

NETWORK OPTIMIZATION BASED ON TRIP PURPOSE

Public transport network optimization based on towards trip purpose differentiated passenger groups

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Delft University of Technology
Master Transport, Infrastructure and Logistics
Thesis report

TU Delft



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INFORMATION

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PREFACE

This document is the crowning glory of 20 years of education. It is the Master thesis that I wrote to obtain my Master of Science degree in Transport, Infrastructure and Logistics (TIL) at the Delft University of Technology under the supervision of Professor Bart van Arem as chair of my graduation committee. Rob van Nes and John Baggen were my daily supervisors. With their knowledge and great help, I have written this thesis.

I've worked with the greatest pleasure on my thesis. I have tried to combine my scientific knowledge from my Bachelors Degree of Urban Planning which I obtained at the University of Amsterdam and the knowledge that I gathered at the educational program of TIL at the Delft University of Technology.

In my research, I aimed to combine both the technical approach of optimizing a public transport network and the social approach of the human dimension in public transport. Those two approaches are inextricably connected to each other. I will show that I have aimed to link them together in this research about public transport optimization based on passenger groups differentiated towards trip purpose.

This thesis was written in cooperation with Movares Consultants & Engineers. Movares –as the name suggests– is specialized in both designing and advising on civil engineering projects and infrastructure. It is not without the inexhaustible help of my supervisor Nicole van der Velden (Movares) that I have managed to do so. Her indefatigable motivation has been a great help to come to this result. Nicole managed time after time to guide me in the right direction. Not by telling me what to do, but by asking critically questions on why and how I was going to take the next step. She managed to hold up a mirror to show me the weak spots of my working methods. Her approach resulted not only in this document, but gave me the opportunity to actually face those weak spots and to improve mu professional skills.

Other colleagues of Movares that were of great help are Chris Verweijen and Henk Bakkenes. Chris was always willing to help me with questions regarding tram networks and operations and Henk was of great help with running the omniTRANS models.

One of the most important pillars of this research was a stated preference survey that was conducted among tram passengers in Rotterdam. I could never have done this by myself and therefore I would like to thank Laura Groenendijk, Koen van Tongeren and in particular Daphne Kerpel. Daphne was my moral support during the full length of the process in which I wrote this thesis.

This thesis could not have been established without the help of Jeroen Henstra from the public transport operator RET. Jeroen was willing to check my data sets of passenger usage. He was also of great help during the stated preference survey by giving advice, tips and tricks. And above all, for granting permission to conduct the stated preference survey at tram stops.

Other people that I would like to thank are of course my partner Joachim Kost, my parents that have supported me during all those years of education and my friends that were always willing to support me and listen to me. And last but not least, Arthur Scheltes, who helped me with the lay-out of this document.

EXECUTIVE SUMMARY

There is a need to optimize public transport due to cutbacks in the financial structure of public transport (Van Oort & Baas, 2011). The trend for more free market in the organization of public transport changes the perspective of financing public transport (Den Hollander & Baggen, 2012). The reduction of financial sources demands the system to optimize, in order to assure its existence and continuity. Besides, urban public transport systems do not function as optimally as they were originally designed, nor as hypothetically possible (Ministry of Transport, Public works and Water management, 2010; SRR, 2009). Nowadays, many studies have been conducted about optimizing public transport systems. Some examples of the leading research on optimizing public transport are studies by Van Nes & Bovy, 2000; Van Nes (2002), Mandl (2003) and Schöbel (2006).

By studying previous researches on optimizing public transport and its users, a gap of knowledge is observed in scientific research in the field of system optimization of public transport (Kocur & Hendrickson, 1982; Chang & Schonfeld, 1991 and Spasovic et al., 1994). These and other previous research have often approached network optimization from the perspective of one whole passenger group. However, network optimization approach from the perspective of towards trip purpose differentiated passenger groups instead of one general passenger group, could lead to better results, since each trip purpose group has specific transport demands and characteristics. The distinguished groups are (1) workers, (2) students, (3) shoppers and (4) others. For example, shoppers don't want to walk long distances to the stop, while workers are more concerned with the total travel time. This information is useful when one would like to optimize or rationalize a public transport system.

This thesis aims to find a more accurate approach of optimizing public transport systems . There is a particular interesting field in the public transport network that is suitable for network optimization. There is a gain in enlarging and optimizing stopping distances, since larger stopping distances result in faster operation in the network (SRA, 2010; SRR, 2012; OVpro [2], 2014). Trip purpose and passenger usage of public transport is related to stopping distances. The distance that one is willing to bridge to a stop is related to the trip purpose, as the example above states. Thus, there exists a relation between stopping distances and the willingness to bridge the distance, based on trip purpose.

Moreover, a number of analytical network optimization methods concluded that operation could be optimized or rationalized when stopping distances are enlarged (Black, 1978, Furth & Rahbee, 2000; Egeter, 1995; Van Nes & Bovy, 2000). From analytical network rationalization, there is an opportunity in enlarging stopping distances. However, these approaches often have difficulties in actually implementing longer stopping distances, due to the refractory topological urban environment. Analytical approaches often lead to general rules of thumbs about stopping distances. For example, this could result in a situation where a shopping center ends up just between two stops, since the general stopping distance was set at 600 meters. Therefore, there is a chance in optimizing a public transport network based on the trip purpose of passenger groups.

This leads to the following main question that is aimed to answer:

To what extend does the use of passengers groups differentiated towards trip purpose contribute to public transport network optimization, with respect to the travel demand of differentiated passenger groups?

It makes sense to approach this research question from both scientific point of view and passenger point of view. The scientific approach is concerned with quantitative network rationalization that results in stop elimination. Meanwhile, the passenger point of view involves qualitative needs and demands towards public transport, expressed in willingness to bridge distances from and towards a public transport stop. This thesis aims to address both fields.

To succeed in achieving this goal, there is a focus on optimization of public transport which is called the *network assessment.* The network assessment aims to optimize stopping distances from a quantitative scientific point of view, with the incorporation of differentiated passenger groups and the urban environment.

Passenger loss is inextricably connected with network optimization, since longer access times and distances will hypothetically result in a partial passenger loss, because longer access distances confine the willingness to bridge those distances (O'Neill et al.,1992); Zhao et al., 2003; Kuby et al., 2004; Schlossberg et al., 2007); Van der Blij et al., 2010; El-Geneidy et al., 2013). Therefore, the second focus of this thesis is on passenger point of view. This topic is addressed in the *passenger assessment*. The passenger assessment aims to find the loss of passengers per passenger group. Moreover, the results of the passenger assessment also suggests a range of compensation measures that hypothetically should prevent fallback of transport usage.

The next two sections do briefly address the process description of the two assessments. Both of the assessments have been applied to a case (tram network in the Dutch city of Rotterdam) to verify the results of the methodology. The results of the case study are displayed *in italic* in every step.

NETWORK ASSESSMENT

An existing stop distance method developed by Wagner (2014) is adapted and applied to optimize stopping distances. The Wagner-method is particular interesting because it links actual passenger usage to stop achievement. The achievement is based on the stop usage versus the amount of in-vehicle passengers that passes by the stop. The recently developed method created the opportunity to test and extend the method.

The method quantifies the effects of stop closing into a Benefit Costs-ratio (BC-ratio). The benefits are expressed as the travel time reduction in seconds for in-vehicle passengers. The cost side is based on additional walking time for passengers that have to access the transport mode via an adjacent stop. If the benefits are larger than the costs, the Benefit Cost-ratio exceeds 1 and theoretically the stop could be closed.

The original method was considered to be incomplete, since it does not fully covers the goal of the network assessment. There is no incorporation of differentiated passenger groups and there is no link towards the urban topological environment. Furthermore, the method only addresses the stop level and not the line and network level. Therefore, the method was extend with the latter two mentioned levels. Moreover, this assessment incorporates the effects of stop closure on line level and even on network level in terms of gain (travel time gain for passengers) and loss. The next section describes the processes of each methodology applied on each level; the stop level-methodology, the line level-methodology and the network level-methodology.

STOP LEVEL

Adaptations to the stop level-method were made so that differentiated passenger groups could be incorporated in the BC-ratio, which resulted in a BC_n-ratio per passenger group (where the n stands for a work, school, shop or other trip purposes). This method mainly focuses on stops that should be abrogated based on the BC-ratio but are nonetheless profitable for a certain group of travelers. Furthermore, the stop level-method was extended with a method to calculate passenger loss on stop level, based on willingness to bridge larger distances to adjacent stops and the resistance to do so.

