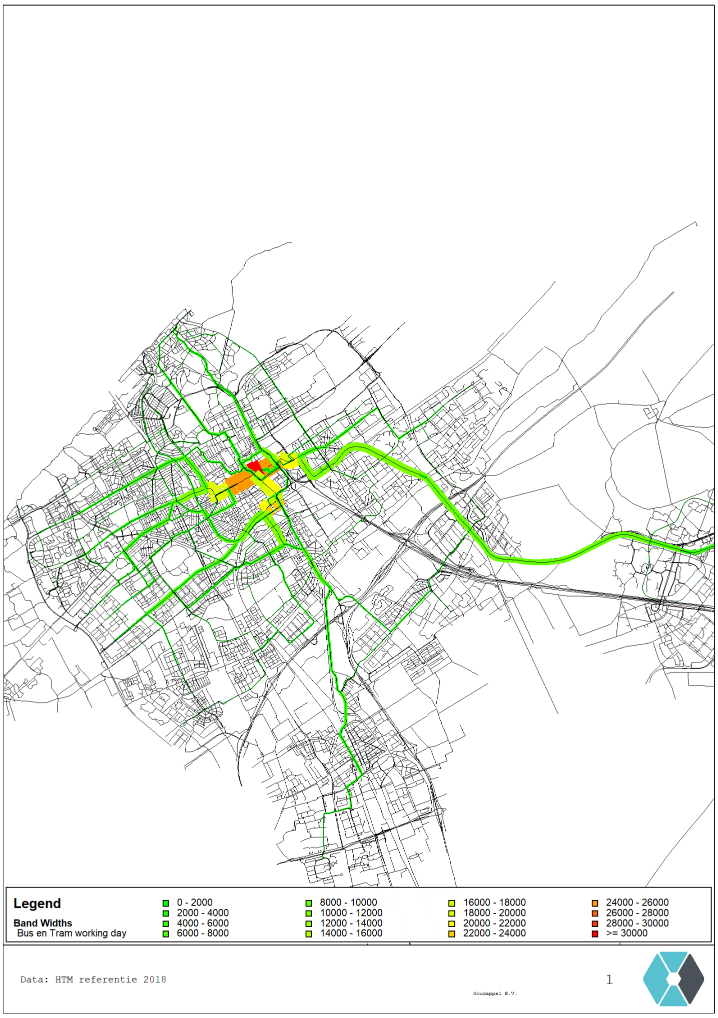


Figure 5.9: Load on network (working day)

The difference in the network loads after implementing the measure is given in figure 5.10. It is zoomed in around the area of Den Haag Centraal and the city center. The green areas show an increase in load when the measure is implemented, the red areas show a decrease in load and the grey areas indicate the same load. This visualization concerns average working days only. Saturdays and Sundays give a similar pattern, only with lower loads, so fewer travelers. Taking a closer look and also comparing figure 5.10 with the tram lines (which are shown in figure C.3 in Appendix C.2), the areas that have an increase of travelers are on line 9 to Zwarte Pad. An increase on this line 9 is expected as the transfer towards line 9 at Den Haag Centraal station has improved (one minute less waiting time) and thus, the disutility of this specific transfer is reduced. The exact flow differences on line 9 to Zwarte Pad are given in table 5.9. The first column gives the tram stop, the second column gives the extra flow of travelers (Pass.), then the extra flow of first time boarders in the network is given (#1 Board), then the extra flow of alighting passengers for the last time in the network (Last Alight), the extra flow of boarding travelers changing at the stop and coming from a different line (Ch. Board), the extra flow of alighting passengers at the stop to a different line (Ch. Alight), the extra flow of boarding travelers walking towards the stop from a different stop (Walk Board), the extra flow of alighting travelers and walking to a different stop (Walk Alight) and the total sum of boarding (Sum Board) and alighting (Sum Alight) are given. As can be seen, at Den Haag Centraal Station (Beneden), 371 more travelers are boarding for the first time at a HTM line on line 9 to Zwarte Pad. 31 of them are probably coming from line 16 to van Boetzelaerlaan because on line 16, 31 less travelers are boarding at Den Haag Centraal and 31 less travelers are alighting at the stop directly after Centraal Station: Korte Voorhout, which is between Centraal Station and the tram stop Dr. Kuyperstraat. The same counts for line 15 to Nootdorp, 26 less travelers are boarding at Den Haag Centraal and 26 less travelers are alighting at the Korte Voorhout tram stop. And as can be seen in the table 5.9, the highest increase of alighting travelers is at the Dr. Kuyperstraat stop. While the disutility from Den Haag Centraal to go on line 9 to Dr. Kuyperstraat is reduced, it becomes more favorable over tram 15 and 16 to the Korte Voorhout stop. Therefore, more travelers are using line 9 to their destination in the area between the Korte Voorhout and Dr. Kuyperstraat, which is an area with a lot of offices. Furthermore, 43 less travelers are taking the shorter line 9 to Madurodam and 2 less travelers are taking the bus 20 to Duinzigt while tram 9 to Zwarte Pad has become more favorable. The remaining 269 more travelers on line 9 to Zwarte Pad are new travelers being attracted to go travel by PT instead of another mode. It is unknown from which modes but while especially an increase of alighting travelers at the direct stops after Den Haag Centraal is found, these are most likely travelers that used to go walking or cycling before. However, also an increase to the Kurhaus stop can be seen, especially in the weekend (see tables C.3, C.4, C.5 and C.6 in Appendix C.3), which can be travelers that used to go by car as well as it is a one hour walk. If that is the case it means that the car use has reduced, which is beneficial for the environment.

In total around 3% more travelers are using line 9 to Zwarte Pad when implementing a one minute reduction of waiting time. All of the increased flow is boarding at Den Haag Centraal. The flow of boarding travelers at Den Haag Centraal increased with around 11.7%. The highest increase of alighting travelers percentage, at the Dr. Kuyperstraat, is around 9.2%. During weekend days the increase of alighting travelers increases especially at the Kurhaus stop (see tables C.3, C.4, C.5 and C.6 in Appendix C.3). While around the Dr. Kuyperstraat a lot of office buildings are located and while the Kurhaus stop is located at the beach of Scheveningen this seems plausible as travelers often do not go to offices in the weekend but go rather to the beaches for leisure. Furthermore, what is interesting to see, is a decrease of travelers boarding on the line at the stops before and after Centraal Station, Kalvermarkt-Stadhuis and Malieveld respectively. The 14 less travelers boarding at line 9 and coming from a different line at the same stop (Ch. Board) are probably coming from line 9 to the other direction, Vrederust, and the shorter line 9 to Vrederust because less travelers are alighting on these lines at the Kalvermarkt-Stadhuis stop. This indicates that a few travelers used to go with line 9 or the shorter line 9 to Kalvermarkt-Stadhuis and then change to the line 9 but towards the other direction again. These travelers probably do not want to wait outside but prefer waiting and sitting in a tram. The 27 less travelers boarding at Malieveld and coming from a different stop (Walk Board) were probably coming from lines 15 or 16 at the Korte Voorhout stop before as less travelers are alighting at the Korte Voorhout stop, which is located close to the Malieveld stop. Thus, these travelers are probably taking the line 9 already at Centraal Station. Lastly, the 3 less travelers boarding at Malieveld on line 9 to Zwarte Pad from a different line at the same stop were probably coming from the shorter line 9 as on that line a few less travelers are alighting at the Malieveld stop. Thus, again these travelers are probably taking the line 9 at Centraal Station already, which has become more interesting as the waiting time and thus the disutility has reduced.

Table 5.9: Stops with flow difference on line 9 to Zwarte Pad (working day) after implementation of the measure

Tram stop	Pass.	#1 Board	Last Alight	Ch. Board	Ch. Alight	Walk Board	Walk Alight	Sum Board	Sum Alight
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	-14	0	0	0	-14	0
175,Den Haag, Centraal Station Beneden	-14	0	0	0	0	0	0	0	0
146,Den Haag, Centraal Station Beneden	-14	371	0	0	0	0	0	371	0
444,Den Haag, Malieveld	357	0	0	0	0	0	0	0	0
433,Den Haag, Malieveld	357	0	29	-3	0	-27	0	-30	30
443,Den Haag, Dr. Kuyperstraat	298	0	0	0	0	0	0	0	0
434,Den Haag, Dr. Kuyperstraat	298	0	81	0	0	0	0	0	81
442,Den Haag, Javabrug	217	0	0	0	0	0	0	0	0
435,Den Haag, Javabrug	217	0	38	0	0	0	0	0	38
441,Den Haag, Laan Copes van Cattenburch	179	0	0	0	0	0	0	0	0
436,Den Haag, Laan Copes van Cattenburch	179	0	43	0	0	0	0	0	43
437,Den Haag, Riouwstraat	136	0	11	-1	0	0	0	-1	11
440,Den Haag, Riouwstraat	125	0	0	0	0	0	0	0	0
439,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
438,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
461,Den Haag, Madurodam (Noord)	125	0	22	0	0	0	0	0	22
460,Den Haag, Wagenaarweg	103	0	0	0	0	0	0	0	0
462,Den Haag, Wagenaarweg	103	0	4	0	0	0	0	0	4
464,Den Haag, Nieuwe Duinweg	99	0	15	0	0	0	0	0	15
458,Den Haag, Nieuwe Duinweg	83	0	0	0	0	0	0	0	0
1088,Den Haag, Circustheater	83	0	24	0	0	0	0	0	24
1,Den Haag, Kurhaus	59	0	0	0	0	0	0	0	0
74,Den Haag, Kurhaus	59	0	50	0	0	0	1	0	51
75,Den Haag, Zwarte Pad Uitstaphalte	8	0	8	0	0	0	0	0	8
41,Den Haag, Zwarte Pad	0	0	0	0	0	0	0	0	0
Total		**371**	**325**	**-18**	**0**	**-27**	**2**	**327**	**327**

The highest increase of travelers is 357 at Den Haag Centraal, meaning the vehicles on line 9 to Zwarte Pad are becoming more crowded, especially at Den Haag Centraal. Crowding gives a disutility (Garcia-Martinez et al., 2018 and Cascajo et al., 2017). Of the disutility factors, crowding is found to increase the disutility even the most. When lines are getting too crowded, travelers may choose different routes (or even modes). Therefore, operators need to take the capacity restrictions and the effects of crowding into account before implementing the measure. Furthermore, synchronizing the timetables of the concerning lines to reduce the waiting time of the concerning transfer, can have an effect on other transfers and lines as these can get more inefficient and unreliable (Lee et al., 2014). Therefore, before choosing to synchronize timetables at a specific transfer better, effects on other lines and transfers and their timetables need to be examined as well.

5.5.2. Conclusion

A waiting time reduction of one minute has been implemented for the most important transfer, to reduce the transfer time loss and to reduce the disutility. This transfer is at Den Haag Centraal between the IC from Amsterdam Centraal towards line 9 to Zwarte Pad. The effects are calculated and the changed flows are given and visualized. The line with the measure, line 9 to Zwarte Pad, get around 3% (371 travelers) flow increase with an increase of boarding travelers of 11.7% (371 travelers) at Den Haag Centraal. Some travelers from lines 15 to Nootdorp, 16 to van Boetzelaerlaan and the shorter line 9 to Madurodam are taking the line 9 to Zwarte Pad instead because line 9 has become more interesting as the disutility has reduced. Especially travelers that used to alight at the Korte Voorhout stop are taking line 9 to the stops Malieveld and especially Dr. Kuyperstraat at line 9 to Zwarte Pad instead. Furthermore, 269 new travelers are using the PT instead of using another mode. Therefore, a waiting time reduction to lower the disutility of a transfer can influence traveler's choice behavior of choosing modes and routes. Before implementing the measure, negative effects such as crowding and possible more inefficient other transfers need to be examined. In the end, more of such waiting time reduction measures could be implemented in a transport model for more (important) transfers, and the following effects thereof can be examined to decide whether to implement the measure.

Figure 5.10: Difference between measure- and reference model level (working day) - zoomed in

6 Discussion

This chapter builds on the results presented in chapter 5 and discusses their implications. The first section discusses the case study results, followed by a section that zooms out and addresses the general implications of this research. After that, the study's methodological contributions are presented, after which its limitations are discussed.

6.1. Implication of case study

Various analyses were performed, targetting the case study specifically. In short, these aimed to identify the transfers with the highest transfer time loss, implement a measure to address the underlying disutility (waiting and walking time), and explore the resulting changes in transport flows. This section discusses the implications of these analyses.

First of all, this study analyzed the transfer stations in the Haaglanden area. By means of visualization, the transfer flows and their relative sizes were identified for each station. Thereafter, each station was evaluated on its disutility factors. As a transfer with a high disutility is not favorable for travelers, it can result in lower flow size(s). Not all (dis)utility factors are examined. Factors such as crowding, disruption of an activity or the ease of wayfinding are not taken into account, but can also influence the flow size. When travelers want to go somewhere and if there is only one (best) option to go there, travelers will probably use this option, also when this option has a transfer. However, while the four most important transfer stations found in this study are close to each other and, therefore, different routes are often possible to take, (dis)utility factors can play a role. Therefore, an aim was to explore the extent to which the observed flow sizes could be explained by the (dis)utility factors at a particular station. The results show that, at least within the Haaglanden area, the (dis)utility factors cannot always explain the transfer (station) flow size(s). For instance, for Den Haag Laan van NOI, it was shown that most of the high flows have a high transfer time, which would be more acceptable if more utility factors such as having (many) facilities or the presence of escalators, were present. However, only one utility factor (real-time information) and significantly more disutility factors (such as the need to level up or down) are present at the station. In other words, despite the limited number of utility factors and the high average transfer time, transfer flows remain high. Therefore it can be concluded that, in this study, disutility factors of a transfer station alone do not always seem to explain transfer flows. The factors having a high demand (travelers have a reason to go somewhere) and that there is sometimes no (better) alternative available, influence transfer flows probably more. Looking into the disutility factors on an individual level and to decide if those can explain the flow sizes, it is found that it is hard to say without actual disutility values. However, as shown by means of the case study, reducing the waiting time of a transfer by one minute can increase the flow size. This indicates that disutility factors, on the scale of individual transfers, seem to explain flow sizes.

Additionally, the study selected an individual transfer (the transfer at Den Haag Centraal between the IC train from Amsterdam Centraal and Tram 9 to Zwarte Pad) which would be suitable for a measure. It had an average transfer time of 6 minutes and 34 seconds. Implementing a waiting time reduction measure of one minute will result in a transfer time of 5 minutes and 34 seconds. Applying this measure therefore allows operators to reduce disutility and increase traveler satisfaction with this particular transfer. However, in interpreting this measure, it is wise to consider the findings by Schakenbos et al. (2016). Schakenbos et al. (2016) find, by doing a stated preference experiment and using a mixed logit model, that a transfer time below 8 minutes may be perceived as stressful because of the fear of missing the connecting vehicle and, therefore, may lead to a higher disutility of the transfer. However, the most important transfers in this study are transfers between train and tram. According to Schakenbos et al. (2016), changing the transfer time from 8 to 5 minutes in such transfers gives only a small disutility. Furthermore, Schakenbos et al. (2016) are determining the disutility for transfers having a headway of 15 minutes. Larger headways will mostly result in higher disutilities. However, the most important transfer in this study has a headway of 7.5 minutes, indicating that it might get a lower disutility. Therefore, it is not assumed that reducing the transfer time by one minute would directly lead to a higher disutility. In other words, in this particular case study of the Haaglanden area, reducing the transfer time of the transfer at Den Haag Centraal between the IC train from Amsterdam Centraal and Tram 9 to Zwarte Pad would be a valuable measure to increase travelers' satisfaction for this particular journey.

The method and results compare to the literature as follows. Firstly, a comparison can be made regarding the approach to identifying transfer stations. This study determines the most important transfer stations based on the flows. Yap et al. (2019) uses the same case study but identifies important stations in a slightly different and more detailed way. Two of the four most important transfer stations identified in this study are also found in Yap et al. (2019); Den Haag Centraal and Den Haag HS. However, Yap et al. (2019) only uses a single-operator smart card dataset of the tram/bus network. In contrast, this study only uses a multi-operator smartcard dataset with transfers between the train and bus/tram and vice versa. Therefore the other important transfer stations in this study (Den Haag Laan van NOI and Delft), are not found in the study of Yap et al. (2019) but other stations are found important. These other stations are all stations where no trains are operating. If Yap et al. (2019) would use a multi-operator smart card dataset, other transfer stations would probably be found important as well.

Another comparison can be made in terms of the found transfer times. The transfer times of the most important transfers in this study have a walking time of around 3 minutes and a waiting time slightly above 3 minutes and 30 seconds. These times do not seem long. However, comparing the walking time and waiting time to the study of Ali et al. (2016), the waiting time of the most important transfers are found to be higher than the waiting time of the examined PT line in Ali et al. (2016). While for other transfer stations in Ali et al. (2016) the walking times are expected to be higher, more comparable waiting times can be expected if the total transfer times stay at the same level. The waiting times in this study, however, are found to be around 30 seconds higher than in Ali et al. (2016).

6.2. General implications

This section discusses the methods and results of this study in a general perspective.

This study shows that a multi-operator smart card dataset contributes to minimizing the disutility of a transfer. By including the attributes: transfer station, the trip and line towards the transfer station (which can also be derived from the check-in stop and the operator name), the trip and line after transferring (which can also be derived from the check-out stop and the operator name), the number of travelers and the average transfer time (which can also be derived from the check-in and check-out times and the number of travelers), the most important transfer stations and individual transfers can be identified and a particular measure can be illustrated that can lower the disutility.
A multi-operator smart card dataset can derive the transfer flows and the transfer times directly, however, the individual disutility factors not. This is not a remarkable result as it would not be possible to include the disutility factors for every transfer directly in a multi-operator smart card dataset. In an ideal situation, these disutility factors are included to determine the transfer's total disutility. As this is not the case, one may apply the following alternative method to gather this information. Firstly, a multi-operator smart card dataset can derive the information of the transfer times and flows of transfers, so the (most) important transfer locations (transfer stations and individual transfers) can be determined.

Once these are identified, individual disutility factors of the transfer locations can be examined manually (for example: by determining the presence of escalators at the transfer station or the walking time of the transfer). This allows for the total disutility of a transfer to be determined, based on which measures can be considered to minimize this disutility.

In determining which measures to implement, it is important to examine the effects of such a measure on the transfer's disutility. Various measures can be applied. Reducing the walking time, for example, by having shorter walking routes or reallocating the stops. Other measurements to lower the disutility, such as constructing escalators or real-time information displays, could be examined in further research as well. This study showed that the specific disutility factor waiting time could be reduced by implementing a measure, such as improving timetable synchronization. Taking measures to minimize the disutility of transfers is favorable for travelers. The satisfaction of the traveler will be improved and traveling with Public Transport can also be more interesting for travelers using other modes, which could lead to mode shifts (and possibly even better for the environment). It is, however, important to consider the consequences when implementing a measure to reduce the disutility, such as a waiting time reduction as it may increase traveler flows. This is also observed in the case study. In turn, such higher flows may lead to (more) crowding. As crowding in most cases weighs higher for the disutility than the waiting time, the effects of the measure should be examined to determine if the measure reduces the total disutility (Garcia-Martinez et al., 2018 and Cascajo et al., 2017). If the total disutility becomes higher due to the measure's implementation, it is not advised to implement it. Furthermore, implementing a measure such as a waiting time reduction by synchronizing the timetables can lead to a higher transfer time and thus a higher disutility for other transfers as these can get more inefficient or less reliable (Lee et al., 2014). If that is the case, in total, more travelers can experience higher transfer times. As a result, the transfer stations getting higher transfer times might need a measure as well, which can lead to more other inefficient transfers that again need a measure. Hence, it is vital to examine the consequences of a measure in a sophisticated way before deciding to implement a measure or not. Overall, a measure that contributes to the minimization of the total disutility of all the travelers in the PT system would be a good measure to implement. Measures that only contribute to the minimization of the disutility of the specific transfer but increase the total disutility of all the travelers in the PT system should not be implemented unless the PT operators or the municipality want to steer travelers to choose different route choices and different PT lines. Then, implementing a specific measure that increases the disutility might be a good idea.