The stop level-method found 172 stops that are candidate for closure, based on the BC-ratio. 111 of these stops have a BC_n-ratio which is smaller than one and thus profitable for a certain passenger group. 50 stops have a BC-ratio bigger than one in both directions.

LINE LEVEL

The stop level-method evaluates each stop separately. This could result in an advice in which rows of stops should be eliminated. However, the elimination of one stop has consequences for the BC-ratio of adjacent stops, since stop distance increases and because it is likely that passengers of the particular closed stop will (partially) spread over adjacent stops. Therefore, this methodology aims to find a method that prevents the elimination of rows of stops. This method was found in applying a greedy algorithm on line level.

This method answers the problem of rows of stops, since it eliminates one stop at the time (with the highest BC-ratio) and then checks the BC-ratio of adjacent stops. By applying this method, the BC-ratio of those adjacent

stops could lower below one, which would *save* the stop from elimination. This process continues until all stops in the particular row are eliminated or saved.

An extra distance constraint is suggested that prevents too large gaps between stops. This constraint can be suggested by the transport authority. In this research, two additional constraints (of 600 and 800 meters) were applied to show the effect.

11 stops of the 50 stops from the stop level-method are saved by the line level-method.

NETWORK LEVEL

On a network level, the stops that are proposed to be eliminated on stop and line level are eliminated. By applying this model, the differences in passenger usage (before and after stop closure) can be checked and compared with the expectations of loss per stop as calculated in the first step on stop level. The network level check verifies the stop level-method, since the effects of stop closure are modeled network wide. Furthermore, the network level checks usage rates over the whole network to check if no deterioration of the network takes place. The network level-approach was conducted by use of the transport simulation software omniTRANS.

The network level-method was solely used to verify the results of the stop and network level. The method proved that the adaptations on these levels does not lead to impoverishment on network level. Therefore, this level does not has to be applied in other cases.

Due to the goal of this study (involve the urban environment in the case), each stop that is proposed for elimination, is checked on network function and urban function. The network function could save the stop, based on interchange function towards other lines. The urban environment function assured stop locations near important locations, such as schools, hospitals and etcetera. The composition of these function depends on the policies of the authority and the operator. But by only applying this step in the last stage of the network assessment, the opportunity is created to discuss the necessity of those stops, even if they are requested by the operator or the authority.

The network level-method found that passenger loss was not as high as expected from theory on stop level. Losses at stops lingered around the 8% to 10%, while the initial stop level-method suggested losses up to 40% to 50%. Furthermore, the network level-method even found increases in transport usage on network level by 2% to even 8%, due to shorter travel times over the whole line.

12 stops have a network-function and are preserved for that function.

As stated in the introduction, this thesis addresses both network rationalization and the effects for differentiated passenger groups to check the consequences. The next section summarizes the processes conducted in the passenger assessment.

PASSENGER ASSESSMENT

Quantitative network rationalization has consequences for the passengers that use the public transport. Public transport has a function to provide transport and network rationalization limits this function partially.

In-vehicle passenger benefit from stop closure, since it reduces their travel time. However, passengers that use a stop that should be closed, are hindered in their travel behavior. Therefore, the passenger assessment aims to determine the consequences of passenger loss in case of stop closure. The applied method to obtain results is a Stated Preference-survey. The passenger assessment aims to find compensations that could reduce the passenger loss. The result of the passenger assessment is a passenger engagement plan that consists compensating measures to 'ease the pain' of stop closure.

The level of passenger loss observed among participants is the most important goal of the passenger assessment. Furthermore, the passenger assessment observes the willingness to travel if certain compensation measures are proposed. These measures are (1) a financial compensation, (2) a better waiting room at adjacent stops and (3)

bicycle parking at adjacent stops. In addition, a (4) higher frequency was added to the SP-survey in the case on request of the operator.

The stated preference survey was conducted among 228 participants on different stops on the network. 52 workers, 55 school-going, 45 shoppers and 76 others. Stops selected for the SP-survey have a BC-ratio bigger than one and a BC_n-ratio as small as possible to assure that the –for the particular differentiated passenger group useful stop- is present at the stop. Due to operational constraints on overall present passengers, in some cases other stops have been chosen.

PASSENGER LOSS FOUND IN PASSENGER ASSESSMENT

The SP-survey stated questions on the acceptability of stop closure. By executing the SP-survey, per compensation measure, passengers were asked on their willingness to travel. This was also asked in case of no compensation.

This resulted in an overview per passenger group about the willingness to travel per compensation measure. Furthermore, respondents in the SP-survey were also asked about other profile data, such as age, daily activity, dependency on public transport, type of ticket and other available transport modes.

The results show that the working group and school-going group consider their travel time as important and value it high, therefore, these groups are willing to travel to adjacent stops, if their particular stop is closed. This implies that stop closure is accepted among the majority of these passenger groups. Shoppers however, are less willing to bridge those bigger distances and therefore loss rates is higher among these group.

Moreover, the results of the SP-survey showed even a willingness to travel more with public transport, if some compensation measures were applied (frequency increase for example). However, the SP-survey did not gave insight in this growth. This growth could come from a changed distribution of mode choice for the same trip purpose, which means that passengers would travel more by the particular mode to their destination. Another possibility is that these passengers would use public transport for other purposes as well.

It has not been proven that compensation is necessary to prevent passenger loss. The biggest passenger groups (work and school) are willing to access via adjacent stops. Closing stops leads only to minor losses among the groups of workers and students (respectively 19% and 20%). The group with the biggest loss (shoppers, 38%) in this case consist of the smallest absolute number of passengers in the network (only 7% of all passengers), which results in minor overall losses.

The next section continues on compensation.

POSSIBLE COMPENSATION MEASURES

The compensation measures were found in literature. A meta-analysis among recently built or extended public transport systems resulted in an overview of possible compensation measures. The passenger assessment found results on compensation measures dedicated for specific passenger groups. The results show a clear connection between the type of proposed compensation and the appreciation for it.

Compensation on reducing waiting time is valued the best by the above mentioned groups, which is translated to higher frequencies in this case (33% increase among workers and even 45% increase among school-going passengers). So, if a stop needs to be removed which is mainly serving these groups of passengers, frequency increase is the best step. Better comfort is a good second option. Doing nothing results in minor losses (up to 20%).

Passengers with the trip purpose 'shopping' are less willing to travel to adjacent stops than the other groups. Up to 60% of the participants travel less or no more at all. Moreover, compensation for this group is less effective. Shoppers are less sensitive to compensation, since the loss of passengers remains high, regardless the type of compensation measure.

RESULT EVALUATION

Closing stops will inevitably –according to the network level-method and the passenger assessment- lead to a loss of passengers. To verify the figures on passenger loss that were suggested by both the stop level-method and the line level-method, a passenger assessment was conducted. Furthermore, this assessment also seeks for possible compensation measures to prevent fallback of transport use. The next section explains the results of both methods.

PASSENGER LOSS

Passenger loss was calculated in three ways. At first, the stop level method calculates passenger loss per stop. Subsequently, modeling the adjusted network (including closed stops) on network level gives new transport usage data. This data contains the spread of passengers over the adjacent stops. Finally, the passenger assessment gives an overview of passengers' reactions towards stop closure and their expected travel behavior.

The proposed method to calculate passenger loss on stop level was considered to be too inaccurate. The losses calculated on stop level did not match the observed rates of passenger loss on network level and in the passenger assignment. Figures of passenger loss were subsequently overestimated by the applied method. Therefore, solely a method to calculate passenger loss is proposed for stop level, while no results have been generated by this method.

The passenger loss as calculated in the network assessment on stop level differs strongly from the observed passenger loss on network level and in the passenger assessment. The latter two approaches give overall lower loss figures.

Furthermore, the loss per group differs as well per differentiated passenger group. While working and school-going passengers mainly remain traveling if their stop is closed, the shoppers are less willing to bridge longer distances to adjacent stops. Meanwhile, shoppers are less constrained in making a trip. They do not have the high need to perform the trip, in contrast to the above-mentioned groups. Therefore, this group is less willing to put extra effort in performing their trip.

Application of compensating measures leads to a certain extend to the preservation of passengers and prevents fallback in terms of usage. However, passenger loss among all passengers groups does not result in major differences in loss figures between the different scenarios of no compensation and compensation. Therefore, compensation is possible, but does not seem to be necessary.

DIFFERENTIATING PASSENGER GROUPS

This research found out that differentiating passenger groups is to a certain extend useful for network optimization, since demands and preferences on public transport for differentiated passenger groups are more specified per passenger group. The biggest gain for the operator, based on this research, is that per stop and per passenger group, a decision can be made on either keeping or removing the stop.

However, it must be admitted that the outcomes of the stated preference did not result into proves that differentiating passengers according to trip purpose leads to a better way of optimizing stopping distances according to passenger groups. Besides the observation that there exists a difference in passenger loss and compensation appreciation between workers and school-going passengers on one hand and shopper on the other hand, no results were found that prove that trip purpose differentiation leads to different results on optimization than when passengers are approached as one solely group.

OTHER RESULTS

The stop and its function are highly linked to the urban environment. Closing stops near shopping centers for example, will lead to loss of passengers, since those shoppers will chose other transport modes. Meanwhile, this has effect on the urban environment as well, since the use of other transport modes have other consequences

in terms of usage. Moreover, closing stops in areas where workers and students dominantly use public transport, has less effects on other mode usages. Those passengers are more willing to bridge those longer access distances.

Furthermore, by applying those passenger groups on network optimization, decisions on stop removal, which this thesis addresses-, could be made more accurately per stop. the amount of passengers and their trip purpose per stop is known, the existence of the stop can more accurately be justified.

So to answer the main question: there exist a possibility in rationalizing a public transport network, based on trip purpose, since there exists a difference in willingness to bridge a certain distance to a stop based on a specific passenger group. However, the differences between those passenger groups are only strongly visible when the group of shoppers is involved. Furthermore, the observed passenger loss suggests that –expect among shoppers- the loss of passengers is limited among all passenger groups. Furthermore, even an increase of usage was observed over the whole network, due to reduced travel times.

NEW METHOD

Among the results of this thesis, is a new method to optimize stopping distances in urban public transport networks. The method consists of an approach on stop level that evaluates the stop usage (the BC-ratio) and an approach on line level that prevents rows of stops from being removed (greedy algorithm). The network level-method was used to verify the stop level-method and is therefore no part of the new method.

STOP LEVEL

The stop level-method is based on the BC-ratio which is calculated according to the following formulas.

Benefit-Cost Ratio = B/C (BC-ratio) [1]

Where
B= Total Benefit
C= Total cost

$Benefit_n$-$Cost_n$ Ratio = B_n/C_n (BC_nratio) [2]

Where
B_n = Benefit for passenger group n
C_n = Cost for passenger group n

The stop is evaluated as follows:

If B/C> 1, the stop removal should be approved
If B/C< 1, the stop removal should be rejected

The BC_n-ratios are based on the Benefits and Costs per passenger group. In the following formulas, passenger groups are specified towards trip purpose.

$B = P_r * T_r$ [3]

Where
B = generalized benefit
P_r = passengers riding trough (number)
T_r = additional travel time due to stop (constant)

The cost for removing a stop is a function of the number of passengers that is using the stop. These passengers experience an increased travel time, because they have to access the network via another stop.

$C = P_a * T_a * W_a$ [4]

Where
C = generalized costs
P_a = passengers accessing or egressing at stop
T_a = net increase in travel time per person to use adjacent stop
W_a = weight for access time

T_a is the average additional travel time experienced by passengers whose stop is removed and have to access via another stop.

$$T_a = D_{aw}/V_w \quad [5]$$

Where
D_{aw} = average additional walking distance to remaining stops
V_w = average walking speed

The stop's service area is assumed half the distance to the nearest stop in each direction. The method assumes passengers to migrate to the nearest remaining stop after elimination.

$$D_{aw} = (D_n * D_f)/(D_n + D_f) \quad [6]$$

Where
D_n = Distance to near stop
D_f = Distance to far stop

The result is a list of stops that has a BC-ratio higher than one and is thus candidate for elimination. Only stops ready for elimination in two directions are actual candidate for close. The next step explains the line level method.

Annex 10 consists a suggestion to recalculate passenger loss. However, the used parameters in this thesis showed that the loss was calculated in an unrealistic way. Therefore, the method could be applied according to the explanation in annex 10, but the parameters need to be revised.

LINE LEVEL

This step does not distinguishes stops with BC > 1 and stops with BC > 1, $BC_n < 1$, since both types of stops are candidate for elimination. Therefore, the greedy algorithm does not make distinction between stops that perform overall badly and stops that perform badly, but have at least one group of passengers that do has stake in keeping the stop. Stops that are eliminated by the greedy algorithm are also candidate for compensation measures (discussed in the passenger assessment). The following steps must be conducted to perform the line level-methodology if a row of stops has been discovered:

1. Select the stop with the highest BC-ratio;
2. Change the stopping distances between the selected stop and the adjacent stops in such a way that they become new consecutive stops;
3. Calculate passenger distribution over adjacent stops;
4. Eliminate original stop and check the new BC-ratios of the former adjacent stops;
5. The process stops when all stops with BC-ratio > 1 are gone either through removal or due to passenger increase.

By incrementally removing the stops with the highest BC-ratio, other stops get the 'opportunity' to reduce their BC-ratio, because passengers redistribute over the adjacent stops. The calculation of passenger redistribution is done via a ratio based on the stopping distances between the near stop and the far stop. This ratio is calculated as follows:

- Near stop ratio: (additional walking distance / near stop distance) * 100%
- Far stop: (additional walking distance / far stop distance) * 100%

The final result is a list of stops that could be eliminated. However, as concluded above, the consequences of stop closure depend on the involved passenger group and therefore the decision of closing a stop should be carefully considered, since the consequences of passenger loss differ per passenger group.

TABLE OF CONTENTS

PART A

1 Introduction to the research 1

2 Problem statement 2

3 Research 4

3.1 Research goal 4

3.2 Research questions 4

3.3 Deliverable 4

3.4 Problem owner 4

3.5 Case study 4

3.6 Scientific relevance 4

3.7 Societal relevance 5

3.8 Scope and research boundaries 5

4 Study approach 7

5 Conclusion 8

PART B

6 Public transport 10

6.1 Institutional playing field 10

6.2 Goals of public transport 11

6.3 Changes in the system 11

6.4 Changes of costs and benefits 12

6.5 Rationalizing the public transport system 14

6.6 Rationalizing stopping distances 14

6.7 Concluding remarks 16

7 Networks 17

7.1 Network concept 17

7.2 Goals of optimization 18

7.3 Modeling stop distance optimization 18

7.4 Network assessment 19

7.5 Selected model 20

7.6 Concluding remarks 20

8 Passengers 21

8.1 Differentiating passenger groups 21

8.2 Differentiation towards trip purpose 21

8.3 Characteristics of differentiated passenger groups 22

8.4 Passenger assessment 23

8.5 Selected method 24

8.6 Attributes of SP-survey 24

8.7 Concluding remarks 27

9 Conclusion 29

PART C

10 Generic methodology overview 31

10.1 Case analysis 31

10.2 Network assessment 31

10.3 Passenger assessment 31

11 Generic case analysis 33

11.1 Quantitative data 33

11.2 Qualitative data 34

12 Generic network assessment 36

12.2 Original assumptions 37

12.3 Adaptations to original method 38

12.4 New assumptions 41

12.5 Adapted method overview 42

12.6 Parameters 43

12.7 Expectations 44

12.8 Result evaluation 44

12.9 Sensitivity analysis 45

12.10 Concluding remarks 45

13 Generic passenger assessment 46

13.1 Stated preference surveys 46

13.2 Attributes of SP-survey 47

13.3 SP-survey compensation attributes 48

13.4 Research structure 48

13.5 Experiment lay-out 50

13.6 Expectations 51

13.7 Concluding remarks 51

14 Conclusion 52

PART D

15 Introduction to the case: Rotterdam tram network 54

15.1 Case requirements 54

15.2 Case selection 54

16 Case analysis of Rotterdam tram network 56

16.1 Quantitative data 56

16.2 Qualitative data 57

16.3 Concluding remarks 58

17 Rotterdam Case network assessment 59

17.1 Model application 59

17.2 Model results 59

17.3 Result evaluation 62
17.4 Concluding remarks 64
18 Case passenger assessment 65
18.1 compensation attributes of engagement plan 65
18.2 Stop selection 66
18.3 Experiment set up 66
18.4 SP-survey Results 67
18.5 Other differentiations 74
18.6 Concluding remarks 74
19 result analysis 76
19.1 Compensation for closed stops 76
19.2 Keep or eliminate a stop 76
19.3 Evaluating loss of passengers 76
PART E
20 General conclusions 79
20.1 Answers to the sub questions 79
20.2 Answers to the main question 81
20.3 General results 82
20.4 Developed methodology and advice on stop elimination 83
21 Recommendations 85
21.1 Model extension 85
21.2 Focus on more infrastructural components 85
21.3 Incorporate passenger representation groups 85
21.4 New approach of passenger loss on stop level 85
PART F
References 87
Annex 1 – Walking distance to adjacent stop 95
Annex 2 – SP-example 97
Annex 3 – Network function 99
Annex 4 – Stop function 102
Annex 5 – Stopping distance and average speed 105
Annex 6 – OmniTRANS scripts 111
Annex 7 – Stop level 113
Annex 8 – Line level 125
Annex 9 – Results of passenger assessment 127
Annex 10 – K-factor passenger loss 131