All in all, this study advocates for using a multi-operator smart card dataset. Its added value is shown in its ability to identify potential transfers that could benefit from the implementation of a disutility reducing measure. It is particularly valuable because it allows for insights beyond just one operator and thus the optimization of a variety of transfers, contributing to higher overall traveler satisfaction. Nevertheless, even with multi-operator smart card datasets, one may distinguish between 1) a dataset that includes all transfers (between single and multiple operators) and 2) a dataset that includes multi-operator transfers only. It is argued that the former is more valuable than the latter. By including single-operator smart card data as well, a more representative picture of the network can be obtained, which allows for a comprehensive picture of the most important transfer stations as well. In other words, in a single-operator smart card dataset only, transfers between different Public Transport operators are missing. In a multi-operator smart card dataset that only includes transfers between different Public Transport operators, the transfers between single operators is missing. Therefore these can provide an under-represented picture of the transfers in the network. Consequently, a multi-operator smart card dataset including transfers between both single and multiple operators is seen as most valuable. From an interview with Translink it is clear that such a multi-operator smart card dataset design is feasible. However, as transfers between multiple operators (and to a different mode) are assumed to have higher transfer times than transfers of a single operator, the multi-operator smart card dataset, used in this study, is seen as representative for the identification of the most important transfers that have a high potential for minimizing the disutility, as the most important transfers are identified by multiplying the transfer flow with the average transfer time. Further research could, however, examine if this assumption is true by redoing this study with a multi-operator smart card dataset that includes transfers of both single and multiple operators.

6.3. Methodological contribution

This section highlights the methodological contributions of this study.

First of all, in this study a multi-operator smart card dataset by NS and HTM is used. Yap et al. (2019) uses a single-operator smart card dataset of HTM. If the multi-operator smart card dataset used in this study would have been used in Yap et al. (2019) and the same important transfer stations as in this study are found, the method of this study is found to be easier and faster to find the important transfer stations as Yap et al. (2019) determines the spatial boundaries of transfer locations first, after which the most important transfers are being determined by use of the Herfindahl-Hirschman Index, which sometimes result in multiple stops for one important transfer location (described as a 'hub' in Yap et al. (2019)). This study, however, only determines the most important transfer stations by looking into the highest traveler flow, and does not distinguish different stops for one transfer location. Therefore, this study sheds light on another method by which to identify and select important transfers.

Additionally, this research introduces a different way of visualizing traveler flow: chord diagrams. Flows of travelers are often visualized in maps, tables or in a schematic way. However, chord diagrams are especially useful when comparing flow sizes, because the flows and the sizes can be seen in one glance. In this study, for each transfer station, the origin and destinations of the flows are given as wind and track directions. The flows are then visualized as an arc with a width according to the flow size. These chord diagrams result in a more clear and merged overview of transfer flows than visualizing all the transfer flows on, for example, a map.

All in all, the total method used in this research provides an approach to get from a multi-operator smart card dataset to a decision on which transfers should be targeted by measures to minimize the disutility. It shows what data a multi-operator smart card dataset should include and which attributes are necessary to determine the most important transfer stations and transfers. Based on the (dis)utility factors of the transfers, together with the transfer flow, transfers can be determined to implement a measure to minimize the disutility.

6.4. Research limitations

This section reflects on the limitations of this research and how these influenced the results and conclusions.

Dataset limitations

This research uses one main multi-operator smart card dataset from two operators where only the transfers between the multi-operators are included. This smart card dataset is just one of many different multi-operator smart card dataset designs possible. For example, other data from the operators are not included, which means that other single-operator data of both operators is missing. As transfers between different operators are assumed to have higher transfer times, these transfers are assumed to be more important than transfers between a single operator. However, this can not be said with certainty and can therefore be a limitation and might lead to different important transfer(s) (stations).

The two operators have requested these datasets from Translink to examine the added value and usability of a multi-operator smart card dataset for their own use. Therefore the attributes included in the datasets were already determined and the researcher needed to work with these specific attributes. However, it is possible to include more different attributes in a multi-operator smart card dataset that consists of useable information for transfers (e.g., card types or fare). So, the datasets used are just an example of a multi-operator smart card dataset and thus, it is harder to generalize results and conclusions based on only one multi-operator smart card dataset design.

The multi-operator dataset consists of a <30 bin for transfers that are not made 30 times or more on an average weekend day and a <40 bin for transfers that are not made at least 40 times or more on an average working day. The low number of transfers is explained by information management ("informatiehuishouding") regulations, mainly regarding privacy. Based on different datasets and calculations, these transfers are given a value of 3.7 times taken. However, this number is an assumption and may have a different value between 1-29 (weekend days) or 1-39 (working days). A transfer could be done on six different days in the dataset, which automatically means that it should have at least a value of six. Therefore, it was also possible to give the sum transfer a value of the number of days the transfer is done. However, it is also possible that a transfer is only done on one day, but 25 travelers are using this transfer. Therefore it is chosen to work with the average of 3.7, but it should be noted that it is an assumption. This assumption can be resolved by aggregating on a higher time interval as the dataset used in this study has a time interval of ten minutes only. For the aim of this study, a time interval aggregation of 24 hours would work. Overall, for other studies, the aggregation level depends on the aim of the research and the flow sizes on the network.

The multi-operator smart card dataset contains information on smart cards only, meaning no data from single paper tickets, e-tickets or tickets paid in the Public Transport vehicle itself are added. The Haaglanden area contains the beach of Scheveningen, which is a famous tourist attraction. These tourist often uses a single paper ticket. Hence, the data used in this research is not complete, especially for the summer months when tourists are visiting the Haaglanden area.

Research method limitations

Travelers transferring from the NS train towards a bus/tram of HTM (the two operators of the multi-operator smart card dataset) are checking out at the platform/station of NS and checking in inside the vehicle of HTM. Travelers transferring from the HTM bus/tram to the NS train are checking out inside the vehicle of HTM and are checking in at the platform/stations of NS. For this last transfer, travelers may already check in minutes before the train departs. However, this cannot be seen in the smart card dataset. Therefore, the transfers from HTM to NS get a relatively lower average transfer time than the transfer of NS towards HTM. A consequence of this is that this study only finds transfers from NS to HTM as important transfers.

The most important transfers in this study are based on the transfer time losses, which is a multiplication of the transfer time (waiting time + walking time) with the total flow of the transfer. When disutility values are known and the most important transfers are determined based on the total disutility of a transfer and the flow, other transfers can be found to be most important.

This study uses the multi-operator smart card dataset to identify the most important transfers and transfer stations. Of the most important transfer stations, the transfer flows are visualized. This could not be done for every line to line separately as this would lead to many transfers, making the diagram illegible. Hence, the flows in this study are visualized by having the flows aggregated in wind and track directions.

This study only examines several top 10s transfers that score poorly on the transfer times and transfer time losses. The emphasis of the method in this study is on the highest transfer time losses and to reduce this with a measure. Transfers with a high average transfer time but a relatively lower flow are not considered to implement a measure. However, applying measures to these transfers might also pose significant improvement opportunities.

Finally, the measure implemented in this study is based on a transport model containing single-operator smart card data. While the data in this research contains only transfers between different operators, it is hard to determine the exact effects of the specific transfer where the measure is implemented. Therefore, the multi-operator smart card dataset used in this study should be added and used in the transport model to determine the effects of the measure better.

7

Conclusion and Recommendations

Until now, it was unknown how a multi-operator smart card dataset can contribute to minimizing the disutility of a transfer in Public Transport. Literature showed that several factors contribute to the disutility of a transfer and that smart card datasets can help identify and examine transfers and transfer flows. This study examined a multi-operator smart card dataset to answer the research question: *In what way can a multi-operator smart card dataset analysis contribute to the minimization of the disutility of transfers for Public Transport journeys?*. This research answers this question and provides recommendations for operators, further research and smart card dataset improvements.

7.1. Conclusion

This research aimed to evaluate how the use of multi-operator smart card datasets can contribute to the minimization of the disutility of Public Transport transfers, and thus increase travelers' satisfaction. This aim is achieved by applying such a dataset to the Haaglanden area, and evaluating its value for the case study as well as beyond the boundaries of the case study.

For this study, a multi-operator smart card dataset of the operators HTM and NS in the Haaglanden area in the Netherlands was used. The dataset uses a 35-minute time interval to identify transfers, meaning that transfers taking over 35 minutes are not taken into account. This study showed that the transfer times and the flows could be derived directly from a multi-operator smart card dataset. Together, these can be used to determine the most important transfer(s) (stations) and their respective (dis)utility factors. (Dis)utility factors (walking time and waiting time that the transfer time consists of, the need to level up or down, the presence of real-time information displays, the number of station facilities and the presence of escalators) are examined for the most important transfer(s) (stations) in more detail. It is concluded that, while actual disutility values are unknown for the case study, it is hard to explain transfer flow sizes by the disutility factors. The factors having a high demand (travelers have a reason to go somewhere) and no better alternative available, influence transfer flow sizes probably more. Having examined the (dis)utility factors, measures can be taken to reduce the disutility of a transfer. In this case study, a measure has been implemented to reduce the waiting time disutility factor and its effects are examined in a transport model. The transfer at Den Haag Centraal between the NS IC train from Amsterdam and the HTM tram line 9 to Zwarte Pad is found to be the most important transfer where a waiting time reduction has the most effect on the total transfer time loss. It is found that a waiting time reduction can change travelers' route- and mode choices, which indicates that the (dis)utility factors seem to explain the flow size. The operators, however, need to examine the effects of a measure as it can lead to more crowding, which increase the disutility, and while other lines and transfers can get more inefficient. The analysis of the multi-operator smart card dataset used in this study has a complementary contribution to minimizing the disutility of a transfer in Public Transport as a whole while the used multi-operator smart card dataset can only identify transfers between multiple operators and does not include transfers between single operators. However, as transfers in a multi-operator smart card dataset are assumed to have higher transfer times than transfers in a single-operator smart card dataset, multi-operator smart card datasets are found to be representative of identifying transfers that have a relatively high disutility.

In other words, this study finds that multi-operator smart card datasets analysis can not directly and by itself minimize the disutility of a transfer in Public Transport, but it can identify the most important transfer stations and individual transfers, for which the associated disutility factors can then be identified manually. Once these have been identified, measures can be implemented to reduce the disutility of a transfer. Therefore, a multi-operator smart card datasets analysis can contribute to minimizing the disutility of a transfer in Public Transport.

All in all, this study sheds light on how multi-operator smart card datasets can contribute to minimizing the disutility of Public Transport transfers. It concludes that, having implemented particularly valuable data and attributes such as: the transfer station, the trip and line towards the transfer station (which can also be derived from the check-in stop and the operator name), the trip and line after transferring (which can also be derived from the check-out stop and the operator name), the number of travelers and the average transfer time (which can also be derived from the check-in- and check-out times and the number of travelers), multi-operator smart card datasets can be used to:

1. Identify the most important transfer stations and individual transfers, where minimizing the disutility has the highest impact
2. Illustrate how one particular measure can lower the transfer time disutility

It is therefore highly valuable for practitioners because operators can use multi-operator smart datasets to gather information on transfers and their disutility, in order to maximize overall satisfaction of their Public Transport. This, in turn, has a positive effect on their reputation as a Public Transport operator and may increase the use of Public Transport. On top of that, this study contributes to the literature as follows. It shows which attributes of a multi-operator smart card dataset are necessary to minimize the disutility of transfers, it shows a method to identify and determine the best transfer locations with a high potential for the minimization of the disutility and it illustrates an example of a measure and how effects thereof can be examined by means of a transport model.

7.2. Recommendations

This study argues that a multi-operator smart card dataset can contribute to minimizing the disutility of a transfer of PT journeys by identifying the most important transfer stations and individual transfers, for which the associated disutility factors can be identified manually and measures can be implemented to reduce the disutility of a transfer. This gave rise to recommendations for operators, researchers and smart card dataset developers.

Recommendation for the operators
This study shows that the transfer at Den Haag Centraal between the NS IC train from Amsterdam and the HTM tram line 9 to Zwarte Pad is the most important transfer where a waiting time reduction has the most effect on the total transfer time loss. The effects of this measure on the transfer's flow are examined in a transport model and shown in figure 5.10 and Appendix C.3. In order to lower this transfer's transfer time, HTM should synchronize line 9 to Zwarte Pad better with the arrival of the IC train from Amsterdam Centraal by changing the timetable. However, as discussed in section 6.2, before doing this, HTM should explore the effects on the flow and the consequent effect on occupancy rates of the vehicles. If crowding occurs, HTM is advised to either add capacity to their vehicles, operate with a higher frequency or, if not possible, to not change the timetable at all as crowding overall gives a higher disutility than waiting times (Garcia-Martinez et al., 2018 and Cascajo et al., 2017). Furthermore, HTM should explore the effects on the impacts on other lines and transfers as these can become more inefficient by implementing a timetable synchronization of particular lines (Lee et al., 2014).

As multiple other important transfers have been identified, besides the one just highlighted, it could be valuable to implement the waiting time measure for these as well. Similarly, the effects can be investigated in a transport model such as OmniTRANS so that HTM may act according to the outcomes. As low transfer times could give a disutility as well (can be perceived as stressful), it is advised to study the optimal transfer time for this case specifically before lowering the transfer times too much.

This study emphasizes the value of a multi-operator smart card dataset in general as well as for the Haaglanden case study. The scope of this research of the smart card dataset for the case study can be expanded by, for instance, focusing on summer days in particular or focusing on specific times of the day. Also, a multi-operator smart card dataset may include other attributes such as the card types to shed light on the types of travelers using (specific) transfers. It is advised to explore the dataset more to define further the full potential of a multi-operator smart card dataset. While the progress of getting to a multi-operator smart card dataset is found to be complex and time-intensive for the operators, both NS and HTM are advised to think about the usefulness of the missing data and information that they can not get from their own single-operator smart card datasets and what information they can instead retrieve from a multi-operator smart card dataset.

Recommendation for research
As discussed, this study clarifies that a multi-operator smart card dataset can not directly minimize the (dis)utility factors of transfers in Public Transport. However, it can contribute by identifying the most important transfers by examining the transfer flow and average transfer times. In section 6.4 it is discussed that other important transfers, however, may be found when the determination of the most important transfers is based on the total disutility of a transfer together with the flows. In order to do this, the disutility values are needed. Then, after determining the most important transfers, the disutility can be minimized by taking measures. While the disutility values are city-specific and are not known for this case, it is advised to study the disutility factors for this case specifically.

As discussed in section 6.4, in addition to multi-operator transfers only, the multi-operator smart card dataset should include transfers from the single operator as well to study if the assumption that transfers between different operators are more important than transfers between a single operator. It is advised to do this study with a multi-operator smart card dataset that includes single-operator data as well to see if any other transfers can be seen as important. Furthermore, based on the dataset used in this study, it is impossible to identify multiple transfer journeys. As multiple transfers in one journey can give different disutility values, the number of transfers in a journey should be included in the dataset.

Recommendation improving smart card datasets
This research also allows for several recommendations on how smart card datasets could be improved or could be used better to enhance their value to contribute to minimize transfer disutilities. Firstly, Translink has to take the information management rules ("informatiehuishouding) into account. These rules mostly have to do with privacy regulations, business confidentiality and competition. Therefore, Translink is not allowed to export datasets where individual journeys or patterns are shown or can be tracked down. Therefore, the dataset used in this study consists of a bin for the low number of transfers being made. These bins are given an assumed value in this study, but it remains inaccurate. It would be useful to work without the bins and thus with actual values. If the researcher could, in the future, make an agreement that he or she only operates inside the company and network of Translink and only exports the results on an aggregate level, a more detailed dataset can be used to examine the flows and transfer times in a more accurate way. Another possibility, as discussed in 6.4 is to work with data that is aggregated on a higher time interval. How high the level aggregation level needs to be depends on the aim of the research and on the flow sizes in the network.

Additionally, it is recommended to include paper tickets, e-tickets and tickets bought inside the vehicles to enhance the representativeness of the data. It is unknown how much data like this is missing in the multi-operator smart card dataset. Operators do have information on these tickets, but because of the information management rules in the Netherlands, these are not added to multi-operator smart card datasets. Therefore it is advised to explore possibilities to make this available.

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Appendices

A

Scientific Paper

The Application of a Multi-Operator Smart Card Dataset to Identify Transfer Locations with a High Potential for Transfer Time Loss Minimization

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Travelers do not like transfers in their Public Transport journey; it gives a disutility. Minimizing this disutility is valuable to increase travelers' satisfaction. To be able to reduce this disutility, transfers have to be identified first. Multi-operator smart card datasets allow for the identification of transfers between different operators, as well as between the same operators. However, it is unknown in the literature how such a multi-operator smart card dataset can contribute to the minimization of transfer disutility in Public Transport. An answer is given by analyzing a multi-operator smart card dataset for the Haaglanden area in the Netherlands that uses a 35-minute time interval to identify transfers. Also, a measure has been implemented for one of the transfers with the highest potential for transfer time loss minimization and the effects on the network are examined in a transport model. It is found that a multi-operator smart card dataset can identify important transfer stations and individual transfers, for which the associated disutility factors can then be identified manually. Then, measures can be implemented to reduce the disutility of a transfer. The measure, a reduction of the waiting time, implemented on a transfer in this study resulted in changing traveler's route- and mode choices. For further research, it is recommended to explore the possible effects of implementing the measure as it can lead to crowding or other inefficient transfers, which could increase the disutility. Furthermore, further research should look into the disutility values of the case study to draw better conclusions whether, and to what degree, (dis)utility factors explain transfer flow sizes for this case specifically.

Key words: public transport, transfers, transfer penalty, (dis)utility, smart card data, transport model

Introduction

Public Transport travelers often need to transfer on their journey. A transfer is a point where different Public Transport lines intersect within the Public Transport network and where travelers can switch to an other line of the same or different operator (Garcia-Martinez et al., 2018). Travelers dislike transfers; it has a so-called disutility (Schakenbos et al. (2016)). Minimizing this disutility is valuable to increase travelers' satisfaction and consequently make the use of Public Transport more attractive. To be able to reduce the perceived disutility, transfers have to be identified first. Smart card datasets contribute to identifying transfers (Liu et al. (2019)). Smart card datasets can be single-operated as well as multi-operated. Single-operator smart card datasets allow for the identification of transfers between the same operators, while multi-operator smart card datasets enable the identification of transfers between different operators as well (Interview HTM (2022); Interview NS (2022)). Therefore, with a multi-operator smart card dataset, a more accurate representation of the transfers in the network can be obtained and transfers can be identified and developed better. However, operators often do not have direct access to multi-operator smart card datasets. Few studies have addressed the use of such multi-operator smart card datasets (e.g. Nishiuchi et al. (2015);Soltani et al. (2015)). However, no literature has been found which focuses particularly on the contribution of multi-operator smart card datasets to the minimization of transfer disutility in Public Transport. If this is known, it is possible to say whether, and in what way, a multi-operated smart card dataset can be used to increase the satisfaction of PT journeys of travelers. Therefore, the main research question of this study was:

"In what way can a multi-operator smart card dataset analysis contribute to the minimization of the disutility of transfers for Public Transport journeys?"