LIST OF FIGURES

Figure 3.1 Position of thesis in the scientific field. 5
Figure 3.2 Focus of this thesis. 5
Figure 4.1 Study approach. 7
Figure 5.1 Scope of thesis. 8
Figure 6.1 Triangular relation between the three groups (own illustration. Based on WRR, 2012). 10
Figure 6.2 Consequences of the participation society for public transport. 12
Figure 6.3 User pays more. The icons are illustrative and not scaled (own illustration). 13
Figure 6.4 Other resources. The icons are illustrative and not scaled (own illustration). 13
Figure 6.5 Fewer benefits. The icons are illustrative and not scaled (own illustration). 13
Figure 6.6 Costs that are involved with the operations of public transport (based on Beimborn, n.y.). 14
Figure 6.7 Concept of stop spacing (Li & Bertini, 2009). 15
Figure 6.8 Problem area of network function in this thesis (Based on: Van Nes & Bovy, 2004). 15
Figure 7.1 The network effect visualized (Nielsen & Lange, 2007). 17
Figure 7.2 Method focus (Based on Van Eck et al., 2012). 18
Figure 10.1 Structure of case analysis. 31
Figure 11.1 Measuring methods for stopping distances. 33
Figure 11.2 Catchment area of the public transport stop (based on Landex & Hansen, 2006). 34
Figure 11.3 Barrier in catchment area (based Landex & Hansen, 2006). 35
Figure 12.1 Suggested adaptations for system levels. 38
Figure 12.2 K-factor applied on solely horizontal basis. 39
Figure 12.3 K-factor also applied on vertical basis. 39
Figure 12.4 Network assessment overview. 43
Figure 12.5 Consequences of BC-ratio for adjacent stops near main stops. 44
Figure 13.1 Passenger assessment overview. 47
Figure 13.2 Stop selection process. 50
Figure 15.1 map of the selected area. The green lines are the tramlines (Schwandl, 2011). 55
Figure 16.1 Share per trip purpose for al tramlines in Rotterdam in 2013 (RET, 2014). 57
Figure 17.1 Analyzed stops. 59
Figure 17.2 Differentiated BC-ratios. 60
Figure 17.3 Results of line-level assessment. 61
Figure 17.4 Stops displayed on map. 63
Figure 17.5 Stops useful for at least one passenger group. 63
Figure 18.1 Performing the SP-survey at the tram stops in Rotterdam. 67
Figure 18.2Results of sample data on compensation valuation for all passenger groups. 68
Figure 18.3 Appreciation of the first measure: stop closure without compensation. 69
Figure 18.4 Appreciation for the second measure: financial compensation. 70
Figure 18.5 Appreciation for the third measure: sheltered waiting rooms at adjacent stops. 70
Figure 18.6 Appreciation for the fourth compensation: guaranteed free cycle parking space at the tram stop. 71
Figure 18.7 Appreciation for the fifth measure: increased frequency. 71
Figure 18.8 First and second choices of working passengers. 72
Figure 18.9 First and second choices for school-going passengers 72
Figure 18.10 First and second choice for shoppers 73
Figure 18.11 First and second choice for others 73
Figure 19.1 influences of different methods on other methods applied in this thesis. 77
Figure 20.1 Rationalizing public transport does not lead to overall lower transport benefits for all passenger groups. 82

LIST OF FIGURES IN ANNEX

Figure A 1 Original situation. 95
Figure A 2 New situation with removed stop. 96
Figure A 3 Example of general SP-survey. 97
Figure A 4 Example of SP-survey as applied in case. 98
Figure A 5 omniTRANS script to distribute trip purpose *work*. 111
Figure A 6 omniTRANS script to distribute trip purpose *shop.* 111
Figure A 7 omniTRANS script to distribute trip purpose *school.* 112

Figure A 8 omniTRANS script to distribute trip purpose *other.* 112
Figure A 9 Differentiation towards age. 127
Figure A 10 Differentiation towards travel frequency 129
Figure A 11 Differentiation towards transport dependency 130
Figure A 12 New suggested approach for passenger loss on stop level. 131

LIST OF TABLES

Table 8.1 Methodological overview of social research methods. 23
Table 8.2 Matrix method to compare different attributes. 25
Table 8.3 Compensating attributes. 27
Table 12.1 Greedy algorithm. 40
Table 12.2 Example of outcome Network Assessment. Tramline 4 towards Hillegersberg. 45
Table 17.1 Passenger loss on network level method 61
Table 17.2 Passenger loss on network level method 61
Table 17.3 Stops that should be closed based on the network assessment. 62
Table 17.4 Stops that should be eliminated, but that are still useful for passenger groups. 63
Table 18.1 Differentiation of profile data observed in the SP-survey. 67
Table 18.2 Observed amounts of passenger loss on stop level -method compared with the results of the SP-survey. 74