This thesis tried to find an answer to this question by examining (dis)utility factors, smart card datasets used worldwide and by introducing a method to identify important transfer locations that have a high potential for the minimization of transfer disutility by using a multi-operator smart card dataset for the PT network of the area around Den Haag, the Netherlands. Furthermore, a measure is implemented for the highest potential transfer to reduce the transfer time loss and the effects on the flow in the network are examined in a transport model.

Methodology

Different methods have been used to answer the research question, which are described in this section.

Literature research

Literature research has been done to get more qualitative data about the factors influencing the disutility of a transfer and to get more information on the design and differences of smart card datasets. Different scientific papers are examined and discussed to analyze which factors influence the disutility of a transfer and which attributes are included in smart card datasets over the world.

Case study and dataset

In this study, a multi-operator smart card dataset is used for a case study. The case study is the Haaglanden area which is the area around Den Haag in the Netherlands. This case study was chosen because of a high percentage of access and egress public transport modes to several big stations, which indicates a high number of transfers. The two main Public Transport operators are NS and HTM. NS operates trains, HTM trams and buses. The multi-operator smart card dataset has data from transfers between NS and HTM and vice versa. It is derived from NS and HTM, who derived it with Translink. The dataset contains data on transfers on average days from the 1st of September until the 30th of September 2019, excluding festive days. It uses a maximum transfer interval of 35 minutes to identify transfers. It consists of information per unique transfer taken at intervals of 10 minutes aggregated for the whole period. For every unique transfer the sum of transfers taken, the first trip (PT line direction), the transfer station, the second trip (PT line direction) and the average transfer time in minutes are included. Therefore, it is possible to examine how many travelers are transferring from a specific direction, where they are transferring, where they are going to and what their average transfer time is. For many unique transfers, a bin is given when the sum is not above 30 (for weekend days) or 40 (for working days). Because of privacy regulations from the information management in the Netherlands, it is not allowed to give exact values for a low number of travelers. To work with these bins with a numerical value, they are given an exact sum by identifying a different dataset, also derived from NS, HTM and Translink. This dataset contained data on the sum of transfers for the same period but in 24-hour time intervals, resulting in no bins. This dataset made it possible to calculate an exact value for the bins in the dataset used in this study. It resulted in a value of 3.7 sum of transfers taken. However, this value is an assumption because the bins could be any value between 1-29 (weekend days) or 1-39 (working days).

Analysis approach

After having the multi-operator smart card dataset prepared for analysis, the transfers were examined. First, the transfers having the highest number of transferring travelers were determined. These are the stations Den Haag Centraal, Den Haag Holland Spoor (HS), Den Haag Laan van NOI and Delft and are found most important out of 11 total transfer stations. For these four transfer stations, the transfer flows and the corresponding average transfer times were visualized and the (dis)utility factors; the need to level up/down, availability of real-time information, the number of station facilities and the presence of escalators were investigated manually. Together, this already gave information on which transfers are favorable and which are not. In the next step, the most important individual transfers of the smart card dataset were examined. Three top 10s were made, a top 10 transfers with the highest transfer times, a top 10 transfers with the highest transfer time loss and a top 10 transfers with the highest transfer time loss for line totals. Together with one of the operators of the case study, HTM, a top 10 was chosen to examine in further detail. For this top 10, the same four (dis)utility factors and the walking and waiting times were investigated. Especially the walking and waiting times were examined in further detail, where the waiting time is determined by subtracting the walking time from the transfer time.

For one of the top 10 transfers, a waiting time reduction as a measure is implemented that reduces the waiting time and thus the transfer time. The transfer with the highest impact on the total transfer time loss by reducing the waiting time by one minute was chosen. This measure was implemented in a transport model (OmniTRANS) to examine and visualize the effects on the flow. The implementation was executed using a reference model level and a new model level where the waiting time is reduced by one minute. Then, the flow change was visualized and exact numbers were given in tables.

Results

This section elaborates on the results of the literature research and the results of the data analysis.

Literature research

Several factors can influence the disutility of a transfer. In this study, scientific papers are examined and the factors they are mentioning are given in table 1. The papers are all mentioning the factors waiting time and walking time. As people value their time, waiting or walking to their connecting vehicle reduces traveler's satisfaction (Garcia-Martinez et al. (2018); Schakenbos et al. (2016); Cascajo et al. (2017); Nielsen et al.

Table 1 Overview of scientific papers that estimates and/or mentions factors that influence the (dis)utility of a transfer

	Wait T	Walk T	Stairs	Crowding	Mode	Real time info	Station fac.	Activity	EofW	Escalators
Garcia-Martinez et al. (2018)	x	x	x	x	x	x		x		
Schakenbos et al. (2016)	x	x			x		x			
Cascajo et al. (2017)	x	x	x	x	x	x	x	x		
Nielsen et al. (2021)	x	x	x				x		x	x
Chowdhury and Ceder (2013)	x	x				x				

Table 2 Overview table of existing literature using smart card data

Source	**City**	**Main goal**	**Attributes**	**Transfer time interval (min)**	**Type smart card dataset**	**Mode**
Seaborn et al. (2009)	London	Identifying transfer behavior	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, mode	15-60	-	Bus, Underground
Ali et al. (2016)	Seoul	Public Transport simulation	Check-in time, check-out time, check-in stop, check-out stop, card ID, mode, card type, line no., distance and fare	30	-	Bus, Metro
Alsger et el. (2015)	Brisbane	Study impact of different transfer time intervals	Check-in time, check-out time, check-in stop, check-out stop, card ID, direction	15-90	-	Bus, train, ferry
Soltani et al. (2015)	Brisbane	Identifying travel behavior	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, direction, line no., operator	-	multi-operator	Bus, rail, ferry
Liu et al. (2019)	Singapore	Replication of PT network	Check-in time, check-in stop, check-out stop, trip ID, card ID, mode, direction, card type, line no., ride time, distance	45	-	Bus, metro
Zhao et al. (2019)	Nanjing	Exploring transfer recognition method	Check-in time, check-out time, vehicle ID, card ID, card type, line no.	20	-	Bus, metro
Nishiuchi et al. (2015)	Kochi City	Better comprehending PT system	Check-in time, check-out time, card ID, card type, operator	60	multi-operator	Bus, tram
Yap et al. (2019)	Den Haag	Introducing methodology to find significant transfer stations	Check-in time, check-out time, check-in stop, check-out stop, trip ID, card ID, line no.	-	single-operator	Bus, tram

(2021); Chowdhury and Ceder (2013)). Furthermore, the need to level up or down at a transfer, crowding, changing modes, needing to interrupt an activity such as reading, or having difficulties finding the way at the transfer can give a disutility as well (Garcia-Martinez et al. (2018); Schakenbos et al. (2016); Cascajo et al. (2017); Nielsen et al. (2021)). Crowding gives the highest disutility of them all. Some factors can reduce the disutility. These utility factors are the presence of real-time information displays, the number of facilities and escalator availability (Garcia-Martinez et al. (2018); Schakenbos et al. (2016); Cascajo et al. (2017); Nielsen et al. (2021); Chowdhury and Ceder (2013)). However, the (dis)utility factors are city-specific, making it hard to generalize and hard to determine the impacts on the disutility for every individual case (Iseki and Taylor (2009)). In this study, the (dis)utility factors crowding, interruption of an activity and the ease of wayfinding are not considered as these require more time-consuming research than the time available in this study.

Smart card data are collected by automated fare collection systems in Public Transport when travelers use these smart cards to check-in or check-out in Public Transport systems (Fu and Gu (2018)). Studies worldwide such as London, Seoul, Brisbane, Singapore, Nanjing, Kochi City and Den Haag have used smart card datasets to examine their Public Transport network and to identify transfers (Ali et al. (2016); Alsger et al. (2015); Liu et al. (2019); Nishiuchi et al. (2015); Seaborn et al. (2009); Soltani et al. (2015); Yap et al. (2019) Zhao et al. (2019)). To identify transfers, a maximum time interval between the check-out time of the first trip and the check-in time of the following trip is used. Most of the scientific papers examined in this study use a maximum time interval of between 15 and 60 minutes. However, an interval between 15 and 90 minutes would not significantly impact the number of transfers found (Alsger et al. (2015)). The smart card datasets studied in the literature have almost all information about the check-in times, check-out times, check-in stops, check-out stops and the smart card ID. More attributes such as the trip ID, the vehicle ID, the mode, the direction, the card type, the line number, the ride time, the operator, the distance and the fare are sometimes included as well. Especially the studies that used smart card datasets that include the operator name are interesting as this indicated that these datasets are multi-operator smart card datasets. An overview of the scientific papers and their attributes are shown in table 2.

(Dis)utility factors of the four most important transfer stations

As can be seen in table 3, at all the transfer stations, apart from some transfers at Den Haag Centraal, the traveler needs to level up or down (stairs) during the transfer, which, as explained in the literature research, increases the disutility. All the four most important transfer stations have displays with real-time information available, which, as explained in the literature research, reduces the disutility. Den Haag Centraal and Den Haag HS have a very large number of station facilities, Den Haag Laan van NOI has only one and is given a medium level and Delft has a large number of facilities according to the size levels described in (Schakenbos et al., 2016). The more facilities available, the lower the disutility, as discussed in the literature research. From the literature research, it also becomes clear that the presence of escalators is reducing the disutility. Den Haag Laan van NOI do not have escalators, the other three transfer stations do have them available.

All in all, this leads to the lowest disutility for transfers at the station Den Haag Centraal and the highest disutility for transfers at station Den Haag Laan van NOI, when looking into the four factors discussed.

Table 3 The four stations and their (dis)utility factors

	Stairs	Real-time info	Station fac.	Escalators
Den Haag Centraal	Yes/No	Yes	very large	Yes
Den Haag HS	Yes	Yes	very large	Yes
Den Haag Laan van NOI	Yes	Yes	medium	No
Delft	Yes	Yes	large	Yes

The transfer flows and their average travel times for the four transfer stations

For the four transfer stations: Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft the number of transfers (the flows) are given per direction pair in a chord diagram. The chord diagrams visualize the flow direction for every traveler that transfers at the specific transfer station. The wind direction corresponds to the direction of the HTM lines (tram or bus) and the track directions correspond to the NS lines' direction (train). The arc's color corresponds with the color of the first trip, i.e., the trip towards the transfer station. It is important to keep in mind that the chord diagrams can not be compared to each other as the different stations have a different total sum of transfers, which are given above the chord diagrams. For the corresponding direction pair, the average transfer times are also visualized for each transfer station.

Den Haag Centraal

As can be seen in figure 1 transfers at Den Haag Centraal are done from/to three different directions by train (via the track to/from Utrecht (Ut), Amsterdam (Ams) or Rotterdam (Rt)) and from/to the four wind directions North (N), East (E), South (S) and West (W). Most travelers transferring at Den Haag Centraal come from the Amsterdam track and continue their journey towards the West or North and vice versa, and from the Utrecht track towards the West and vice versa. However, the largest flows are between the West towards the Amsterdam track and vice versa. Looking into the average transfer time graph in figure 2, the flow from the Amsterdam track towards the West has an average transfer time slightly above the weighted average of all the transfer times at Den Haag Centraal: 8.3 over 7.7 minutes. Of the largest flows, the flow from the Amsterdam track towards the North has the highest average transfer time; 9.8 minutes.

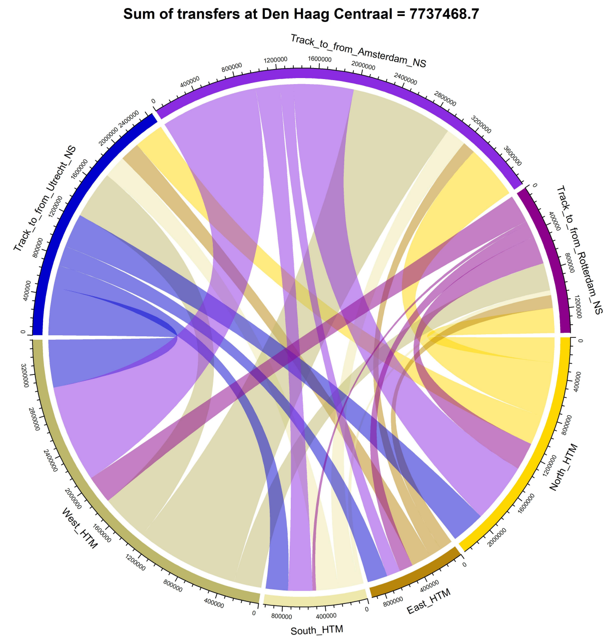

Figure 1 Transfer flow at Den Haag Centraal

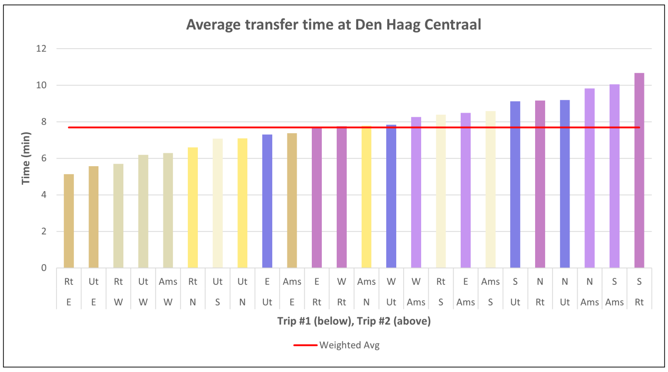

Figure 2 Average transfer time at Den Haag Centraal

Den Haag HS

As can be seen in figure 3, transfers at Den Haag HS are done from/to three different directions by train (via the track to/from Amsterdam (Ams), Rotterdam (Rt) and Den Haag Centraal (DHC)) and from/to the four wind directions North (N) , East (E), South (S) and West (W). The transfers to the East direction are almost negligible. Most travelers transferring at Den Haag HS are coming from the Rotterdam track towards the North and vice versa and from the Amsterdam track towards the South and vice versa. Looking into the average transfer time graph in figure 4, the largest flow, the flow from the Rotterdam track to the North has an average transfer time of around 8.6 minutes which is slightly above the weighted average of all the transfers at Den Haag HS. The graph shows a significant difference between the average travel time for the highest six transfers and the other transfers. This difference is because these six transfers with the highest average transfer times have a very low number of transfers, implying that these transfers are not common. However, by taking a closer look, the specific transfers are mostly not even possible at HS. This means travelers are walking to/from a different stop and thus automatically have a higher transfer time, or the specific transfers are not logical to make as it would be more efficient to stay in a vehicle and transfer at a different station/stop. This leads to high transfer times for only a few travelers, resulting in high average transfer times. However, the weighted average transfer time (the red line) is representative as it is a weighted average. It is shown that the high transfer times (around 20 minutes) do not significantly impact the weighted average, which is 7.8 minutes.

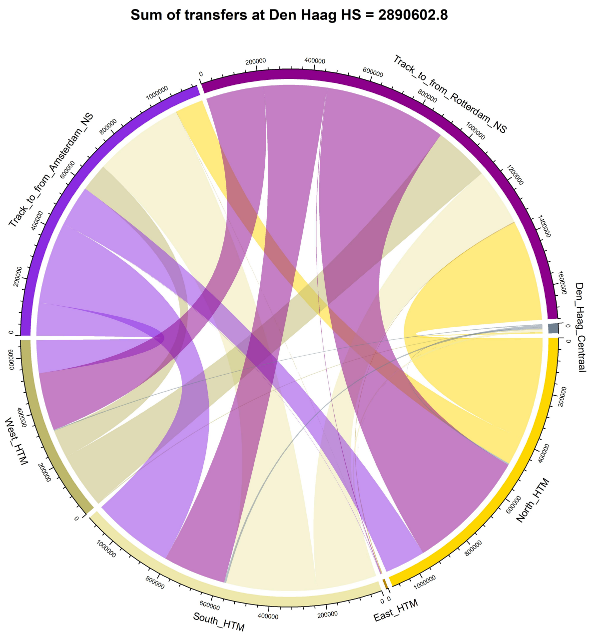

Figure 3 Transfer flow at Den Haag HS

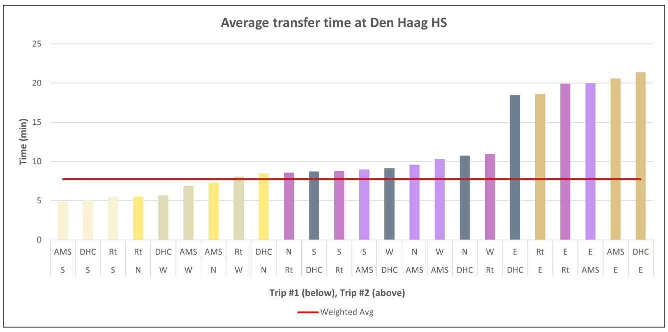

Figure 4 Average transfer time at Den Haag HS

Den Haag Laan van NOI

As can be seen in figure 5 transfers at Den Haag Laan van NOI are done from/to three different directions by train (via the track to/from Amsterdam (Ams), Rotterdam (Rt) and Den Haag Centraal (DHC)) and from/to the four wind directions North (N), East (E), South (S) and West (W). Most travelers that are transferring at Den Haag Laan van NOI are coming from the Amsterdam track and are transferring to the East and the West and are coming from the East and transferring towards the Amsterdam track. What is remarkable is the difference between the flow from the Amsterdam track towards the West and vice versa: 197,584 transfers and 107,486 transfers. So far, at the Den Haag Centraal and Den Haag HS stations, the flows were always similar in size for both ways. However, at Den Haag Laan van NOI this is thus not always the case. Overall, 503,016 travelers are transferring towards the train while 637,705 travelers are transferring towards the tram or bus. This gap can probably be explained by a higher flow of travelers traveling further into the city and taking a train at a different transfer station on the way back.

Looking into the average transfer time graph in figure 6, the directions from the Amsterdam track towards the East and West have an average transfer time of around 6.7 and 8.7 minutes, respectively. The average transfer time of travelers coming from the East and transferring towards the Amsterdam track has the lowest average transfer time of (only) 4.8 minutes.

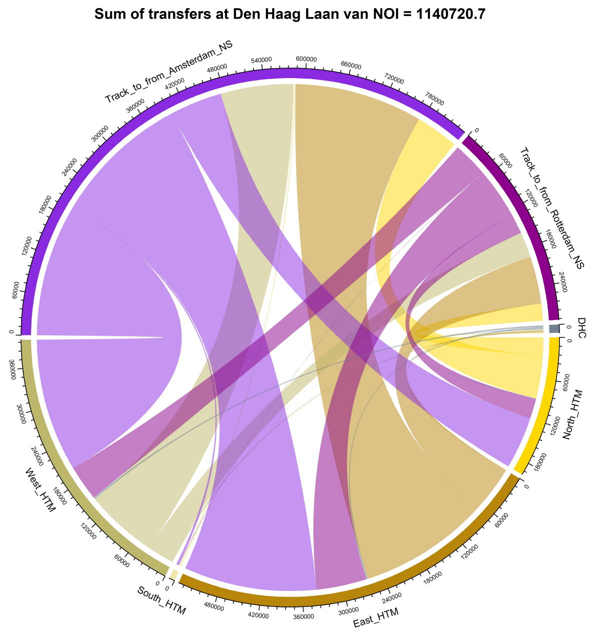

Figure 5 Transfer flow at Den Haag Laan van NOI

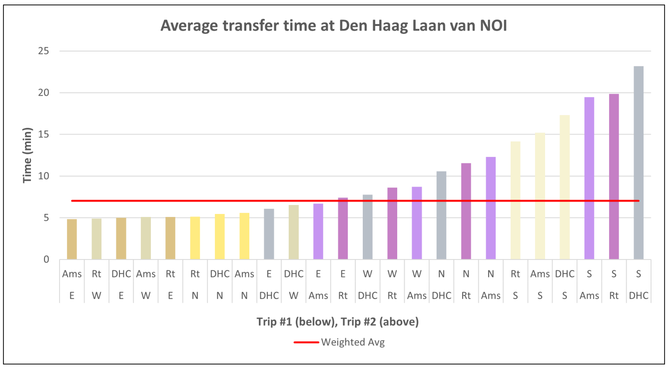

Figure 6 Average transfer time at Den Haag Laan van NOI

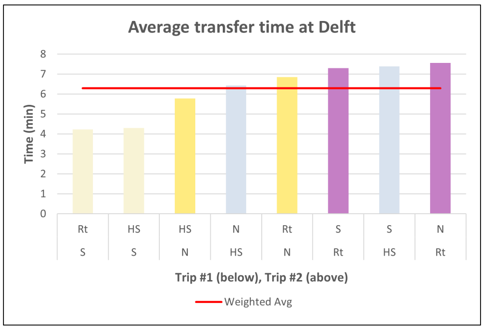

Figure 8 Average transfer time at Delft

Delft

As can be seen in figure 7 transfers at Delft are done from/to two different directions by train (via the track to/from HS and Rotterdam (Rt)) and from/to two wind directions North (N) and South (S). Most travelers that are transferring at Delft are coming from the HS track and transferring towards the South and vice versa and are coming from the North and going to the Rotterdam track and vice versa. Looking into the average transfer time graph in figure 8, the flows from the Rotterdam track towards the North and from the HS track towards the South are the highest, around 7.6 and 7.4 minutes, respectively. These transfers with the highest average transfer time have a large flow as well.

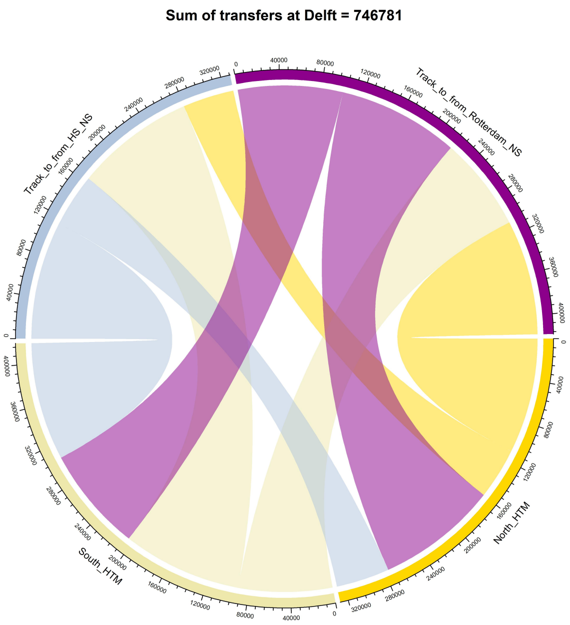

Figure 7 Transfer flow at Delft

Explaining the flow sizes by the transfers' (dis)utility factors

One would expect that higher (lower) average transfer times have a lower (higher) flow as higher transfer times are not favorable because they give the transfer a disutility. For the four transfer stations, this is not always the case. Sometimes this can be explained by the other (dis)utility factors discussed. For example, for the Den Haag HS station, not considering the first six highest average transfer times, as these are uncommon transfers, the transfer from the Rotterdam track towards the West has the next highest average transfer time of 11 minutes. This transfer has the sixth-highest flow. Therefore, this is a relatively high flow with a relatively high average transfer time. This can partially be explained because there is the availability of escalators, real-time information and many facilities that reduce the disutility of the transfer. However, sometimes the (dis)utility factors can not explain high (low) average transfer times and (low) high flows. For example, for Den Haag Laan van NOI, some of the higher flows have a high average transfer time, which could be explained because real-time information is available. However, transferring travelers need to level up or down, have almost no facilities and do not have escalators, which does not reduce the disutility of these transfers.
Overall, it is hard to explain the flow size by transfer stations' (dis)utility factors. Assumptions can be made, but it is not directly possible from a multi-operator smart card dataset to explain the flow size by (dis)utility factors. The flow size is probably mainly explained by high demand (travelers have a reason to go somewhere) and the fact that sometimes there is no (better) alternative available. This results in travelers using a specific route and transfer even if this has a high disutility. Because transfer stations are known, further manual examination of the (dis)utility factors can be done in following steps. However, it is not precisely known how strong the (dis)utility values are for this case. When these are known, it may be possible to better explain the flow size by the (dis)utility factors better.

Top10s of individual transfers

The transfers with the highest average transfer times are shown in table 4. While these transfers are either impossible at the given transfer station to transfer directly or are done at specific times (early morning), the transfer sums are relatively low. Therefore a new top 10 has been made that includes the sum of transfers; a top 10 transfers with the highest transfer time loss.

Table 5 shows the ten transfers with the highest transfer times loss. There are 3577 unique transfers done in the dataset, but the top 10 unique transfers have a share of 9.08% of the total transfer time loss. What can be noted immediately is that the six highest all concern IC trains coming from Amsterdam Centraal. These transfers together already have a transfer time loss percentage of 6.22%. This means that these six transfers have a transfer time loss of 6.22% of the total transfer time loss. Reflecting on the flows in the chord diagrams, this is not remarkable. The flows from the Amsterdam Centraal direction are, for the most important transfer stations, high and the average transfer times of these flows are not low, resulting in high transfer time loss.

The top 10 line total transfers with the highest transfer time loss are given in table 6. There are 128 total lines in total. However, the top 10 total lines with the highest transfer time loss already have a share of 63.6%. The table shows that the IC train from Amsterdam Centraal has a total percentage of 12.8%. This percentage implies that this total transfer time loss of the "Trip #1 line" has a share of 12.8% of all the total transfer time loss of the total lines. The total "Trip #2 line" to Amsterdam Centraal has not the same share that one would expect. The plausible reason is that the transfer time from a HTM line to a NS train is lower than the other way around, as the traveler does not need to check-in on the NS train. It is possible to check-in already at the station entrance, before the platform and before the train even arrives. Therefore the total of lines to Amsterdam has "only" a share of 6.6% and thereby finds itself in third place. The total of lines towards the tram 9 to the Zwarte Pad has a share of 7% and finds itself in second place.

The transfer with the highest transfer time loss

After consultation with HTM, the conclusion is drawn that the top 10 transfers with the highest transfer time loss is the most interesting to examine in further detail. As in table 5, each transfer could be done at different transfer stations, the main transfer station that is used together with the corresponding (dis)utility factors waiting and walking time are given in table 7. The transfer from the Train IC from Amsterdam Centraal at Den Haag Centraal towards tram 16 to Van Boetzelaerlaan has the highest share on the total transfer time loss (around 1.08%). This transfer is followed by the transfer from the Train IC from Amsterdam Centraal at Den Haag Centraal towards tram 9 to Zwarte pad (around 1.06%) and the transfer from the train IC from Amsterdam Centraal at Den Haag Centraal towards tram 3 to Arnold Spoelplein (around 1.03%).
As walking and waiting times give the traveler a disutility, the transfers with a higher transfer time would have a higher disutility (when all other factors are equal). Then, the transfer at Den Haag Centraal between the train IC from Groningen towards the tram 9 to Zwarte Pad has the highest disutility and the transfer at Den Haag Centraal between the train IC from Amsterdam Centraal towards tram 2 to Kraayensteinlaan has the lowest disutility.
The four other disutility factors discussed in this research: need to level up or down (stairs), availability of real-time information, number of facilities present and the presence of escalators for these transfers are examined as well for the individual transfers. These factors were already given in table 3, however, for some transfers at Den Haag Centraal, travelers need to level up or down and for some transfers, travelers do not need to level up or down. As leveling up or down gives a disutility, this can explain the first and second place transfers with the highest transfer time loss: the Train IC from Amsterdam Centraal towards tram 16 to van Boetzelaerlaan (around 1.08%) and to tram 9 to Zwarte Pad (around 1.06%). For these transfers, the travelers do not need to level up or down to get to their following vehicle, which lead to a lower disutility and which can lead to a higher flow. They have a high flow because the transfer times of these transfers are not the highest, but they have the highest transfer time losses. However, all in all, for the individual transfers, it is hard to explain the flow sizes by the (dis)utility factors with certainty. Again assumptions can be made, but the flow size is probably mainly explained by high demand (travelers have a reason to go somewhere) and the fact that sometimes there is no (better) alternative available.

Measure implementation

Now that the details of the most important transfers and their transfer stations are known, the transfer that has the highest impact on the total transfer time loss is determined when reducing the waiting time by one minute, which can be facilitated by synchronizing the timetables of the concerning lines better. In table 8 the most important transfers for the specific transfer stations are given including the percentage difference when the waiting time is reduced by one minute. This "difference" column gives the highest impact on the total transfer time loss. The transfer from the train IC from Amsterdam Centraal at Den Haag Centraal towards tram 9 to Zwarte Pad has the highest impact on the transfer time loss (given in bold in table 8). A one-minute decrease in waiting time reduces the total transfer time loss by around 0.16 percentage points. This means that the total transfer time loss of all the transfers together decreased by around 0.16 points by having the waiting time reduction for this transfer. The share of this transfer on the total transfer time loss without a waiting time reduction was around 1.06% and when implementing the one minute reduction of waiting time, this will decrease to a share of around 0.9%.

If reducing the waiting time for the train IC from Amsterdam Centraal at Den Haag Centraal towards Tram 9 to Zwarte Pad by one minute, this transfer will get more attractive as the disutility will decrease. Therefore, this measure is implemented and tested in a Public Transport model in OmniTRANS to see and visualize the effects on traveler flows.
The difference in the network loads after implementing the

Table 4 Top 10 highest average transfer time

Top	Trip #1	Transfer station	Trip #2	Average Time (min)
1	Train IC from Utrecht Centraal	Den Haag HS	Tram 12 to Markenseplein	24.97
2	Train IC from Utrecht Centraal	Den Haag HS	Tram 11 to Strandweg	22.01
3	Train IC from Duivendrecht	Den Haag HS	Bus 26 to Kijkduin	20.3033
4	Train SPR from Amsterdam Centraal	Den Haag Centraal	Tram 1 to Zwarte Pad	19.62
5	Train IC from Lelystad Centrum	Den Haag Laan van NOI	Tram 19 to Delft station	19.25
6	Train IC from Amsterdam Centraal	Den Haag Laan van NOI	Tram 19 to Delft station	18.66
7	Train IC from Enschede	Den Haag Centraal	Tram 1 to Zwarte Pad	18.2483
8	Train IC from Amersfoort Schothorst	Den Haag Centraal	Tram 1 to Zwarte Pad	17.9025
9	Train IC from Zwolle	Den Haag Centraal	Tram 1 to Zwarte Pad	17.62
10	Train IC from Utrecht Centraal	Den Haag Centraal	Tram 1 to Zwarte Pad	17.256

Table 5 Top 10 transfers with the highest transfer time loss in percentages of total transfer time loss (=3577 transfers)

Top	Trip #1	Trip #2	Percentage (%)
1	Train IC from Amsterdam Centraal	Tram 3 to Arnold Spoelplein	1.3384
2	Train IC from Amsterdam Centraal	Tram 16 to Van Boetzelaerlaan	1.2127
3	Train IC from Amsterdam Centraal	Tram 9 to Zwarte Pad	1.1927
4	Train IC from Amsterdam Centraal	Tram 2 to Kraayensteinlaan	0.8420
5	Train IC from Amsterdam Centraal	Tram 4 to De Uithof	0.8206
6	Train IC from Amsterdam Centraal	Tram 9 to De Dreef	0.8127
7	Train IC from Groningen	Tram 3 to Arnold Spoelplein	0.7435
8	Train IC from Leeuwarden	Tram 3 to Arnold Spoelplein	0.7117
9	Train IC from Groningen	Tram 9 to Zwarte Pad	0.7040
10	Train IC from Amsterdam Centraal	Tram 1 to Abtswoudsepark	0.6987

Table 6 Top 10 line totals with the highest transfer time loss in percentages of total transfer time loss (=128 lines)

Top	(Total) Trip #1 line	(Total) Trip #2 line	Percentage (%)
1	Train IC from Amsterdam Centraal	-	12.8022
2	-	Tram 9 to Zwarte Pad	6.9998
3	-	Train IC to Amsterdam Centraal	6.6387
4	-	Tram 3 to Arnold Spoelplein	6.2724
5	-	Tram 16 to Van Boetzelaerlaan	5.6164
6	Train IC from Vlissingen	-	5.4745
7	Train SPR from Dordrecht	-	5.0515
8	Train IC from Dordrecht	-	4.9920
9	Train IC from Groningen	-	4.9052
10	Train IC from Leeuwarden	-	4.8202

Table 7 Division walking and waiting times* for the top transfers with the highest transfer time loss in percentages of total transfer time loss - per transfer station (for reference see table 5)

*Walking times are measures by hand and might fluctuate due to crowding, individual walking speed, platform changes and alighting position at the platform

Top	Transfer Station	Share (%) transfer time loss	Transfer time (min)	avg Walking time (min)	avg Waiting time (min)	Percentage waiting (%)
1	Den Haag Centraal	1.0316	7:09	2:55	4:14	59.2
2	Den Haag Centraal	1.0808	6:52	2:50	4:02	58.8
3	Den Haag Centraal	1.0594	6:34	2:50	3:44	56.9
4	Den Haag Centraal	0.7367	5:20	2:55	2:25	45.2
5	Den Haag Centraal	0.5856	5:25	2:55	2:30	47.8
6	Den Haag HS	0.5531	6:39	3:05	3:34	53.7
7	Den Haag Centraal	0.7293	6:31	2:55	3:36	55.2
8	Den Haag Centraal	0.6990	6:46	2:55	3:51	58.2
9	Den Haag Centraal	0.7028	7:30	2:50	4:40	62.3
10	Delft	0.4273	7:06	3:20	3:46	53.1

measure is given in figure 9. It is zoomed in around the area of Den Haag Centraal and the city center. The green areas show an increase in load when the measure is implemented, the red areas show a decrease in load and the grey areas indicate the same load. This visualization concerns average working days only. Saturdays and Sundays give a similar pattern, but with lower loads, so fewer travelers. The area with an increase in travelers is on line 9 to Zwarte Pad. An increase on this line 9 is expected as the transfer towards line 9 at Den Haag Centraal station has improved (one minute less waiting time) and thus, the disutility of this specific transfer is reduced. The exact flow differences on line 9 to Zwarte Pad are given in table 9. Line 9 to Zwarte Pad, get around 3% (371 travelers) flow increase with an increase of boarding travelers of 11.7% (371 travelers) at Den Haag Centraal. Some (26, 31, 46 and 2) travelers from lines 15 to Nootdorp , 16 to van Boetzelaerlaan, the shorter line 9 to Madurodam and bus 20 to Duinzigt, are taking the line 9 to Zwarte Pad instead because line 9 has become more interesting as the disutility has reduced. Especially travelers that used to alight at the Korte Voorhout stop are taking line 9 to the stops Malieveld and especially Dr. Kuyperstraat at line 9 to Zwarte Pad instead. Dr. Kuyperstraat has the highest increase of alightning travelers (81), but the Kurhaus stop also has a high increase (50), which is, relatively, more on weekend days. Furthermore, 269 new travelers are using the PT instead of using another mode. Therefore, a waiting time reduction to lower the disutility of a transfer can influence travelers' choice behavior of choosing certain routes and modes. Before implementing the measure, negative effects such as crowding and possible more inefficient other transfers need to be examined. Eventually, more of such waiting time reduction measures could be implemented in a transport model for more (important) transfers, and the following effects thereof can be examined to decide whether to implement the measure.

Table 8 Top transfers with the highest transfer time loss in percentages of total transfer time loss - including share difference on transfer time loss when implementing the measure

Top	Trip #1	Transfer station	Trip #2	Share transfer time loss (%)	Share transfer time loss when -1 min waiting time (%)	Difference (% points)
1	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 3 to Arnold Spoelplein	1.0316	0.8875	0.1441
2	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 16 to Van Boetzelaerlaan	1.0808	0.9233	0.1575
3	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 9 to Zwarte Pad	1.0594	0.8982	**0.1612**
4	Train IC from Amsterdam Centraal	Den Haag Centraal	Tram 2 to Kraayensteinlaan	0.7367	0.5985	0.1382
5	Train IC from Amsterdam Centraal	Den Haag Centaal	Tram 4 to De Uithof	0.5856	0.4774	0.1082
6	Train IC from Amsterdam Centraal	Den Haag HS	Tram 9 to De Dreef	0.5531	0.4529	0.1002
7	Train IC from Groningen	Den Haag Centraal	Tram 3 to Arnold Spoelplein	0.7293	0.6173	0.1120
8	Train IC from Leeuwarden	Den Haag Centraal	Tram 3 to Arnold Spoelplein	0.6990	0.5957	0.1034
9	Train IC from Groningen	Den Haag Centraal	Tram 9 to Zwarte Pad	0.7028	0.6090	0.0938
10	Train IC from Amsterdam Centraal	Delft	Tram 1 to Abtswoudsepark	0.4273	0.3671	0.0602

Table 9 Stops with flow difference on line 9 to Zwarte Pad (working day) after implementation of the measure

Tram stop	**Pass.**	**#1 Board**	**Last Alight**	**Ch. Board**	**Ch. Alight**	**Walk Board**	**Walk Alight**	**Sum Board**	**Sum Alight**
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	-14	0	0	0	-14	0
175,Den Haag, Centraal Station Beneden	-14	0	0	0	0	0	0	0	0
146,Den Haag, Centraal Station Beneden	-14	371	0	0	0	0	0	371	0
444,Den Haag, Malieveld	357	0	0	0	0	0	0	0	0
433,Den Haag, Malieveld	357	0	29	-3	0	-27	0	-30	30
443,Den Haag, Dr. Kuyperstraat	298	0	0	0	0	0	0	0	0
434,Den Haag, Dr. Kuyperstraat	298	0	81	0	0	0	0	0	81
442,Den Haag, Javabrug	217	0	0	0	0	0	0	0	0
435,Den Haag, Javabrug	217	0	38	0	0	0	0	0	38
441,Den Haag, Laan Copes van Cattenburch	179	0	0	0	0	0	0	0	0
436,Den Haag, Laan Copes van Cattenburch	179	0	43	0	0	0	0	0	43
437,Den Haag, Riouwstraat	136	0	11	-1	0	0	0	-1	11
440,Den Haag, Riouwstraat	125	0	0	0	0	0	0	0	0
439,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
438,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
461,Den Haag, Madurodam (Noord)	125	0	22	0	0	0	0	0	22
460,Den Haag, Wagenaarweg	103	0	0	0	0	0	0	0	0
462,Den Haag, Wagenaarweg	103	0	4	0	0	0	0	0	4
464,Den Haag, Nieuwe Duinweg	99	0	15	0	0	0	0	0	15
458,Den Haag, Nieuwe Duinweg	83	0	0	0	0	0	0	0	0
1088,Den Haag, Circustheater	83	0	24	0	0	0	0	0	24
1,Den Haag, Kurhaus	59	0	0	0	0	0	0	0	0
74,Den Haag, Kurhaus	59	0	50	0	0	0	1	0	51
75,Den Haag, Zwarte Pad Uitstaphalte	8	0	8	0	0	0	0	0	8
41,Den Haag, Zwarte Pad	0	0	0	0	0	0	0	0	0
Total		**371**	**325**	**-18**	**0**	**-27**	**2**	**327**	**327**

Discussion

Implications of case study

For Den Haag Laan van NOI, it was shown that most of the high flows have a high transfer time, which would be more acceptable if more utility factors such as having (many) facilities or the presence of escalators were present. However, only one utility factor (real-time information) and significantly more disutility factors (such as the need to level up or down) are present at the station. This and more results show that, at least within the Haaglanden area, the (dis)utility factors cannot always explain the transfer (station) flow size(s). The demand (having a reason to go somewhere) and having no (better) alternative available influence the transfer flow sizes probably more. However, as shown by means of the case study, reducing the waiting time of a transfer by one minute can increase the flow size as travelers choose different routes and modes. This indicates that (dis)utility factors, seem to explain flow sizes on the scale of individual transfers.