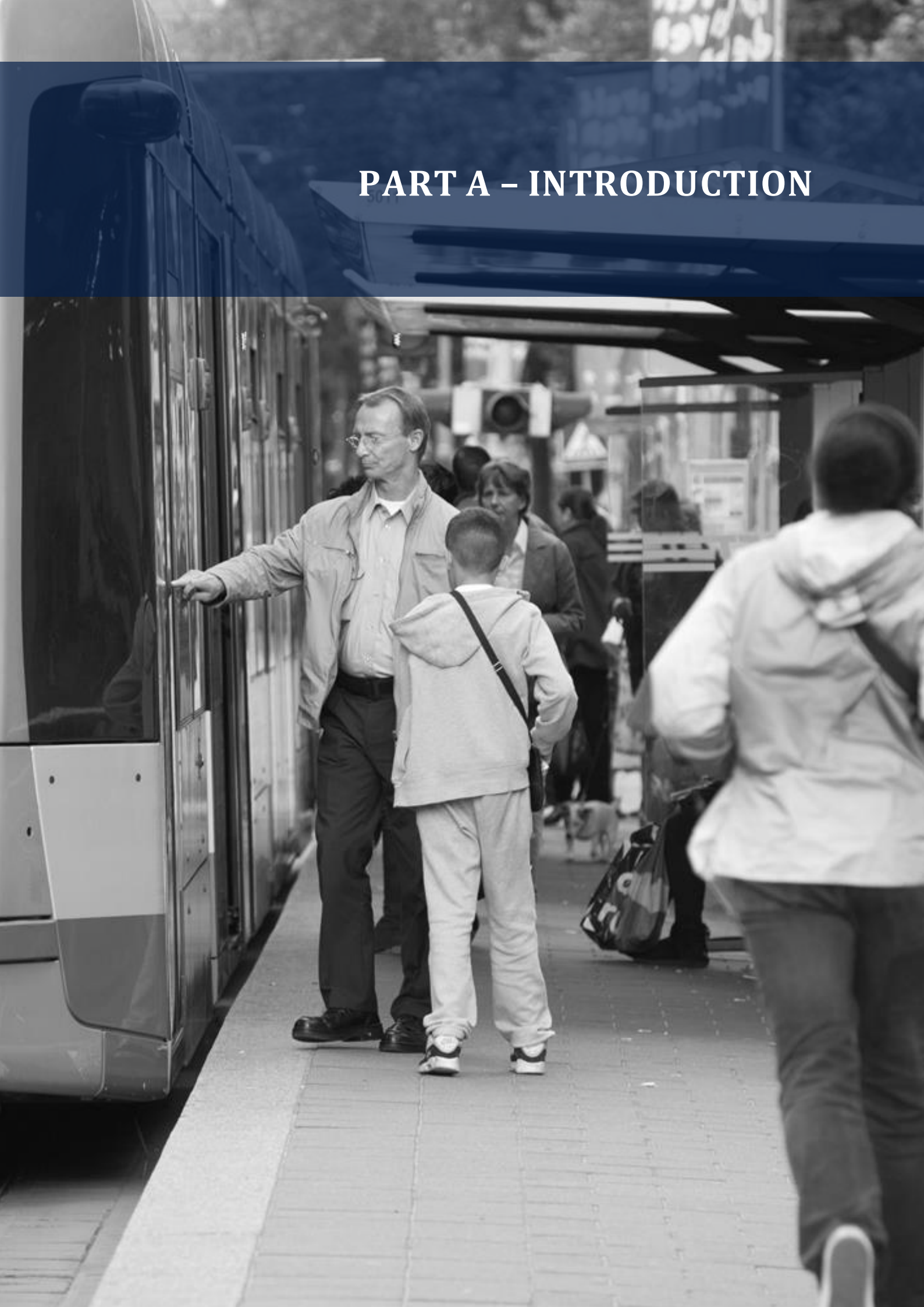
LIST OF TABLES IN ANNEX

Table A 1 Network function. 99
Table A 2 Urban environment stop function. 102
Table A 3 Stopping distances and average speed – line 4. 105
Table A 4 Stopping distances and average speed – line 7. 106
Table A 5 Stopping distances and average speed – line 8. 107
Table A 6 Stopping distances and average speed – line 21. 108
Table A 7 Stopping distances and average speed – line 23. 109
Table A 8 Stopping distances and average speed – line 25. 110
Table A 9 BC-ratio and passenger loss – line 4. 113
Table A 10 BC-ratio and passenger loss – line 7. 114
Table A 11 BC-ratio and passenger loss – line 8. 115
Table A 12 BC-ratio and passenger loss – line 21. 116
Table A 13 BC-ratio and passenger loss – line 23. 117
Table A 14 BC-ratio and passenger loss – line 25. 119
Table A 15 Stops with BC>1 lines 4, 7 and 8. 120
Table A 16 Stops with BC>1 lines 21, 23 and 25. 121
Table A 17 BC>1 and BC_n <1 lines 4, 7 and 8. 122
Table A 18 BC>1 and BC_n <1 lines 21, 23 and 25. 123
Table A 19 Stops with BC>1 in two directions. 124
Table A 20 Applied greedy algorithm on line level. 125

LIST OF ABBREVIATIONS

BC	Benefit Cost
BC_n	Benefit Cost for group n
NA	Network assessment
PT	Public transport
PA	Passenger assessment
SP-survey	Stated Preference-survey
RET	Rotterdamse Elektrische Tram (transport operator in Rotterdam)
SRR	Stadsregio Rotterdam (transport authority in Rotterdam)

PART A – INTRODUCTION



1 INTRODUCTION TO THE RESEARCH

Recently, institutional relations in the Dutch society between government and citizens started to shift in terms of responsibility. The participation society is the result of this shift. This process was acknowledged for the first time nationwide during the King's speech in 2013 (Elsevier, 2013).

Nonetheless, the involved institutional changes that are related to this transition, have already been taking place for years. One of the most important aspects of this transition is the systematical change in the governmental financial structure (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013). Choices have to be made on what is, and what is not, financed by the government (ROB, 2012).

Changing expenditures by the government leads to different distributions of benefits for citizens (De Beer, 2011). This trend is also the base of the discussion about the supply of public transport and its finances (Putters, 2014). Moreover, this process is often related with costs reductions. In addition, reducing costs in public transport is anything but new (Van der Wetering, 1983)

There is a need to optimize public transport due to cutbacks in the financial structure of that public transport (Van Oort & Baas, 2011). The trend for a more market-based approach in the organization of public transport changes the perspective of financing public transport (Den Hollander & Baggen, 2012). The reduction of financial resources demands the system to optimize, in order to assure its existence and continuity.

This thesis contains research a new distribution of those costs and benefits of differentiated public transport passengers. The changing society is the trigger to start a discussion on which costs of the system should be covered by whom and which benefits of the system belong to which user. This leads to a reverse discussion in which the presence of a certain public transport (PT) service is not obvious, but should be evaluated in terms of costs and benefits to justify its existence.

The concept of a participation society in the public transport organization and changing expenditures and costs leads to the question how benefits should be distributed among citizens of the society. In public transport, this means the supply of transport to which passengers. To cope with the question how benefits/supply should be distributed, a myriad of approaches is possible.

This thesis aims to find a new approach of public transport optimization that helps to make choices on supply of public transport and thus distribution of benefits and to map the reaction of the passenger on this optimized system.

The next section points out the problem field in which the research takes place. Thereafter follows the research goal and the research structure.

2 PROBLEM STATEMENT

As stated in the introduction, reductions in the financial system and changes in the institutional context of the operation of public transport urge the current system to become more efficient. On the other hand, the need for mobility is high (Koolen & Tertoolen, 2006). Making the public transport system more efficient -or optimizing- is a precise work. Deterioration is lurking if this process is groundlessly approached.

Urban public transport systems do not function as optimally as they were originally designed, nor as hypothetically possible (Ministry of Transport, Public works and Water management, 2010; SRR, 2009). At the present moment, many studies have been conducted about optimizing public transport systems. A small selection of leading researches on optimizing public transport was made by Mandl (1980), Van Nes (2002), and Schöbel (2006).

Public transport optimization focuses on different fields of the system, depending on the goal of the optimization. Nonetheless, many previous researches approached the user of the system (the passenger) as one average group, regardless the optimization goal (Schäfeler, 1998; Furth & Rahbee, 2000). Only a limited amount of researches treat differentiation of passengers in combination with optimization of public transport systems (Van der Waard [1], 1998; Van Nes, 2003; Koenis, 2008).

Thus, there is a gap in science between public transport system optimization and its approach from the perspective of different passenger groups. This void is especially present when differentiation is based on the trip purpose of passengers. Trip purpose is one of the most fundamental ways of differentiation, since the trip purpose reflects the main goal to make a trip. The studied theory shows that differentiating towards trip purpose is a possible way of differentiation, because of the fact that different travel characteristics contain information about the travel behavior and characteristics per passenger group (Wardman, 2001; Balcombe et al., 2004) or choice modeling (Van der Waard, 1988 [1]; Koenis, 2008).

This thesis therefore suggests differentiation of passenger groups so that the different group characteristics can be used in the optimization of a public transport system. By differentiating passengers into different groups, a more accurate insight is obtained that helps to change the system, because it is assumed that each group of passengers has specific travel characteristics. These characteristics could be involved by stop distance optimization, which is the purpose to do so. The goal is to close the gap between optimization and the approach of differentiated passenger groups.

Besides, if one assumes that every differentiated group has specific characteristics and thus related demands, it must be acknowledged that optimizing a system in relation to those groups could lead to a better and more accurate result. It is expected that approaching passenger groups as one average group would produce the same results an optimized situation based on trip purpose characteristics.

It is therefore also interesting to find out which passenger groups will travel less if their stop is eliminated. This creates the opportunity to map the reaction of these groups to enlarged stopping distances and it creates the opportunity to seek for possible compensation measures that should prevent fallback of transport usage. Examples of compensation are more comfortable waiting rooms, better accessibility to adjacent stops and higher frequencies of public transport.

There are different options to economize public transport supply (Fielding, 1987; Van Oudheusden et al., 1995 and Black, 1995). There are different network characteristics suitable for optimization. An overview:

- network speed;
- line distance;
- timetable frequency;
- reliability;
- network flow;
- stopping distance.

There is a particular interesting field in the public transport systems in which savings can be achieved, namely stopping distances in the network. There is a gain to make in optimizing the stopping distances. Optimized stopping distances results in faster operation of the network (SRR, 2012; SRA, 2010; OVpro [2], 2014).

That does not mean that for example one out of two stops can be eliminated. The passenger that uses the network does have interest in specific stopping locations. Passengers that access a transport network via a stop, profit by using that stop. However, passengers that do not use the particular stop are adversely affected by that stop, since it increases their travel times. That means that changing stopping locations is one of the approaches of optimizing a public transport network.

This thesis focuses on optimizing stopping distance. According to different previous scientific papers and current policies, there is a gain to make in increasing stopping distances and thus increasing operational speed (Verweijen, 1992; SRR, 2009; Van Nes & Bovy, 2000, Van der Blij et al., 2010).

Based on the gap in research and science in using differentiated passenger groups based on trip purpose and the opportunity to optimize stopping distances, the following problem statement is formulated:

Public transport networks should rationalize, because of reductions in the financial system. Previous optimization strategies mainly treated passenger groups as one average group, while differentiating passenger groups could lead to better insight in optimizing public transport systems.

The introduction and the problems statement showed that there is an opportunity to approach public transport optimization from differentiated passenger group perspective. The next section explains the research. In the third part of the thesis, an extensive overview of different approaches of differentiation and optimization is given and justified. Thereafter follow the methodological description and the case application.