General implications

In this study, it is found that a multi-operator smart card dataset can identify the most important transfer stations and individual transfers, for which the associated disutility factors can be identified manually and, after that, measures can be implemented to minimize the disutility of a transfer. Therefore, a multi-operator smart card dataset contributes to minimizing the disutility of a transfer.

To determine which measures to implement, it is important to examine the effects of such a measure in the network as it can lead to more crowding, which gives a (high) disutility (Garcia-Martinez et al., 2018 and Cascajo et al., 2017). Furthermore, a measure such as synchronizing timetables better, can lead to more inefficient and unreliable other transfers (Lee et al., 2014).

Methodological contribution

As opposed to Yap et al. (2019), a slightly different approach has been used to find important transfer stations. This study determines the most important transfer stations in an easier and faster way as it is only looking into the highest travelers flow and not distinguishing different stops for one transfer location.

Furthermore, this research introduces a different way of visualizing traveler flow: chord diagrams. Flows of travelers are often visualized in maps, tables or in a schematic way. However, chord diagrams are especially useful when comparing flow sizes because the flows and sizes can be seen in one glance.

Figure 9 Effect on flow after implementing the measure

Research limitations

The multi-operator smart card dataset used in this study is only one design out of many. Therefore, other multi-operator smart card datasets might get more (or less) detailed results and conclusions, or have more information included, such as the type of travelers using the transfers. Furthermore, this study's multi-operator smart card dataset consisted of a 30 and 40 bin for transfers that are not made 30 or 40 times or more. This low number of transfers is explained by information management regulations (privacy). Based on different datasets and calculations, these transfers are given a value (of 3.7) times taken. However, this number is an assumption and may have a different value for particular transfers.
Transfers from HTM to NS get a relatively lower average transfer time than transfers of NS towards HTM as travelers transferring from the NS train towards a bus/tram of HTM are checking out at the platform/station of NS and checking in inside the vehicle of HTM and travelers transferring the other way around are checkin out inside the vehicle of HTM and are checking in at the platform/station of NS. For this last transfer, travelers may already check in minutes before the train departs, resulting in lower average transfer times. Consequently, this study finds transfers from NS to HTM as important transfers only.

Conclusion

This research aimed to evaluate how the use of multi-operator smart card datasets can contribute to the minimization of the disutility of Public Transport transfers, thus increasing travelers' satisfaction.

For this study, a multi-operator smart card dataset of the operators HTM and NS in the Haaglanden area in the Netherlands was used. The dataset uses a 35-minute time interval to identify transfers, meaning that transfers taking over 35 minutes are not considered. This study showed that the transfer times and the flows could be derived directly from a multi-operator smart card dataset. Together, these can be used to determine the most important transfer(s) (stations) and their respective (dis)utility factors. (Dis)utility factors (walking time and waiting time that the transfer time consists of, the need to level up or down, the presence of real-time information displays, the number of station facilities and the presence of escalators) are examined for the most important transfer(s) (stations) in more detail. It is concluded that, it is hard to explain transfer flow sizes by the (dis)utility factors of transfer stations as there could be multiple other reasons that are mainly contributing to the transfer flow size, such as high demand (travelers have a reason to go somewhere) and having no alternative available.
Having examined the (dis)utility factors, measures can be taken to reduce the disutility of a transfer. In this case study, a measure has been implemented to reduce the waiting time disutility factor and its effects are examined in a transport model. It is found that a waiting time reduction can increase the flow and can change travelers' route- and mode choices. This indicates that the (dis)utility factors of individual transfers influence and can explain the transfer flow size. Operators need to examine the effects of a measure as it can lead to more crowding, which increases the disutility, and while other lines and transfers can get more inefficient. The analysis of the multi-operator smart card dataset used in this study has a complementary contribution to minimizing the disutility of a transfer in Public Transport as a whole while the used multi-operator smart card dataset can only identify transfers between multiple operators and does not include transfers between single operators. However, as transfers in a multi-operator smart card dataset are assumed to have higher transfer times than transfers in a single-operator smart card dataset, multi-operator smart card datasets are found to be representative of identifying transfers that have relatively high disutilities.

In other words, this study finds that multi-operator smart card datasets analysis can not directly and by itself minimize the disutility of a transfer in Public Transport, but it can identify the most important transfer stations and individual transfers, for which the associated disutility factors can then be identified manually. Once these have been identified, measures can be implemented to reduce the disutility of a transfer. Therefore, a multi-operator smart card datasets analysis can contribute to minimizing the disutility of a transfer in Public Transport.

All in all, this study sheds light on how multi-operator smart card datasets can contribute to minimizing the disutility of Public Transport transfers. It concludes that, having implemented particularly valuable data and attributes such as: the transfer station, the trip and line towards the transfer station (which can also be derived from the check-in stop and the operator name), the trip and line after transferring (which can also be derived from the check-out stop and operator name), the number of travelers and the average transfer time (which can also be derived from the check-in- and check-out times and the number of travelers), multi-operator smart card datasets can be used to:

(1) Identify most important transfer stations and individual transfers, where minimizing the disutility has the highest impact
(2) Illustrate how one particular measure can lower the transfer time disutility

It is therefore highly valuable for practitioners because operators can use multi-operator smart datasets to gather information on transfers and their disutility, in order to maximize overall satisfaction of their Public Transport. This, in turn, has a positive effect on their reputation as a Public Transport operator and may increase the use of Public Transport. On top of that, this study contributes to the literature as follows. Firstly, it shows which attributes of a multi-operator smart card dataset are required to be able to identify appropriate transfers and consequently minimize the disutility of transfers. Secondly, it adds to the current literature by proposing a method by which a multi-operator smart card dataset can be applied to identify and determine transfer locations with a high potential for disutility minimization. Lastly, it demonstrates the implementation of an example measure and how effects can be examined by means of a transport model.

Recommendations

The results and conclusions gave rise to recommendations for operators, researchers and smart card dataset developers.

To examine if the method to find the most important transfer stations results in the same transfer stations as was found in Yap et al. (2019), the method of Yap et al. (2019) should be used for the multi-operator smart card dataset used in this study. Yap et al. (2019) determines the spatial boundaries of transfer locations first, after which the most important transfer stations are determined by use of the Herfindahl-Hirschman Index, which can result in multiple stops for one important transfer location. This study, however, only determines the most important transfer stations by looking into the highest travel flow, and does not distinguish different stops for one transfer location.

As multi-operator smart card datasets are assumed to have higher transfer times than single-operator smart card datasets, a multi-operator smart card dataset is seen as representative for identifying the most important transfer(s) stations with a high potential for minimizing the disutility. However, to examine if this assumption is valid, single-operator smart card data should be included and this study should be redone to see if this results in the same important transfer(s) stations.

It is furthermore recommended to study the exact (dis)utility values of the case specifically. Then, the (dis)utility of a transfer can be determined with an actual value and better conclusions can be drawn whether, and to what degree, (dis)utility factors explain the transfer flow sizes.

If privacy regulation play a role for low number of travelers in the smart card dataset, this can result in bins. A multi-operator smart card dataset should then be aggregated on a high time interval level to avoid these bins. How high the level of aggregation need to be depends on the aim of the research and on the flow sizes in the network.

Lastly, no paper-tickets, e-tickets and tickets bought inside the vehicles are included in the multi-operator smart card dataset. To enhance the representativeness of a smart card dataset, this data should also be included.

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B

The data and analysis

B.1. Reference tables

Table B.1: From lines (#1st trip) - traveling from a direction towards Den Haag Centraal station

Line	Direction from
Bus 18 to Centraal Station	South
Bus 18 to De Schilp	North
Bus 18 to Laan from Clingendael	South
Bus 20 to Centraal Station	North
Bus 20 to Theo Mann Bouwmeesterlaan	Den Haag Centraal
Bus 21 to Lozerlaan	North
Bus 21 to Zwarte Pad	South
Bus 22 to Centraal Station	North
Bus 22 to De Schilp	West
Bus 22 to Markenseplein	South
Bus 22 to Rijswijk Station	West
Bus 22 to Theo Mann Bouwmeesterlaan	West
Bus 22 to Zwarte Pad	-
Bus 23 to Colijnplein	North
Bus 23 to Kijkduin	North
Bus 23 to Voorburg Station	North
Bus 23 to Zwarte Pad	West
Bus 24 to Centraal Station	-
Bus 24 to Kijkduin	East
Bus 24 to Station Mariahoeve	West
Bus 25 to Grote Markt	South
Bus 25 to Lozerlaan	West
Bus 26 to Kijkduin	South
Bus 26 to Leeghwaterplein	-
Bus 26 to Leyenburg	South
Bus 26 to Station Hollands Spoor	West
Bus 26 to Voorburg Station	West
Bus 27 to Randveen	East
Bus 27 to Station Mariahoeve	South
Bus 28 to Centraal Station	-
Bus 28 to Norfolk	East
Bus 28 to Voorburg Station	West
Bus 29 to Oude Waalsdorperweg	South
Bus 29 to Rijswijk Station	North
Bus 31 to Centraal Station	West
Bus 31 to Vredespaleis	Den Haag Centraal
Bus 34 to De Savornin Lohmanplein	East
Bus 34 to Javalaan	West
Bus 61 to Centraal Station	North
Bus 61 to Zwarte Pad	Den Haag Centraal
Tram 1 to Abtswoudsepark	North
Tram 1 to Centraal Station	-
Tram 1 to Gravenstraat	South
Tram 1 to Javastraat	-
Tram 1 to Station Hollands Spoor	-
Tram 1 to from Boetzelaerlaan	South
Tram 1 to Zwarte Pad	South
Tram 11 to Loosduinseweg	North
Tram 11 to Rijswijkseplein	North
Tram 11 to Strandweg	South
Tram 12 to Markenseplein	South
Tram 12 to Rijswijkseplein	West
Tram 15 to Centraal Station	South
Tram 15 to Nootdorp Centrum	Den Haag Centraal
Tram 16 to Centraal Station	-
Tram 16 to Dorpskade	North
Tram 16 to from Boetzelaerlaan	South
Tram 17 to Centraal Station	South
Tram 17 to Dorpskade	Den Haag Centraal
Tram 19 to Delft Station	East
Tram 19 to HMC Antoniushove	South
Tram 19 to Weigelia	South
Tram 2 to HMC Antoniushove	West
Tram 2 to Kraayensteinlaan	East
Tram 2 to Station Laan from NOI	West
Tram 3 to Arnold Spoelplein	East
Tram 3 to Brouwersgracht	East
Tram 3 to Centraal Station	West
Tram 3 to Centrum-West	West
Tram 3 to De Savornin Lohmanplein	Den Haag Centraal
Tram 3 to HMC Westeinde	-
Tram 3 to Monstersestraat	-
Tram 4 to Centrum-West	-
Tram 4 to De Uithof	East
Tram 4 to HMC Westeinde	-
Tram 4 to Javalaan	West
Tram 4 to Lansingerland-Zoetermeer	West
Tram 4 to Monstersestraat	East
Tram 53 to De Savornin Lohmanplein	East
Tram 53 to Station Laan from NOI	West
Tram 6 to Centraal Station	-
Tram 6 to Dillenburgsingel	West
Tram 6 to Leyenburg	East
Tram 6 to Margarethaland	West
Tram 9 to Centraal Station	-
Tram 9 to De Dreef	North
Tram 9 to Madurodam	South
Tram 9 to Zuiderpark	-
Tram 9 to Zwarte Pad	South

Table B.2: From lines (#1st trip)- traveling from a direction towards Den Haag Centraal station part 2

Line	Direction from
Train IC from Amersfoort Schothorst	Voorburg direction
Train IC from Amsterdam Centraal	NOI direction
Train IC from Bergen op Zoom	HS direction
Train IC from Den Haag Centraal	Den Haag Centraal
Train IC from Dordrecht	HS direction
Train IC from Eindhoven	HS direction
Train IC from Enschede	Voorburg direction
Train IC from Groningen	NOI direction
Train IC from Leeuwarden	NOI direction
Train IC from Leiden Centraal	NOI direction
Train IC from Lelystad Centrum	NOI direction
Train IC from Roosendaal	HS direction
Train IC from Rotterdam Centraal	HS direction
Train IC from Schiphol Airport	NOI direction
Train IC from Utrecht Centraal	Voorburg direction
Train IC from Vlissingen	HS direction
Train IC from Zwolle	NOI direction
Train SPR from Amsterdam Centraal	NOI direction
Train SPR from Den Haag Centraal	Den Haag Centraal
Train SPR from Dordrecht	HS direction
Train SPR from Gouda Goverwelle	Voorburg direction
Train SPR from Haarlem	NOI direction
Train SPR from Hertogenbosch 's	HS direction
Train SPR from Hoorn Kersenboogerd	NOI direction
Train SPR from Lelystad Centrum	NOI direction
Train SPR from Rotterdam Centraal	HS direction
Train SPR from Utrecht Centraal	Voorburg direction

Table B.3: Towards lines (#2nd trip) - transferring at Den Haag Centraal station and going towards a direction

Line	Direction to
Bus 18 to Centraal Station	North
Bus 18 to De Schilp	South
Bus 18 to Laan van Clingendael	North
Bus 20 to Centraal Station	Den Haag Central
Bus 20 to Else Mauhs/Theo Mann	North
Bus 20 to Theo Mann Bouwmeesterlaan	North
Bus 21 to Lozerlaan	South
Bus 21 to Zwarte Pad	North
Bus 22 to Centraal Station	Den Haag Central
Bus 22 to De Schilp	South
Bus 22 to Markenseplein	West
Bus 22 to Oude Waalsdorperweg	North
Bus 22 to Rijswijk Station	South
Bus 22 to Theo Mann Bouwmeesterlaan	North
Bus 22 to Zwarte Pad	North
Bus 23 to Coplein	West
Bus 23 to Kijkduin	West
Bus 23 to Voorburg Station	East
Bus 23 to Zwarte Pad	North
Bus 24 to Centraal Station	Den Haag Central
Bus 24 to Kijkduin	West
Bus 24 to Station Mariahoeve	East
Bus 25 to Grote Markt	West
Bus 25 to Lozerlaan	South
Bus 26 to Kijkduin	West
Bus 26 to Station Hollands Spoor	South
Bus 26 to Voorburg Station	South
Bus 27 to Randveen	South
Bus 27 to Station Mariahoeve	East
Bus 28 to Centraal Station	Den Haag Central
Bus 28 to Norfolk	West
Bus 28 to Voorburg Station	East
Bus 29 to Oude Waalsdorperweg	North
Bus 29 to Rijswijk Station	South
Bus 31 to Centraal Station	Den Haag Central
Bus 31 to Vredespaleis	West
Bus 34 to Arnold Spoelplein	West
Bus 61 to Centraal Station	Den Haag Central
Bus 61 to Zwarte Pad	North
Bus 9 to Zwarte Pad	North

Table B.4: Towards lines (#2nd trip) - transferring at Den Haag Centraal station and going towards a direction part 2

Line	Direction to
Tram 1 to Abtswoudsepark	South
Tram 1 to Centraal Station	Den Haag Central
Tram 1 to Gravenstraat	West
Tram 1 to Kurhaus	North
Tram 1 to Station Hollands Spoor	South
Tram 1 to Van Boetzelaerlaan	West
Tram 1 to Zwarte Pad	North
Tram 11 to Rijswijkseplein	South
Tram 11 to Strandweg	North
Tram 12 to Markenseplein	West
Tram 12 to Rijswijkseplein	South
Tram 15 to Centraal Station	Den Haag Central
Tram 15 to Nootdorp Centrum	South
Tram 16 to Centraal Station	Den Haag Central
Tram 16 to Dorpskade	South
Tram 16 to Van Boetzelaerlaan	North
Tram 17 to Centraal Station	Den Haag Central
Tram 17 to Dorpskade	South
Tram 17 to Station Hollands Spoor	South
Tram 19 to Delft Station	South
Tram 19 to HMC Antoniushove	East
Tram 19 to Weigelia	East
Tram 2 to HMC Antoniushove	East
Tram 2 to Kraayensteinlaan	West
Tram 2 to Station Laan van NOI	East
Tram 3 to Arnold Spoelplein	West
Tram 3 to Brouwersgracht	West
Tram 3 to Centraal Station	Den Haag Central
Tram 3 to Centrum-West	East
Tram 3 to De Savornin Lohmanplein	West
Tram 3 to HMC Westeinde	West
Tram 3 to Monstersestraat	West
Tram 4 to Centrum-West	East
Tram 4 to De Uithof	West
Tram 4 to HMC Westeinde	West
Tram 4 to Javalaan	East
Tram 4 to Lansingerland-Zoetermeer	East
Tram 4 to Monstersestraat	West
Tram 53 to De Savornin Lohmanplein	West
Tram 53 to Station Laan van NOI	East
Tram 6 to Dillenburgsingel	East
Tram 6 to Leyenburg	West
Tram 6 to Margarethaland	East
Tram 9 to Centraal Station	Den Haag Central
Tram 9 to De Dreef	South
Tram 9 to Madurodam	North
Tram 9 to Zuiderpark	South
Tram 9 to Zwarte Pad	North
Train IC to Amersfoort	Voorburg direction
Train IC to Amersfoort Schothorst	Voorburg direction
Train IC to Amsterdam Centraal	NOI direction
Train IC to Den Haag Centraal	Den Haag Central
Train IC to Dordrecht	HS direction
Train IC to Eindhoven	HS direction
Train IC to Enschede	Voorburg direction
Train IC to Groningen	NOI direction
Train IC to Leeuwarden	NOI direction
Train IC to Roosendaal	HS direction
Train IC to Rotterdam Centraal	HS direction
Train IC to Schiphol Airport	NOI direction
Train IC to Utrecht Centraal	Voorburg direction
Train IC to Vlissingen	HS direction
Train IC to Zwolle	NOI direction
Train SPR to Amsterdam Centraal	NOI direction
Train SPR to Dordrecht	HS direction
Train SPR to Gouda Goverwelle	Voorburg direction
Train SPR to Haarlem	NOI direction
Train SPR to Hertogenbosch 's	HS direction
Train SPR to Schiphol Airport	NOI direction
Train SPR to Utrecht Centraal	Voorburg direction