3 RESEARCH

Based on the introduction and the problem statement, the research goal, main and sub questions and deliverables are formulated and stated below.

3.1 RESEARCH GOAL

This thesis aims to close the gap between technical-rational network optimization and social passenger behavior differentiated towards trip purpose as explained in the first section of the thesis. The goal is to optimize stopping distances of a public transport system according to the differences in characteristics of towards trip purpose differentiated passenger groups. In addition, this thesis seeks for reaction on stop distance optimization and suggests possible compensation measures to prevent fallback of usage.

3.2 RESEARCH QUESTIONS

The main research question is formulated as follow:

To what extend does the use of passengers groups differentiated towards trip purpose contribute to public transport network optimization, with respect to the travel demand of differentiated passenger groups?

The following sub questions are formulated in addition to the main question:

1. What is the current challenge in urban public transport related to network optimization?
2. Does differentiation of passengers contribute to network optimization?
3. How do passenger groups react to optimized stopping distances?
4. Do compensating attributes cost efficiently contribute to public transport use?
5. Is compensation necessary to prevent fallback of transport usage in case of stop closure and what compensation can be applied?

The research is structured in such a way that the sub questions structure the literature framework in the next part. The main question is answered in the conclusion.

3.3 DELIVERABLE

Due to the nature of the main question, the deliverable is a method in which optimizing stopping distance is executed on a rational basis, with respect to the effects for differentiated passenger groups. There is an engagement plan incorporated for network rationalization for those passengers who will experience decreased or increased supply of transport. The methodology generates advice for strategic decision level and is dedicated for transport policies for one to five years from now.

3.4 PROBLEM OWNER

The research addresses a problem owner. The problem owner of this problem is a public transport operator of an urban transportation network in the Netherlands. This actor is responsible for the operation and participates in the discussion of network performance.

3.5 CASE STUDY

The developed methodology is generally applicable on similar cases. The methodology was verified by application on the tram network of Rotterdam. The case selection and application is explained in part D.

The next section explains the study approach, the scope of the thesis and the scientific and societal relevance. Thereafter follows the conclusion of this chapter.

3.6 SCIENTIFIC RELEVANCE

Passenger groups are often approached as one group with one average traveler (Kocur & Hendrickson, 1982; Chang & Schonfeld, 1991; Spasovic et al., 1994). Differentiation of passenger groups solely towards trip purpose

has not often been done before. It is assumed in this thesis that differentiating towards trip purpose could lead to a more detailed insight in effects of network changes for different travel groups (APTA, 2007). This insight is important, because it could lead to a more precise overview of demands of passenger groups. This thesis will explore the effects of different passenger groups in relation to network optimization. Therefore, this thesis focuses on the field between rational and technical network rationalization and social behavior of passenger. The figure below visualizes the scientific field in which this thesis is placed.

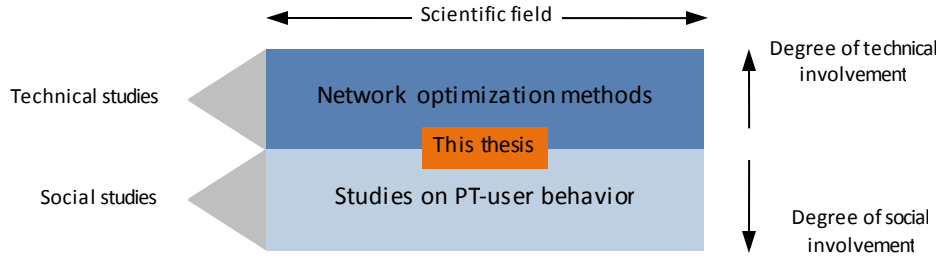


Figure 3.1 Position of thesis in the scientific field.

3.7 SOCIETAL RELEVANCE

There is a trade-off between access points (stops) and travel time. Closely spaced stops provide short access distances for passengers but also increases in-vehicle trip time (vehicles have to stop regularly). Long stopping distances cause passengers to have a long access time, but it reduces the in vehicle travel time (Li & Bertini, 2007).

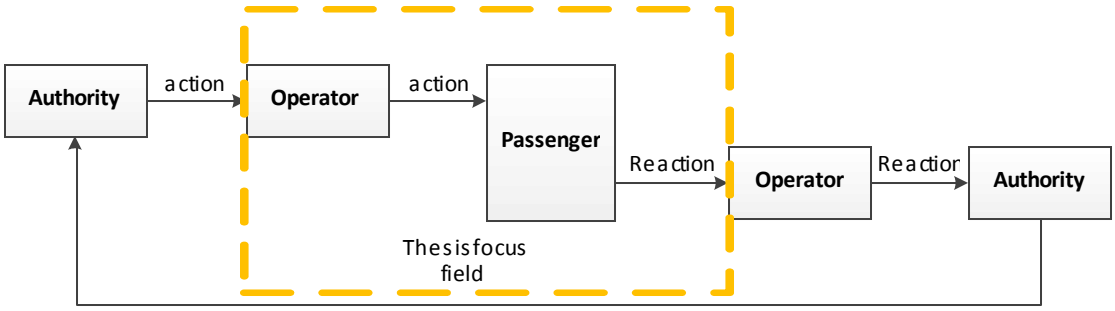


Figure 3.2 Focus of this thesis: differentiated passenger groups are confronted with an action and they will react in a certain way (own illustration).

This thesis should be placed in the current debate about changing costs and benefits in the society and the consequences for users (passengers), the government and the operator of a public transport system. The core of this thesis lies in the relation between differentiated passenger groups that have a certain transport *demand* and the operator and authority that offer a *supply* of transport that is under pressure due to changing financing structures.

3.8 SCOPE AND RESEARCH BOUNDARIES

This thesis focuses on differentiated passenger groups and their related benefits of using public transport. The differentiated passenger groups are further explained in chapter 8.

Furthermore, the focus is on urban public transport networks in urban environments. The time scope of this thesis is at a strategic level. Advices that are generated are addressed on strategic level, in a time slot of 0 to 5 years (Van der Velde, 1999).

This thesis addresses urban public transport networks on stop level. This transport network level is chosen, because the problem of short stopping distances and thus low operational speed manifests at this level.

Furthermore, earlier introduced short stopping distances offer an opportunity to rationalize. This implies that lines and network layout are not considered in the process of rationalizing.

It is assumed that the case network operates in a reliable and robust way. This thesis does not address delay management and the optimization of unstable operations.

The goal of network adjustments is targeted at reducing travel times for the network by increasing speed. Increasing operational speed is done by changing and eliminating the stopping locations. By having reducing travel times due to stop removal, the network should become more attractive.

Other infrastructural elements are also influencing the vehicle speeds in the network. Other important influencing elements are traffic light systems, crossings, curves, the degree of separated infrastructure, and bridges. Due to the nature of this thesis, these elements are not part of the solution space to increase network speeds.

Furthermore, this thesis focuses on the Dutch constitutional organizational structure. The general method that is developed in this study is therefore applicable to other similar Dutch cases.

4 STUDY APPROACH

This thesis addresses two main topics, which are a focus on optimization of public transport and a focus on differentiation of passenger groups. The approach is built up so that the context of the thesis is limited and to the problem statement as mentioned above. This step is taken in the literature framework.

The literature framework also explores previous scientific work and theories towards urban public transport network optimizations and the different approaches of passenger group differentiation. The result of this approach is multiple;

- Boundaries to the thesis;
- Network optimization method;
- Overview of characteristics of passenger groups.

After the literature study, a *network assessment* is applied on generic level. This network assessment gives an overview of all steps that must be taken to apply the network-part of the methodology on a case. Thereafter follows the *passenger assessment* on generic level. The passenger assessment aims to find the reaction of passenger groups towards optimized stopping distances. Furthermore, this assessment seeks for compensation measures that should prevent fallback in usage, if applicable.

Subsequently, both the network assessment and the passenger assessment are applied to a case and results are generated. In the last step, the results are evaluated and generalized. Finally, the conclusions are drawn, together with the recommendations and advice for further research.

Every part starts with a small introduction and ends with a concluding chapter. The scheme below visualizes the structure of the research.