Table B.5: From lines (#1st trip) - traveling from a direction towards Den Haag HS

Line	Direction from
Bus 18 to Centraal Station	-
Bus 18 to De Schilp	North
Bus 18 to Laan from Clingendael	South
Bus 20 to Centraal Station	North
Bus 20 to Theo Mann Bouwmeesterlaan	North
Bus 21 to Lozerlaan	North
Bus 21 to Zwarte Pad	South
Bus 22 to De Schilp	West
Bus 22 to Markenseplein	South
Bus 22 to Rijswijk Station	West
Bus 22 to Theo Mann Bouwmeesterlaan	West
Bus 23 to Colijnplein	North
Bus 23 to Kijkduin	North
Bus 23 to Voorburg Station	North
Bus 23 to Zwarte Pad	West
Bus 24 to Kijkduin	East
Bus 24 to Station Mariahoeve	West
Bus 25 to Grote Markt	South
Bus 25 to Lozerlaan	West
Bus 26 to Kijkduin	South
Bus 26 to Leeghwaterplein	-
Bus 26 to Leyenburg	South
Bus 26 to Station Hollands Spoor	West
Bus 26 to Voorburg Station	West
Bus 27 to Randveen	East
Bus 27 to Station Mariahoeve	South
Bus 28 to Centraal Station	-
Bus 28 to Norfolk	East
Bus 28 to Voorburg Station	West
Bus 29 to Oude Waalsdorperweg	South
Bus 29 to Rijswijk Station	North
Bus 31 to Centraal Station	West
Bus 61 to Centraal Station	North
Bus 61 to Zwarte Pad	North
Tram 1 to Abtswoudsepark	North
Tram 1 to Centraal Station	-
Tram 1 to Gravenstraat	South
Tram 1 to Station Hollands Spoor	HS
Tram 1 to from Boetzelaerlaan	South
Tram 1 to Zwarte Pad	South
Tram 11 to Loosduinseweg	North
Tram 11 to Rijswijkseplein	North
Tram 11 to Strandweg	South
Tram 12 to Markenseplein	South
Tram 12 to Rijswijkseplein	West
Tram 15 to Centraal Station	South
Tram 15 to Nootdorp Centrum	North
Tram 16 to Centraal Station	-
Tram 16 to Dorpskade	North
Tram 16 to from Boetzelaerlaan	South
Tram 17 to Centraal Station	South
Tram 17 to Dorpskade	North
Tram 17 to Station Hollands Spoor	HS
Tram 19 to Delft Station	East
Tram 19 to Weigelia	South
Tram 2 to HMC Antoniushove	West
Tram 2 to Kraayensteinlaan	East
Tram 3 to Arnold Spoelplein	East
Tram 3 to Brouwersgracht	East
Tram 3 to Centraal Station	West
Tram 3 to Centrum-West	West
Tram 3 to De Savornin Lohmanplein	-
Tram 3 to HMC Westeinde	-
Tram 4 to De Uithof	East
Tram 4 to HMC Westeinde	-
Tram 4 to Javalaan	West
Tram 4 to Lansingerland-Zoetermeer	West
Tram 4 to Monstersestraat	East
Tram 53 to Station Laan from NOI	-
Tram 6 to Dillenburgsingel	West
Tram 6 to Leyenburg	East
Tram 9 to Centraal Station	-
Tram 9 to De Dreef	North
Tram 9 to Madurodam	South
Tram 9 to Zuiderpark	-
Tram 9 to Zwarte Pad	South

Table B.6: From lines (#1st trip) - traveling from a direction towards Den Haag HS part 2

Line	Direction from
Train HSN from Amsterdam Centraal	NOI direction
Train HSN from Breda grens	Moerwijk direction
Train IC from Amsterdam Centraal	NOI direction
Train IC from Bergen op Zoom	Moerwijk direction
Train IC from Den Haag Centraal	Den Haag Central
Train IC from Dordrecht	Moerwijk direction
Train IC from Duivendrecht	NOI direction
Train IC from Eindhoven	Moerwijk direction
Train IC from Groningen	NOI direction
Train IC from Leiden Centraal	NOI direction
Train IC from Lelystad Centrum	NOI direction
Train IC from Roosendaal	Moerwijk direction
Train IC from Rotterdam Centraal	Moerwijk direction
Train IC from Schiphol Airport	NOI direction
Train IC from Utrecht Centraal	NOI direction
Train IC from Vlissingen	Moerwijk direction
Train SPR from Amsterdam Centraal	NOI direction
Train SPR from Den Haag Centraal	Den Haag Central
Train SPR from Dordrecht	Moerwijk direction
Train SPR from Gouda Goverwelle	Voorburg direction
Train SPR from Haarlem	NOI direction
Train SPR from Hertogenbosch ’s	Moerwijk direction
Train SPR from Rotterdam Centraal	Moerwijk direction
Train SPR from Utrecht Centraal	Voorburg direction

Table B.7: Towards lines (#2nd trip) - transferring at Den Haag HS and going towards a direction

Line	Direction to
Bus 18 to Centraal Station	North
Bus 18 to De Schilp	South
Bus 18 to Laan van Clingendael	North
Bus 20 to Theo Mann Bouwmeesterlaan	North
Bus 21 to Lozerlaan	South
Bus 21 to Zwarte Pad	North
Bus 22 to De Schilp	South
Bus 22 to Markenseplein	West
Bus 22 to Oude Waalsdorperweg	North
Bus 22 to Rijswijk Station	South
Bus 22 to Theo Mann Bouwmeesterlaan	North
Bus 23 to Colijnplein	West
Bus 23 to Kijkduin	West
Bus 23 to Zwarte Pad	North
Bus 24 to Kijkduin	West
Bus 24 to Station Mariahoeve	East
Bus 25 to Grote Markt	West
Bus 25 to Lozerlaan	South
Bus 26 to Kijkduin	West
Bus 26 to Leeghwaterplein	South
Bus 26 to Leyenburg	West
Bus 26 to Station Hollands Spoor	HS
Bus 26 to Voorburg Station	South
Bus 27 to Randveen	South
Bus 27 to Station Mariahoeve	East
Bus 28 to Centraal Station	-
Bus 28 to Norfolk	West
Bus 28 to Voorburg Station	East
Bus 29 to Oude Waalsdorperweg	North
Bus 29 to Rijswijk Station	South
Bus 31 to Vredespaleis	West
Bus 61 to Centraal Station	North
Bus 61 to Zwarte Pad	North

Table B.8: Towards lines (#2nd trip) - transferring at Den Haag HS and going towards a direction part 2

Line	Direction to
Tram 1 to Abtswoudsepark	South
Tram 1 to Centraal Station	North
Tram 1 to Gravenstraat	West
Tram 1 to Kurhaus	North
Tram 1 to Van Boetzelaerlaan	West
Tram 1 to Zwarte Pad	North
Tram 11 to Rijswijkseplein	South
Tram 11 to Strandweg	North
Tram 12 to Goudenregenstraat	West
Tram 12 to Markenseplein	West
Tram 12 to Rijswijkseplein	South
Tram 15 to Centraal Station	North
Tram 15 to Nootdorp Centrum	South
Tram 16 to Centraal Station	North
Tram 16 to Dorpskade	South
Tram 16 to Van Boetzelaerlaan	North
Tram 17 to Centraal Station	North
Tram 17 to Dorpskade	South
Tram 17 to Station Hollands Spoor	HS
Tram 19 to Delft Station	South
Tram 19 to HMC Antoniushove	East
Tram 19 to Weigelia	East
Tram 2 to HMC Antoniushove	East
Tram 2 to Kraayensteinlaan	West
Tram 2 to Station Laan van NOI	East
Tram 3 to Arnold Spoelplein	West
Tram 3 to Centraal Station	North
Tram 3 to Centrum-West	East
Tram 3 to De Savornin Lohmanplein	West
Tram 4 to De Uithof	West
Tram 4 to HMC Westeinde	West
Tram 4 to Javalaan	East
Tram 4 to Lansingerland-Zoetermeer	East
Tram 4 to Monstersestraat	West
Tram 53 to De Savornin Lohmanplein	West
Tram 6 to Dillenburgsingel	East
Tram 6 to Leyenburg	West
Tram 6 to Margarethaland	East
Tram 9 to Centraal Station	-
Tram 9 to De Dreef	South
Tram 9 to Madurodam	North
Tram 9 to Zuiderpark	South
Tram 9 to Zwarte Pad	North
Train HSN to Amsterdam Centraal	NOI direction
Train HSN to Breda grens	Moerwijk direction
Train IC to Amsterdam Centraal	NOI direction
Train IC to Den Haag Centraal	Den Haag Central
Train IC to Dordrecht	Moerwijk direction
Train IC to Duivendrecht	NOI direction
Train IC to Eindhoven	Moerwijk direction
Train IC to Lelystad Centrum	NOI direction
Train IC to Roosendaal	Moerwijk direction
Train IC to Rotterdam Centraal	Moerwijk direction
Train IC to Utrecht Centraal	NOI direction
Train IC to Vlissingen	Moerwijk direction
Train SPR to Den Haag Centraal	Den Haag Central
Train SPR to Dordrecht	Moerwijk direction
Train SPR to Haarlem	NOI direction

Table B.9: From lines (#1st trip) - traveling from a direction towards Den Haag Laan van NOI

Line	Direction from
Bus 18 to Centraal Station	South
Bus 18 to De Schilp	North
Bus 20 to Centraal Station	North
Bus 21 to Lozerlaan	North
Bus 21 to Zwarte Pad	South
Bus 22 to Centraal Station	North
Bus 22 to De Schilp	West
Bus 22 to Markenseplein	South
Bus 22 to Rijswijk Station	West
Bus 22 to Theo Mann Bouwmeesterlaan	West
Bus 23 to Colijnplein	North
Bus 23 to Kijkduin	North
Bus 23 to Voorburg Station	North
Bus 23 to Zwarte Pad	West
Bus 24 to Kijkduin	East
Bus 24 to Station Mariahoeve	West
Bus 25 to Grote Markt	South
Bus 26 to Kijkduin	South
Bus 26 to Station Hollands Spoor	West
Bus 26 to Voorburg Station	West
Bus 27 to Randveen	East
Bus 27 to Station Mariahoeve	South
Bus 28 to Centraal Station	South
Bus 28 to Voorburg Station	West
Bus 29 to Rijswijk Station	North
Bus 31 to Centraal Station	West
Bus 61 to Centraal Station	North
Bus 61 to Zwarte Pad	West
Tram 1 to Abtswoudsepark	North
Tram 1 to Gravenstraat	South
Tram 1 to Zwarte Pad	South
Tram 11 to Loosduinseweg	North
Tram 11 to Rijswijkseplein	North
Tram 11 to Strandweg	South
Tram 12 to Rijswijkseplein	West
Tram 15 to Centraal Station	South
Tram 15 to Nootdorp Centrum	West
Tram 16 to Centraal Station	-
Tram 16 to Dorpskade	North
Tram 16 to from Boetzelaerlaan	South
Tram 17 to Centraal Station	South
Tram 17 to Dorpskade	West
Tram 19 to Delft Station	East
Tram 19 to HMC Antoniushove	South
Tram 19 to Weigelia	South
Tram 2 to HMC Antoniushove	West
Tram 2 to Kraayensteinlaan	East
Tram 2 to Station Laan from NOI	West
Tram 3 to Arnold Spoelplein	East
Tram 3 to Brouwersgracht	East
Tram 3 to Centraal Station	West
Tram 3 to Centrum-West	West
Tram 3 to De Savornin Lohmanplein	West
Tram 3 to HMC Westeinde	-
Tram 3 to Monstersestraat	-
Tram 4 to Centrum-West	-
Tram 4 to De Uithof	East
Tram 4 to HMC Westeinde	-
Tram 4 to Javalaan	West
Tram 4 to Lansingerland-Zoetermeer	West
Tram 4 to Monstersestraat	East
Tram 53 to Station Laan from NOI	West
Tram 6 to Dillenburgsingel	West
Tram 6 to Leyenburg	East
Tram 9 to Centraal Station	-
Tram 9 to De Dreef	North
Tram 9 to Zwarte Pad	South
Train IC from Amsterdam Centraal	Mariahoeve direction
Train IC from Bergen op Zoom	HS direction
Train IC from Den Haag Centraal	Den Haag Central
Train IC from Dordrecht	HS direction
Train IC from Duivendrecht	Mariahoeve direction
Train IC from Groningen	Mariahoeve direction
Train IC from Leeuwarden	Mariahoeve direction
Train IC from Leiden Centraal	Mariahoeve direction
Train IC from Lelystad Centrum	Mariahoeve direction
Train IC from Roosendaal	HS direction
Train IC from Rotterdam Centraal	HS direction
Train IC from Schiphol Airport	Mariahoeve direction
Train IC from Vlissingen	HS direction
Train IC from Zwolle	Mariahoeve direction
Train SPR from Amsterdam Centraal	Mariahoeve direction
Train SPR from Den Haag Centraal	Den Haag Central
Train SPR from Dordrecht	-
Train SPR from Gouda Goverwelle	-
Train SPR from Haarlem	Mariahoeve direction
Train SPR from Hertogenbosch ’s	-
Train SPR from Hoorn Kersenboogerd	Mariahoeve direction
Train SPR from Leiden Centraal	Mariahoeve direction
Train SPR from Rotterdam Centraal	-
Train SPR from Utrecht Centraal	-

Table B.10: Towards lines (#2nd trip) - transferring at Den Haag Laan van NOI and going towards a direction

Line	Direction to
Bus 18 to De Schilp	South
Bus 18 to Laan van Clingendael	North
Bus 20 to Centraal Station	West
Bus 20 to Theo Mann Bouwmeesterlaan	North
Bus 21 to Lozerlaan	South
Bus 21 to Zwarte Pad	North
Bus 22 to De Schilp	South
Bus 22 to Markenseplein	West
Bus 22 to Oude Waalsdorperweg	North
Bus 22 to Rijswijk Station	South
Bus 22 to Theo Mann Bouwmeesterlaan	North
Bus 23 to Colijnplein	West
Bus 23 to Kijkduin	West
Bus 23 to Voorburg Station	East
Bus 23 to Zwarte Pad	North
Bus 24 to Kijkduin	West
Bus 24 to Station Mariahoeve	East
Bus 25 to Lozerlaan	South
Bus 26 to Kijkduin	West
Bus 26 to Voorburg Station	South
Bus 27 to Randveen	South
Bus 27 to Station Mariahoeve	East
Bus 28 to Centraal Station	West
Bus 28 to Norfolk	West
Bus 28 to Voorburg Station	East
Bus 29 to Oude Waalsdorperweg	North
Bus 29 to Rijswijk Station	South
Bus 31 to Centraal Station	West
Bus 31 to Vredespaleis	West
Bus 34 to Javalaan	East
Bus 61 to Centraal Station	West
Bus 61 to Zwarte Pad	North
Tram 1 to Abtswoudsepark	South
Tram 1 to Gravenstraat	West
Tram 1 to Zwarte Pad	North
Tram 11 to Loosduinseweg	West
Tram 11 to Rijswijkseplein	South
Tram 11 to Strandweg	North
Tram 12 to Markenseplein	West
Tram 12 to Rijswijkseplein	South
Tram 15 to Centraal Station	West
Tram 15 to Nootdorp Centrum	South
Tram 16 to Dorpskade	South
Tram 16 to Van Boetzelaerlaan	North
Tram 17 to Centraal Station	West
Tram 17 to Dorpskade	South
Tram 17 to Station Hollands Spoor	South
Tram 19 to Delft Station	South
Tram 19 to HMC Antoniushove	East
Tram 19 to Weigelia	East
Tram 2 to HMC Antoniushove	East
Tram 2 to Kraayensteinlaan	West
Tram 2 to Station Laan van NOI	NOI
Tram 3 to Arnold Spoelplein	West
Tram 3 to Brouwersgracht	West
Tram 3 to Centraal Station	West
Tram 3 to Centrum-West	East
Tram 3 to De Savornin Lohmanplein	West
Tram 3 to Monstersestraat	West
Tram 4 to Centrum-West	East
Tram 4 to De Uithof	West
Tram 4 to HMC Westeinde	West
Tram 4 to Javalaan	East
Tram 4 to Lansingerland-Zoetermeer	East
Tram 4 to Monstersestraat	West
Tram 53 to De Savornin Lohmanplein	West
Tram 53 to Station Laan van NOI	NOI
Tram 6 to Dillenburgsingel	East
Tram 6 to Leyenburg	West
Tram 9 to De Dreef	South
Tram 9 to Madurodam	North
Tram 9 to Zwarte Pad	North
Train IC to Amsterdam Centraal	Mariahoeve direction
Train IC to Den Haag Centraal	Den Haag Centraal
Train IC to Dordrecht	HS direction
Train IC to Duivendrecht	Mariahoeve direction
Train IC to Groningen	Mariahoeve direction
Train IC to Leeuwarden	Mariahoeve direction
Train IC to Lelystad Centrum	Mariahoeve direction
Train IC to Roosendaal	HS direction
Train IC to Rotterdam Centraal	HS direction
Train IC to Schiphol Airport	Mariahoeve direction
Train IC to Vlissingen	HS direction
Train IC to Zwolle	Mariahoeve direction
Train SPR to Amsterdam Centraal	Mariahoeve direction
Train SPR to Den Haag Centraal	Den Haag Centraal
Train SPR to Gouda Goverwelle	-
Train SPR to Haarlem	Mariahoeve direction
Train SPR to Hoofddorp	Mariahoeve direction
Train SPR to Leiden Centraal	Mariahoeve direction
Train SPR to Schiphol Airport	Mariahoeve direction

Table B.11: From lines (#1st trip) - traveling from a direction towards Delft station

Line	Direction from
Bus 18 to Laan van Clingendael	North
Bus 18 to De Schilp	North
Bus 21 to Lozerlaan	North
Bus 22 to De Schilp	North
Bus 22 to Markenseplein	North
Bus 23 to Colijnplein	North
Bus 23 to Kijkduin	North
Bus 23 to Zwarte Pad	North
Bus 24 to Kijkduin	North
Bus 24 to Station Mariahoeve	North
Bus 26 to Kijkduin	North
Bus 26 to Station Hollands Spoor	North
Bus 26 to Voorburg Station	North
Bus 27 to Station Mariahoeve	North
Bus 29 to Rijswijk Station	North
Tram 1 to Abtswoudsepark	North
Tram 1 to Centraal Station	South
Tram 1 to Gravenstraat	South
Tram 1 to Zwarte Pad	South
Tram 11 to Rijswijkseplein	North
Tram 12 to Markenseplein	North
Tram 12 to Rijswijkseplein	North
Tram 15 to Centraal Station	North
Tram 15 to Nootdorp Centrum	North
Tram 16 to Dorpskade	North
Tram 16 to Van Boetzelaerlaan	North
Tram 17 to Centraal Station	North
Tram 17 to Dorpskade	North
Tram 19 to Delft Station	North
Tram 19 to HMC Antoniushove	North
Tram 19 to Nootdorp Centrum	North
Tram 19 to Weigelia	North
Tram 2 to HMC Antoniushove	North
Tram 2 to Kraayensteinlaan	North
Tram 3 to Arnold Spoelplein	North
Tram 3 to Centrum-West	North
Tram 4 to De Uithof	North
Tram 4 to Javalaan	North
Tram 4 to Lansingerland-Zoetermeer	North
Tram 6 to Dillenburgsingel	North
Tram 6 to Leyenburg	North
Tram 9 to De Dreef	North
Tram 9 to Zwarte Pad	North
Train IC from Amsterdam Centraal	Rijswijk direction
Train IC from Bergen op Zoom	Delft-campus direction
Train IC from Den Haag Centraal	Rijswijk direction
Train IC from Dordrecht	Delft-campus direction
Train IC from Duivendrecht	Rijswijk direction
Train IC from Eindhoven	Delft-campus direction
Train IC from Leiden Centraal	Rijswijk direction
Train IC from Lelystad Centrum	Rijswijk direction
Train IC from Roosendaal	Delft-campus direction
Train IC from Rotterdam Centraal	Delft-campus direction
Train IC from Schiphol Airport	Rijswijk direction
Train IC from Utrecht Centraal	Rijswijk direction
Train IC from Vlissingen	Delft-campus direction
Train SPR from Amsterdam Centraal	Rijswijk direction
Train SPR from Den Haag Centraal	Rijswijk direction
Train SPR from Dordrecht	Delft-campus direction
Train SPR from Gouda Goverwelle	Rijswijk direction
Train SPR from Haarlem	Rijswijk direction
Train SPR from Hertogenbosch ’s	Delft-campus direction
Train SPR from Rotterdam Centraal	Delft-campus direction
Train SPR from Utrecht Centraal	-

Table B.12: Towards lines (#2nd trip) - transferring at Delft station and going towards a direction

Line	Direction to
Bus 18 to De Schilp	North
Bus 18 to Laan van Clingendael	North
Bus 21 to Zwarte Pad	North
Bus 22 to De Schilp	North
Bus 22 to Markenseplein	North
Bus 23 to Colijnplein	North
Bus 23 to Kijkduin	North
Bus 23 to Zwarte Pad	North
Bus 24 to Station Mariahoeve	North
Bus 26 to Kijkduin	North
Bus 26 to Voorburg Station	North
Bus 28 to Norfolk	North
Bus 28 to Voorburg Station	North
Tram 1 to Abtswoudsepark	South
Tram 1 to Centraal Station	North
Tram 1 to Gravenstraat	North
Tram 1 to Kurhaus	North
Tram 1 to Van Boetzelaerlaan	North
Tram 1 to Zwarte Pad	North
Tram 11 to Strandweg	North
Tram 12 to Markenseplein	North
Tram 15 to Centraal Station	North
Tram 15 to Nootdorp Centrum	North
Tram 16 to Dorpskade	North
Tram 16 to Van Boetzelaerlaan	North
Tram 17 to Centraal Station	North
Tram 17 to Dorpskade	North
Tram 19 to Delft Station	South
Tram 19 to HMC Antoniushove	North
Tram 19 to Nootdorp Centrum	North
Tram 19 to Weigelia	North
Tram 2 to Kraayensteinlaan	North
Tram 3 to Arnold Spoelplein	North
Tram 3 to Centrum-West	North
Tram 4 to De Uithof	North
Tram 4 to Javalaan	North
Tram 4 to Lansingerland-Zoetermeer	North
Tram 6 to Dillenburgsingel	North
Tram 6 to Leyenburg	North
Tram 9 to De Dreef	North
Tram 9 to Zwarte Pad	North
Train IC to Amsterdam Centraal	Rijswijk direction
Train IC to Den Haag Centraal	Rijswijk direction
Train IC to Dordrecht	Delft-campus direction
Train IC to Duivendrecht	Rijswijk direction
Train IC to Eindhoven	Delft-campus direction
Train IC to Lelystad Centrum	Rijswijk direction
Train IC to Roosendaal	Delft-campus direction
Train IC to Rotterdam Centraal	Delft-campus direction
Train IC to Utrecht Centraal	Rijswijk direction
Train IC to Vlissingen	Delft-campus direction
Train SPR to Den Haag Centraal	Rijswijk direction
Train SPR to Dordrecht	Delft-campus direction

B.2. R codes

The following code is the code to get the chord diagram of Den Haag HS.

```
install.packages(”circlize”)
install.packages(”readxl”)
setwd(”C:/Users/jensing/Documents/Thesis/R/Nieuw”)
library(circlize)
library(readxl)

options(scipen=999)

Data <- read-excel(”AlleenHSflows_nieuw2.xlsx”)
View(Data)

grid.col = c(North_HTM = ”FFD700”, East_HTM = ”B8860B”, South_HTM = ”EEE8AA”, West_HTM =
”BDB76B”, Track_to_from_Amsterdam_NS = ”8A2BE2”, Track_to_from_Rotterdam_NS = ”8B008B”,
Den_Haag_Centraal = ”708090”))

chordDiagram(Data, grid.col = grid.col)

title(”Sum of transfers at Den Haag HS = 2890602.8”)

dev.copy(jpeg,’HSnieuw_2.png’, width=9, height=9, units=”in”, res=500)
dev.off()
```

For all the four different transfer stations: Den Haag Centraal, Den Haag HS, Den Haag Laan van NOI and Delft, the codes are almost the same. For every direction a different color code is used:

- North_HTM = #FFD700
- East_HTM = #B8860B
- South_HTM = #EEE8AA
- West_HTM = #BDB76B
- Track_to_from_Amsterdam_NS = #8A2BE2
- Den_Haag_Centraal = #708090
- Track_to_from_Rotterdam_NS = #8B008B
- Track_to_from_Utrecht = #0000CD
- Track_to_from_HS_NS = #B0C4DE

C
Results

C.1. Network loads

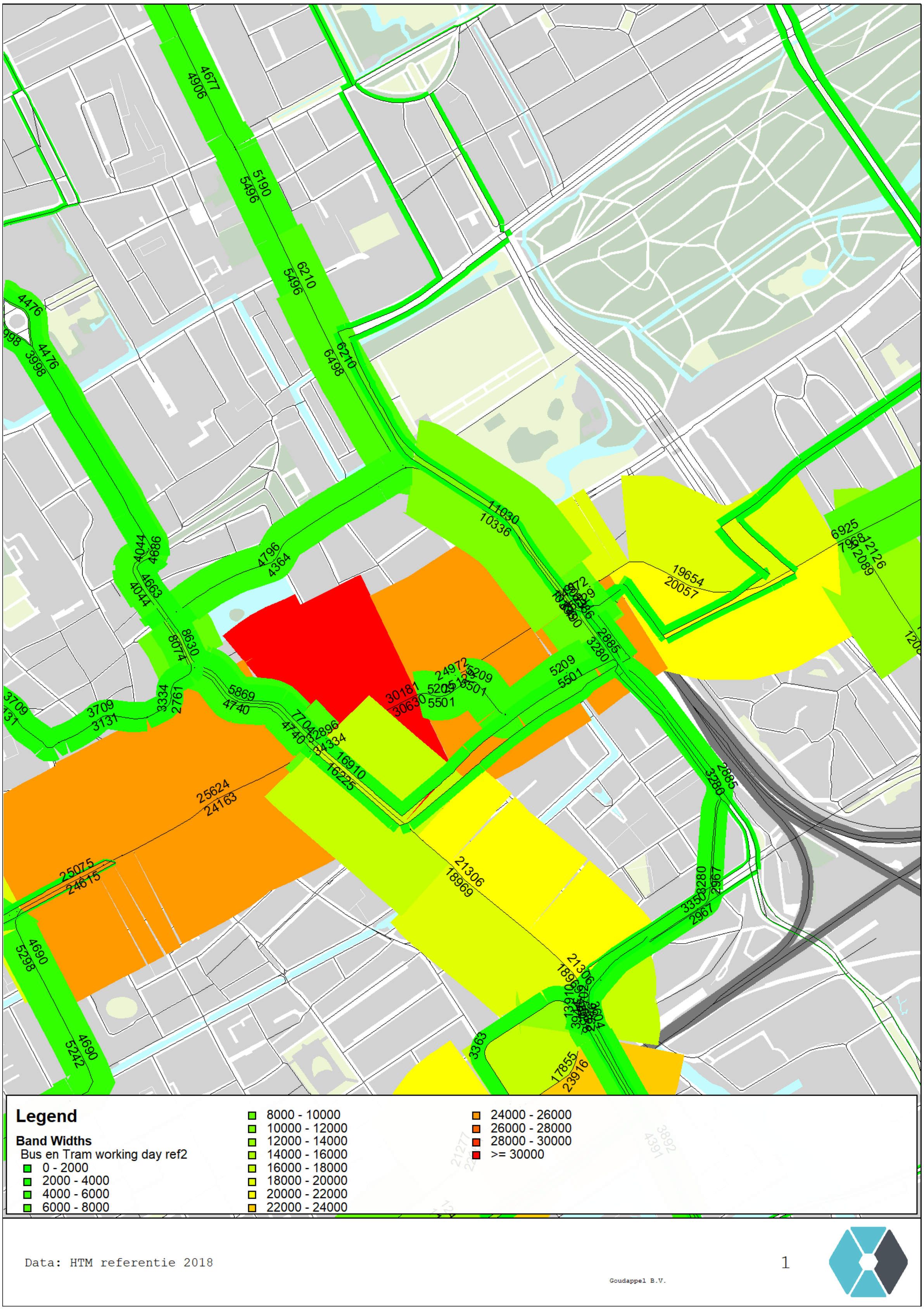

Figure C.1: Load on network in reference model level (working day) - zoomed in

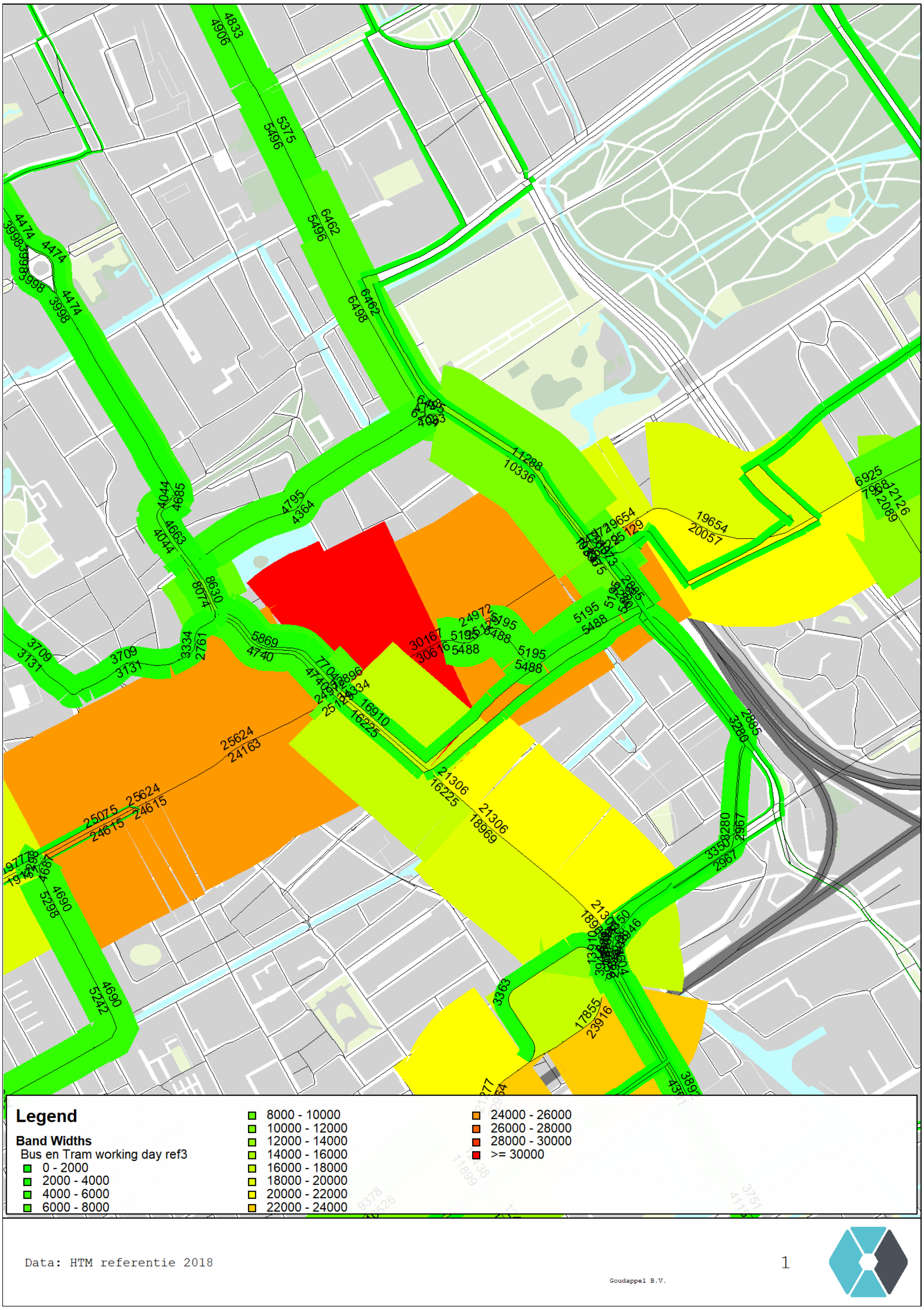

Figure C.2: Load on network in measure model level (working day) - zoomed in

C.2. Tramlines and tram stops

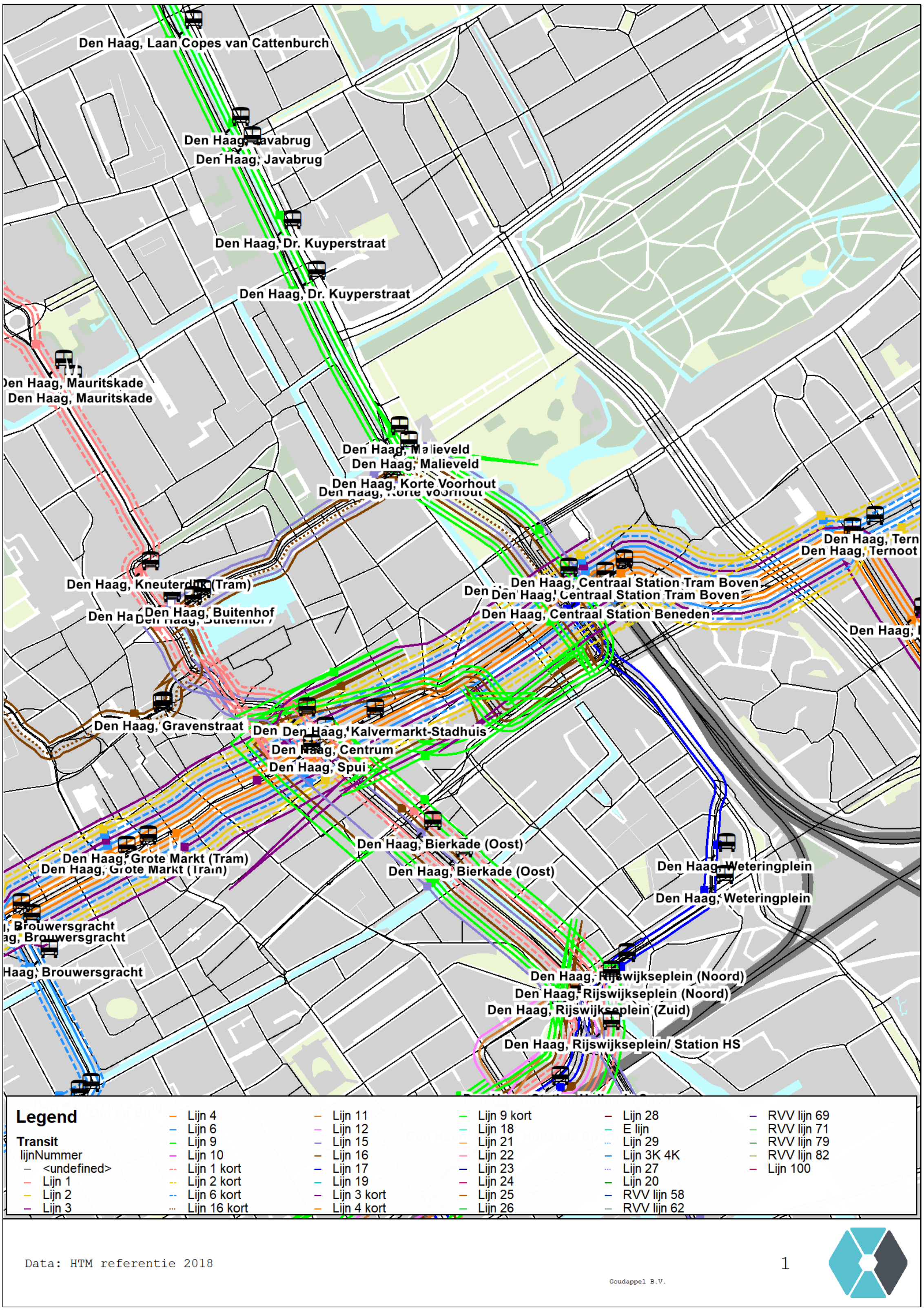

Figure C.3: Tramlines and stops (zoomed in at city center of Den Haag)

C.3. Tables with flow differences between measure model level and reference model level

Table C.1: Flow difference after implementing measure on line 9 to Zwarte Pad (working day)

Tram stop	Pass.	#1 Board	Last Alight	Ch. Board	Ch. Alight	Walk Board	Walk Alight	Sum Board	Sum Alight
426,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
452,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
451,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
427,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
450,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
428,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
429,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
449,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
161,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
186,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
185,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
162,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
184,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
163,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
430,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
448,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
447,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
431,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
446,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
432,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
445,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
111,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
78,Den Haag, Jacob Catsstraat	0	0	0	0	0	0	0	0	0
1092,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
16,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
15,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
61,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	-14	0	0	0	-14	0
175,Den Haag, Centraal Station Beneden	-14	0	0	0	0	0	0	0	0
146,Den Haag, Centraal Station Beneden	-14	371	0	0	0	0	0	371	0
444,Den Haag, Malieveld	357	0	0	0	0	0	0	0	0
433,Den Haag, Malieveld	357	0	29	-3	0	-27	0	-30	30
443,Den Haag, Dr. Kuyperstraat	298	0	0	0	0	0	0	0	0
434,Den Haag, Dr. Kuyperstraat	298	0	81	0	0	0	0	0	81
442,Den Haag, Javabrug	217	0	0	0	0	0	0	0	0
435,Den Haag, Javabrug	217	0	38	0	0	0	0	0	38
441,Den Haag, Laan Copes van Cattenburch	179	0	0	0	0	0	0	0	0
436,Den Haag, Laan Copes van Cattenburch	179	0	43	0	0	0	0	0	43
437,Den Haag, Riouwstraat	136	0	11	-1	0	0	0	-1	11
440,Den Haag, Riouwstraat	125	0	0	0	0	0	0	0	0
439,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
438,Den Haag, Madurodam (Noord)	125	0	0	0	0	0	0	0	0
461,Den Haag, Madurodam (Noord)	125	0	22	0	0	0	0	0	22

Table C.2: Flow difference after implementing measure on line 9 to Zwarte Pad - continued (working day)