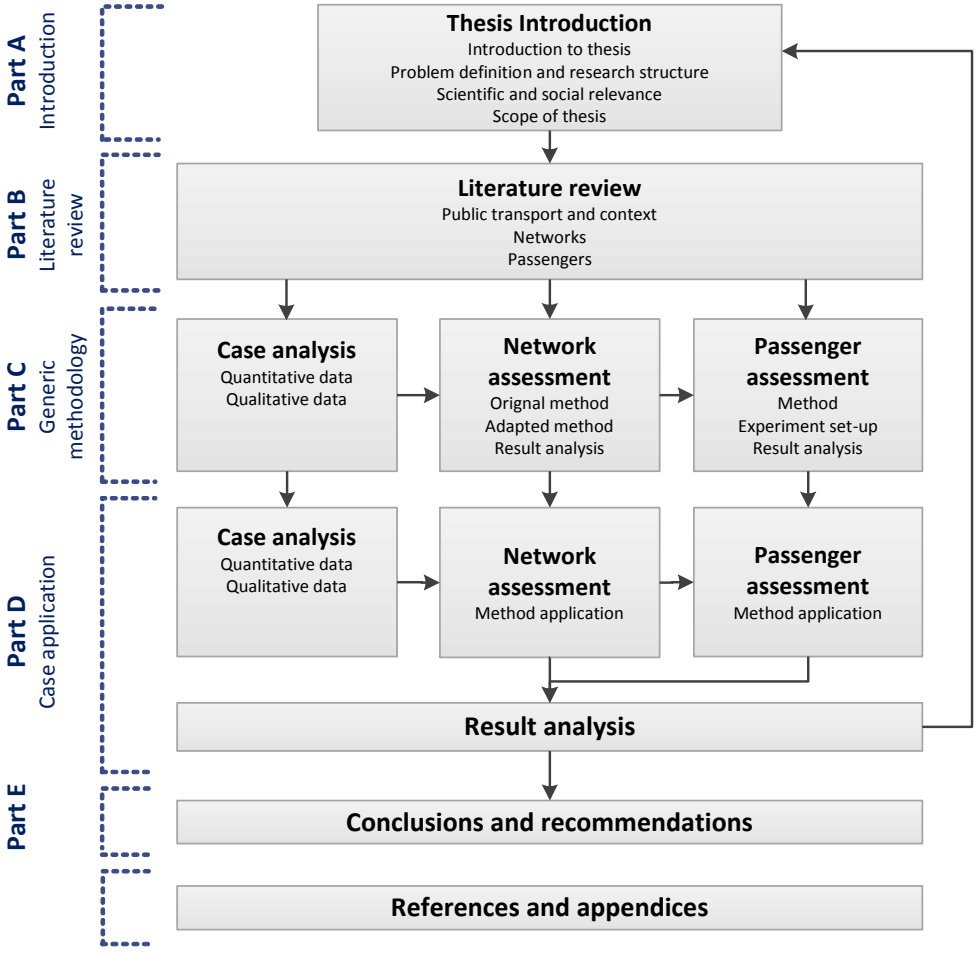


Figure 4.1 Study approach.

5 CONCLUSION

This thesis addresses cost reductions by rationalizing the public transport network by editing stop locations. The distribution of passenger benefits in public transport will change, if the network is rationalized. Passengers may experience increase or decrease of benefits. It is important to find out how different passenger groups will experience the changes of benefits and –if necessary- how these groups can be compensated, to prevent fallback of public transport usage.

The figure below schematizes the scope from the broad societal change towards the narrowed-down topic about network rationalization and the consequences for differentiated passenger groups.

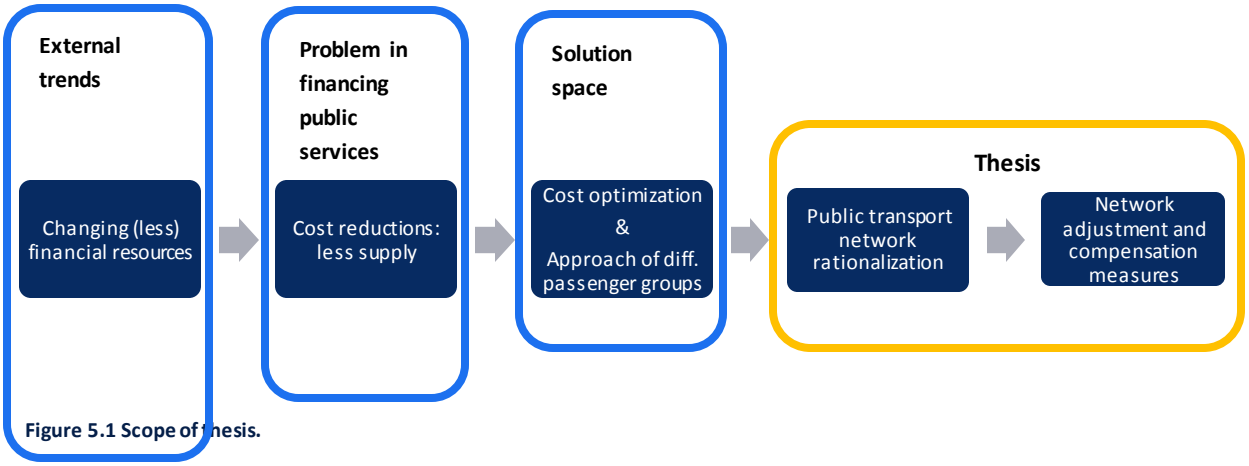
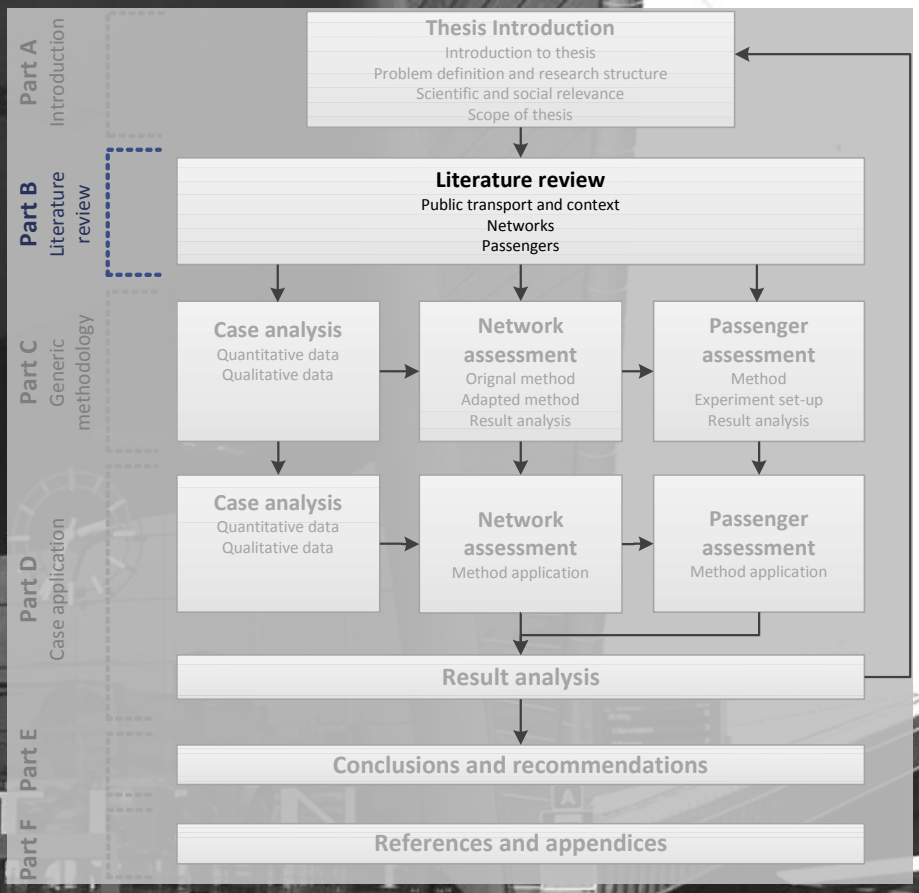


Figure 5.1 Scope of thesis.

PART B – LITERATURE RESEARCH



The first chapter of the literature research guides the reader towards the core of the research. After setting the context of public transport, the network-section follows in which network functionality and network optimization methods are discussed. The literature framework ends with the purpose of passenger group differentiation.

6 PUBLIC TRANSPORT

The first part of the literature framework is about public transport. This part aims to set boundaries to the context to narrow down to the core problem that is addressed.