Tram stop	Pass.	#1 Board	Last Alight	Ch. Board	Ch. Alight	Walk Board	Walk Alight	Sum Board	Sum Alight
460,Den Haag, Wagenaarweg	103	0	0	0	0	0	0	0	0
462,Den Haag, Wagenaarweg	103	0	4	0	0	0	0	0	4
464,Den Haag, Nieuwe Duinweg	99	0	15	0	0	0	0	0	15
458,Den Haag, Nieuwe Duinweg	83	0	0	0	0	0	0	0	0
1088,Den Haag, Circustheater	83	0	24	0	0	0	0	0	24
1,Den Haag, Kurhaus	59	0	0	0	0	0	0	0	0
74,Den Haag, Kurhaus	59	0	50	0	0	0	1	0	51
75,Den Haag, Zwarte Pad Uitstaphalte	8	0	8	0	0	0	0	0	8
41,Den Haag, Zwarte Pad	0	0	0	0	0	0	0	0	0
Total		**371**	**325**	**-18**	**0**	**-27**	**2**	**327**	**327**

Table C.3: Flow difference after implementing measure on line 9 to Zwarte Pad (Saturday)

Tram stop	Pass.	#1 Board	Last Alight	Ch. Board	Ch. Alight	Walk Board	Walk Alight	Sum Board	Sum Alight
426,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
452,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
451,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
427,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
450,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
428,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
429,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
449,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
161,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
186,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
185,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
162,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
184,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
163,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
430,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
448,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
447,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
431,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
446,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
432,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
445,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
111,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
78,Den Haag, Jacob Catsstraat	0	0	0	0	0	0	0	0	0
1092,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
16,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
15,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
61,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	0	0	0	0	0	0
175,Den Haag, Centraal Station Beneden	0	0	0	0	0	0	0	0	0
146,Den Haag, Centraal Station Beneden	0	71	0	0	0	0	0	71	0
444,Den Haag, Malieveld	71	0	0	0	0	0	0	0	0
433,Den Haag, Malieveld	71	0	3	0	0	0	0	0	3
443,Den Haag, Dr. Kuyperstraat	67	0	0	0	0	0	0	0	0
434,Den Haag, Dr. Kuyperstraat	67	0	4	0	0	0	0	0	4
442,Den Haag, Javabrug	63	0	0	0	0	0	0	0	0
435,Den Haag, Javabrug	63	0	3	0	0	0	0	0	3
441,Den Haag, Laan Copes van Cattenburch	60	0	0	0	0	0	0	0	0
436,Den Haag, Laan Copes van Cattenburch	60	0	3	0	0	0	0	0	3
437,Den Haag, Riouwstraat	57	0	2	0	0	0	0	0	2
440,Den Haag, Riouwstraat	55	0	0	0	0	0	0	0	0
439,Den Haag, Madurodam (Noord)	55	0	0	0	0	0	0	0	0
438,Den Haag, Madurodam (Noord)	55	0	0	0	0	0	0	0	0
461,Den Haag, Madurodam (Noord)	55	0	6	0	0	0	0	0	6

Table C.4: Flow difference after implementing measure on line 9 to Zwarte Pad - continued (Saturday)

Tram stop	**Pass.**	**#1 Board**	**Last Alight**	**Ch. Board**	**Ch. Alight**	**Walk Board**	**Walk Alight**	**Sum Board**	**Sum Alight**
460,Den Haag, Wagenaarweg	49	0	0	0	0	0	0	0	0
462,Den Haag, Wagenaarweg	49	0	1	0	0	0	0	0	1
464,Den Haag, Nieuwe Duinweg	48	0	4	0	0	0	0	0	4
458,Den Haag, Nieuwe Duinweg	44	0	0	0	0	0	0	0	0
1088,Den Haag, Circustheater	44	0	10	0	0	0	0	0	10
1,Den Haag, Kurhaus	34	0	0	0	0	0	0	0	0
74,Den Haag, Kurhaus	34	0	30	0	0	0	0	0	30
75,Den Haag, Zwarte Pad Uitstaphalte	4	0	4	0	0	0	0	0	4
41,Den Haag, Zwarte Pad	0	0	0	0	0	0	0	0	0
Total	**0**	**71**	**70**	**0**	**0**	**0**	**0**	**71**	**71**

Table C.5: Flow difference after implementing measure on line 9 to Zwarte Pad (Sunday)

Tram Stop	Pass.	#1 Board	Last Alight	Ch. Board	Ch. Alight	Walk Board	Walk Alight	Sum Board	Sum Alight
426,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
452,Den Haag, De Dreef	0	0	0	0	0	0	0	0	0
451,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
427,Den Haag, Beresteinlaan/Melis Stokelaan	0	0	0	0	0	0	0	0	0
450,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
428,Den Haag, Revalidatiecentrum	0	0	0	0	0	0	0	0	0
429,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
449,Den Haag, Wolweversgaarde (Tram)	0	0	0	0	0	0	0	0	0
161,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
186,Den Haag, Leggelostraat	0	0	0	0	0	0	0	0	0
185,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
162,Den Haag, Leyweg/Melis Stokelaan	0	0	0	0	0	0	0	0	0
184,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
163,Den Haag, Loevesteinlaan (Noord)	0	0	0	0	0	0	0	0	0
430,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
448,Den Haag, Zuiderpark/Melis Stokelaan	0	0	0	0	0	0	0	0	0
447,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
431,Den Haag, Anna Bijnslaan	0	0	0	0	0	0	0	0	0
446,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
432,Den Haag, Dynamostraat	0	0	0	0	0	0	0	0	0
445,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
111,Den Haag, Wouwermanstraat	0	0	0	0	0	0	0	0	0
78,Den Haag, Jacob Catsstraat	0	0	0	0	0	0	0	0	0
1092,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
16,Den Haag, Station Hollands Spoor	0	0	0	0	0	0	0	0	0
15,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
61,Den Haag, Bierkade (Oost)	0	0	0	0	0	0	0	0	0
145,Den Haag, Kalvermarkt-Stadhuis	0	0	0	0	0	0	0	0	0
175,Den Haag, Centraal Station Beneden	0	0	0	0	0	0	0	0	0
146,Den Haag, Centraal Station Beneden	0	55	0	0	0	0	0	55	0
444,Den Haag, Malieveld	55	0	0	0	0	0	0	0	0
433,Den Haag, Malieveld	55	0	2	0	0	0	0	0	2
443,Den Haag, Dr. Kuyperstraat	53	0	0	0	0	0	0	0	0
434,Den Haag, Dr. Kuyperstraat	53	0	3	0	0	0	0	0	3
442,Den Haag, Javabrug	50	0	0	0	0	0	0	0	0
435,Den Haag, Javabrug	50	0	3	0	0	0	0	0	3
441,Den Haag, Laan Copes van Cattenburch	47	0	0	0	0	0	0	0	0
436,Den Haag, Laan Copes van Cattenburch	47	0	4	0	0	0	0	0	4
437,Den Haag, Riouwstraat	43	0	2	0	0	0	0	0	2
440,Den Haag, Riouwstraat	41	0	0	0	0	0	0	0	0
439,Den Haag, Madurodam (Noord)	41	0	0	0	0	0	0	0	0
438,Den Haag, Madurodam (Noord)	41	0	0	0	0	0	0	0	0
461,Den Haag, Madurodam (Noord)	41	0	4	0	0	0	0	0	5

Table C.6: Flow difference after implementing measure on line 9 to Zwarte Pad - continued (Sunday)

Tram Stop	**Pass.**	**#1 Board**	**Last Alight**	**Ch. Board**	**Ch. Alight**	**Walk Board**	**Walk Alight**	**Sum Board**	**Sum Alight**
460,Den Haag, Wagenaarweg	37	0	0	0	0	0	0	0	0
462,Den Haag, Wagenaarweg	37	0	0	0	0	0	0	0	0
464,Den Haag, Nieuwe Duinweg	36	0	4	0	0	0	0	0	4
458,Den Haag, Nieuwe Duinweg	32	0	0	0	0	0	0	0	0
1088,Den Haag, Circustheater	32	0	12	0	0	0	0	0	12
1,Den Haag, Kurhaus	20	0	0	0	0	0	0	0	0
74,Den Haag, Kurhaus	20	0	18	0	0	0	0	0	18
75,Den Haag, Zwarte Pad Uitstaphalte	2	0	2	0	0	0	0	0	2
41,Den Haag, Zwarte Pad	0	0	0	0	0	0	0	0	0
Totaal	**0**	**55**	**55**	**0**	**0**	**0**	**0**	**55**	**55**

D

D: Results interviews

In this chapter qualitative, in-depth information is presented, collected by means of two interviews with two PT operators; HTM and NS. The interview with HTM took place on the 2nd of February 2022 and the interview with NS took place on the 3rd of February 2022. Information retrieved from the interviews will provide an answer to the third sub-question: *What is missing in single operator smart card data to accomplish having better transfers between different PT operators?*. This chapter starts with an elaboration on the single operator smart card datasets and the use of these datasets. This is followed by an elaboration on the multiple-operator smart card datasets and their opportunities. Thirdly, a comparison will be made between single- and multiple operator smart card datasets. Thereafter the proposed ideal situation from the perspective of PT operators will be sketched.

D.1. Single operator smart card datasets

In this section the single operator smart card datasets will be elaborated on. Firstly, an elaboration on the use of these datasets will be given. This is followed by an overview of the attributes that the datasets does and does not consist of. Lastly, an elaboration on the insights of what the operators can not get from these datasets will be elaborated.

Usable insights

Single operator smart card datasets are used by both HTM and NS. The most important goal of using these datasets is to develop a substantiated transportation plan where the modifications of the following year will be developed and communicated to the client (Interview HTM) and to optimize the timetable (Interview NS). The single operator smart card dataset for HTM is used to determine the occupancy rates of PT lines and vehicles (Interview HTM). By exploring these rates, decisions will be made on whether the frequency of specific PT lines need to increase, (when there is a higher occupancy rate) decrease (when there is a lower occupancy rate) or remain constant.
The single operator smart card dataset for the NS is used in a similar way, to identify the highest traveler flows and also to identify the most important transfers between the NS trains. Timetable optimization is then done as follows. First, designing the timetable as good as possible for the user and second, to determine where the materials (trains, units etc) need to be deployed (Interview NS). If from the single operator smart card data NS is able to see that more and more travelers are using a specific train line, they can choose to plan and deploy more train units on that specific line to transport the travelers as efficiently as possible. So, whereas HTM is using the single operator smart card dataset to see if the frequencies of the lines needs to be changed, NS is (also) using it to see if the trains need a change of materials such as changing train units.
Furthermore, the single operator dataset can be used for multiple other reasons, such as exploring the number of check-ins at a specific stop in order to create an optimal design, or to change the timetable and coupling those with specific school times (Interview HTM).

Attributes

Check-in and check-out time, the date, the stop (HTM), the product on the smart card, vehicle number (HTM), trip ID (HTM) and check-in gate (NS) are attributes included in the single operator smart card

datasets of HTM/NS (Interview HTM; Interview NS). This data can be used in applications where it can be compared with the timetable and thus an estimation can be made to determine where the vehicle drove and which vehicle travelers have been used (Interview NS). The ID numbers of the smart cards are not visible in the data for the operators because those can be traced back to the individual traveler, which is not allowed due to privacy regulations (in the Netherlands) (Interview HTM; Interview NS).
A following limitation due to these privacy regulations is that there is no information about the exact origin and destination of travelers' journey. It is therefore unknown where the travelers are exactly coming from/to or what their goal of their journey is (Interview HTM).

Insights that can not be derived
There are insights that operators would like to see but which cannot be provided by the single operator smart card datasets, mostly due to the privacy regulations that are involved.
First of all, it is not possible to identify the exact origin and destination of the traveler's journey, therefore the operators do not know whether the travelers depart from or travels to within or outside the region (Interview HTM). This is also of importance to coordinate the access- and egress transport. Right now there are some insights in the access- and egress transport, however this is mainly based on surveys, meaning that the data is based on samples and thus may not fully represent the population (Interview NS). Another insight is that it is not possible to get an accurate insight of the age of the travelers. Although these datasets do have information about the product (e.g., student, elderly, business), the exact age is unknown. This is especially important for the elderly as someone can be 65 years old or 85 years old while having the same product on their smart card. However, an 85 year old traveler is likely to be less mobile than a 65 year old traveler (Interview HTM). This is valuable information for the operator as they can adapt their network or vehicle accordingly. Furthermore, parallel tracks (tracks by different operators parallel to each other) are not fully represented in the insights derived from single operator datasets (Interview NS). Lastly, and one of the most relevant finding is the inability of a single-operator smart card dataset to develop better transfers between different operators, especially when a proper substantiation is desired.

D.2. Multi-operator smart card datasets

In this section the multiple operator smart card datasets will be elaborated on. In the first part (potential) insights of these datasets will be elaborated on. The second part considers if and in what way the operators are already using multiple operator smart card datasets.

(Potential) insights
Having multiple operator smart card dataset enables an operator to see transfers between lines of its own and the line of the other operator in the dataset. By knowing these transfers and the details (number of transfers, the transfer time) the operator can determine if the timetable needs to be changed to the specific transfer. This would be mainly the case for low-frequency lines (evenings) as for these lines it is easier to design optimal transfers. By analysing the transfer flows the operator can see if travelers are structurally taking the specific transfer. Then it can be determined if changing the timetable for an optimal transfer is valuable or not (Interview HTM). It would, furthermore, be possible with these datasets to get extra information about the parallel lines and the access- and egress transport in the bigger cities. Especially in cities with a complex network and different mode choices to travel from A to B it is often not easy to get a good view on the details without a multiple operator smart card dataset. Furthermore, a multiple operator smart card dataset allows for even better market insights (next to having a single operator smart card dataset) (Interview NS).

Usability
The use of multiple operator smart card datasets is uncommon among the operators within this research (Interview HTM; Interview NS). At most, a multiple operator smart card dataset will be requested to work on a specific problem that involves two operators (Interview NS). The data obtained and used in this research is a so-called pilot dataset to explore what insights can be gathered and if such a dataset is in the end of the process of sufficient added value or not (Interview HTM; Interview NS). The process to get a multiple operator smart card dataset takes a lot of time, work and also money (mainly man hours costs) (Interview HTM). Furthermore, such data consist of company-sensitive information. Besides, operators need to take into account competition rules, one may not simply give insights to one other

operator, especially if those are beneficial for your own business' strategy (Interview NS). Also, it is often difficult to get a similar detail of the data of the other operator with these datasets. Therefore you have to select the data that allows for a joint picture (Interview NS). Another downside of a multiple operator smart card dataset is, also because of privacy regulations, that the data considers a threshold with respect to the number of travelers. If within a time interval for a specific transfer less than 50 (sometimes 30 or 40) travelers are making this transfer, this will be noted as "lower than 50 travelers". Therefore, you do not know if 49 or 1 traveler(s) are making this transfer within that specific time interval. All in all, working with multiple operator smart card datasets involved numerous insecurities, which is why its use is uncommon.

D.3. Comparison of single- and multiple operator smart card datasets

In single operator smart card datasets all travelers that travel in the network of the same operator can be detected. This includes transferring travelers within the network, i.e. traveling with the same operator (Interview HTM). With a multiple operator smart card dataset the transferring travelers that travel between different PT operators in the network can be detected. So a multiple operator smart card dataset can complement a single operator smart card dataset with additional information about travelers coming from or going to a different operator. While operators are using a single operator smart card dataset to develop a transportation plan and timetables, the multiple operator smart card dataset can provide even more insights to facilitate this development. If an operator for example observes a high number of travelers from a central station (which is often a transfer station) towards a specific bus, tram or metro (BTM) line and this is only the case for a few vehicles on specific times, than such observations can be tested with a multiple operator smart card dataset to examine if these high number of travelers are transferring passengers from the train. If this is the case, then these transfers may be optimized by letting the BTM line connect to this specific train (Interview HTM). These are ideas where a multiple operator smart card datasets can contribute to better transportation plans and timetables. However, for some operators a part of the transferring travelers can already be observed in a single operator smart card dataset. This is because for some transfers and for specific operators, no entry fee is needed when you check-in while this is the case if a traveler starts their journey (Interview HTM). This is however case specific and does not apply for every transfer. Furthermore, this would only be the case for travelers transferring into the system and not transferring out of the system. Besides, this only counts for the travelers that normally do pay entry fees as well (Interview HTM).
Things that still cannot be seen with a multiple operator smart card dataset are insight of the age of travelers just as the exact origins and destinations. This is because of privacy regulations which are still in force when using a multiple operator smart card dataset. However, with a multiple operator smart card dataset the operator gets additional information about the directions of where the travelers are traveling from or traveling to, so information about the origin and destination of the traveler is more specific than before.

D.4. An ideal smart card dataset

Operators would like to have a smart card dataset that can contribute to getting the best transportation plan and timetable (train units, frequencies, times etc) (Interview NS). There is already a lot of information that is valuable from single operator smart card datasets, however, if additional information can be obtained where from/to travelers are transferring, it would certainly be of valuable information which would enrich the analysis (Interview HTM). In an ideal situation insights of smart card data from other operators are known (Interview HTM).
Furthermore, if there were no privacy regulations, operators would like to have more personal information of the travelers. What their travel behaviour is: how often they travel, what their origin and destination is, why they make a specific journey/trip and what the age of the traveler is (Interview HTM; Interview NS). Operators do not only want to know this for optimizing their transportation plans and timetables, but also for marketing. If such information is known, specific campaigns can be done to get (specific) travelers more in the PT. This could even lead to a lower share of car users which is beneficial for the environment.

D.5. Improving the single operator smart card dataset

Operators, HTM and NS, strive to have the best transportation plans and timetables. Single operator smart card datasets do have a lot of information to optimize these plans and timetables. They miss however substantiated data to analyse transfers between different operator(s) which is available in a multiple operator smart card dataset. This would give more valuable information to make the transportation plans and timetables even better. While each operator has its own smart card dataset and do not have information of other operators' dataset, they need to couple these datasets to get to those extra information about the transfers between a different operator. All in all, a multi-operator smart card dataset that contains both transfers between the operators as well as the transfers of the same operators (single operated data) would be ideal to identify transfers. From an interview with Translink this is possible (interview Tranlink).

D.6. Conclusion

This chapter summarised qualitative, in-depth information derived from interviews with HTM and NS to provide an answer to the third sub-question: *What is missing in single operator smart card data to accomplish having better transfers between different PT operators?*

A single operator smart card dataset does not have (complete) information about travelers that transfer between different operators (Interview HTM; Interview NS). In a single operator smart card dataset the operators cannot observe (properly) where their travelers are going to or are coming from and if they are traveling out of their system. Operators may have assumptions of where the most important transfers between different operators are but they do not have access to exact and substantiated data for this (interview NS; interview HTM). However, by having such information the operators can develop their transportation plans and timetables even better and more accurate.

In single operator smart card datasets, details about the travelers are not known. If individual transferring travelers can be followed and personal information about these travelers can be obtained, better transfers can be facilitated. However, this is not allowed due to privacy regulations. This means that such data is not included in smart card datasets (Interview HTM; Interview NS). This may however be different in other countries with other cases.

All together, single operator smart card data is missing substantiated data of the coupled journeys of multiple operators. Data that includes the flows and the transfer times between trips of different operators would help accomplishing better transfers between different PT operators. Furthermore, more exact origin and destination information and personal information of the traveler do help accomplishing better transfers between different PT operators as well.

Due to the privacy regulations, personal information about the travelers are also not included in a multiple operator smart card dataset. Nevertheless, a multi-operated smart card dataset can contribute to a single operator smart card dataset in identifying and examining the transferring flows from different operators. By doing so, transportation plans and timetables can be developed even better which may result in better facilitated transfers between different PT operators. The ideal smart card dataset would be a multi-operated smart card dataset that includes single-operated smart card data as well including data of personal information.