One of the main drivers behind urbanization and urban growth is infrastructure. Infrastructure facilitates transport. Using transport is a derived demand from other activities (Vilhelmson, 1999). The demand for transport exists because it is necessary in order to join activities that take place at a specific location. The trip is made if the benefits transcend the trip costs generalized in time, money or effort. There are various modes of urban public transport systems. Every transport mode has specific characteristics that define the type of transportation, such as speed, capacity and frequency (Hoyle & Knowles, 1992; Dijst, 1999; Vilhelmson, 1999; Vuchic 2002, Hansen et al., 2008). The mode addressed in this thesis (tram) is defined by low average speeds (comparable to bus) and medium capacities (higher than bus, lower than metro).

6.1 INSTITUTIONAL PLAYING FIELD

There are three key actors to determine in the field of public transport: the *government/transport authority* (shortly: authority) sets criteria and requirements for the level of transport that must be offered (CVOC, 2002; WRR, 2012). These demands are political driven (Bovines et al., 2001; Heldeweg, 2010). The requirements frame the mission for the *operator* who translates the requirements into physical supply of transport. The operator provides the actual public transport and the *customer* (passenger) uses the public transport. At their turn, the passenger demands transport from the operator and has a certain influence on the decision-making process of the government. The *passengers* can be differentiated according to different factors based on passenger behavior.

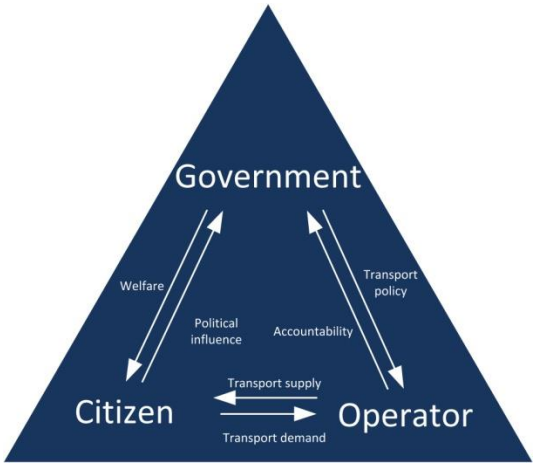


Figure 6.1 Triangular relation between the three groups (own illustration. Based on WRR, 2012).

Current discussions are about the availability of public transport in time and location: should the government provide public transport everywhere and at any time, or are communities expected to have own accountability for their transport (KpVV, 2013). An example of organizing own public transport is a local bus service in rural areas, operated by volunteers. The point is that governments are confronted with the challenge to reduce costs: shifting the responsibilities from government to the user is one of the solutions. So is the local bus service (Van Wijk, 2013).

6.2 GOALS OF PUBLIC TRANSPORT

Public transport in urban environments has three important functions. Public transport exists because of a (1) social function, (2) substitution function and (3) to ensure and enlarge accessibility (Egeter et al., 1994; CVOV, 2003). The social function ensures mobility for those who have difficulties with arranging their own transportation. The substitution function is the competitive function with other modes of transportation. Public transport contributes in such a way to a sustainable transport mode without congestion (Geurs & Van Wee, 1997; BBC, 2014). The third function is to ensure the accessibility of places that are difficult to access with other transportation modes, like the inner city center or a big railway station (CVOV, 2003; Rutten, 2012). The accent on different goals may vary over time and network level (Smit & Van Thiel, 2002; CPB, 2009).

According to political choices (made by the authority), some functions of public transport are considered to be more important than other functions. Changes in public transport affect all the actors, but they are initiated from governmental perspective. Cutbacks in financing public transport are also part of those changes. It should be noted that the government also reacts on the will of the operator and –moreover- on the will of the citizen. This concept is secured by a democratic state (Overheid.nl, 2014).

Correspondingly, the government decides on public transport supply. When cutbacks are needed, it is important to consider the consequences for the passengers. The problem statement as mentioned in the first part, will affect the supply side of public transport. It is therefore important that the government (and thus the authority) has a clear overview on the effects of public transport cutbacks. Another term used for that process is the *rationalization* of public transport system (Niger, 2011).

The next section discusses the different possibilities that affect the public transport system when the authority decides to rationalize the system.

6.3 CHANGES IN THE SYSTEM

When discussing cutbacks, rationalizing and thus cost-optimization of public transport, the concept of costs and benefits must be explained. Costs are related to the finances that the government spends on public transport. Benefits are related to the profit or gain that passengers have by using the system. Benefits must be seen in the broadest sense.

6.3.1 COSTS

Costs of the network come from factors. The most important costs for the transport network can be determined by the network density (stop- and line spacing), operational speed and frequency (CVOV, 2005). Costs directly influenced by the network are the amount of vehicles and staff necessary for operating the network. The higher the level of stops and lines, the more potential supply of transport, but also the higher the costs are (Schoemaker, 2002; Murray & Xiaolan, 2003).

Historically, transit operators began to think in network perspectives when they expanded their network together with the developing city. The bigger picture of transit became important. Lieberman states that the big picture is often lost today, since operators have to deal with cuts in the budget and shrinking operating budgets. Often, short-term decisions are being taken to save money. Those 'solutions' often harm the network and thus the broader context of the transport network gets damaged (Lieberman, 2008). This eventually leads to lower benefits. It is therefore of great value to conduct the process of rationalizing with accuracy.

6.3.2 REVENUES AND BENEFITS

The major finances to operate public transport come from the authority as subsidy. By providing subsidy for public transport, the Authority is able to require a certain level of transport supply. Other revenues of public transport do come from the customer. By selling tickets for transportation, the operator generates revenues. On average, ticket sale covers 25 to 50 percent of the costs for the transportation (KiM, 2009). Growing amounts of passengers will lead to higher revenues and more subsidies, if remitted on quantitative base. Other sources of revenues are advertising and retail for example (IPO, 2004; CVOV, 2005).

While benefits are not the same as revenues, it is important to consider the *profit* for the passenger a as a benefit. Because while passengers pay a certain amount of costs to use public transport (revenues for the operators), the amount of benefit is higher for those passengers. This concept is explained in the *passenger*-part of the literature research.

6.4 CHANGES OF COSTS AND BENEFITS

Increasing revenues can be done by attracting more passengers to the network. Decreasing costs of the public transport network involves financial reductions on the urban public transport. In order to reduce costs of the network, there are different measures that can be taken (Kerstholt & Paradies, 2004).

Potential cost reduction measures

If the financial resources of public transport are lowered, eventually the costs must lower as well, since they have to match the lower resources. This has various consequences (assuming benefits are correlated with the cost structure): less supply of transport, lower frequencies, and etcetera. The concept is visualized in the figure below.

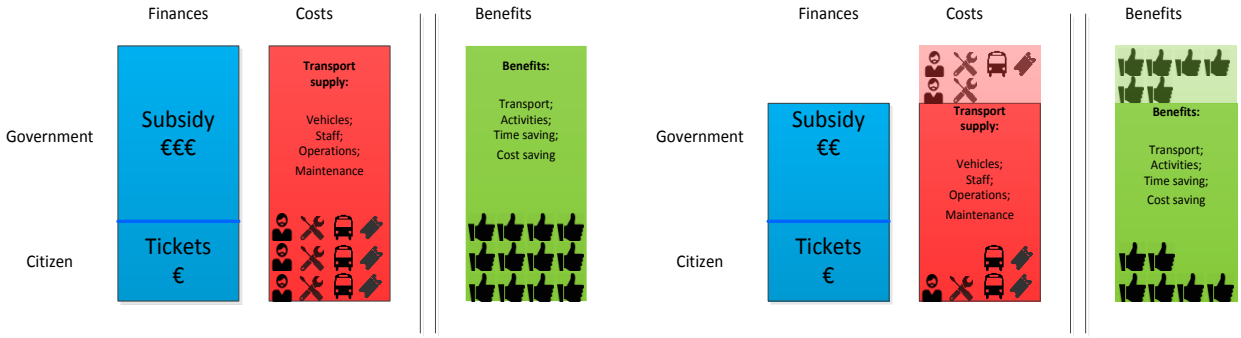


Figure 6.2 Consequences of the participation society for public transport. Fewer benefits are supplied for the user (citizen), due to reduced financial resources. The icons are illustrative and not scaled (own illustration).

Considering the participation society -briefly addressed in the introduction-, politicians will have to decide what is acceptable for the level of benefits or supply of public transport to decreases. This is a political decision. There are various options to deal with the decreasing financial resources from the government for public transport. These options are discussed below. The starting point is the reduction of finances from the government, as concluded in the previous section.

1) User pays more: the gap in financial resources is completely covered by the user. Ticket prices will increase to cover costs. This option is unlikely to occur, since ticket prices should double or even triple. The level of financial resources that should be compensated is high, according to the fact that the user only pays approximately 25% of its own trip, nowadays (see figure 6.3).

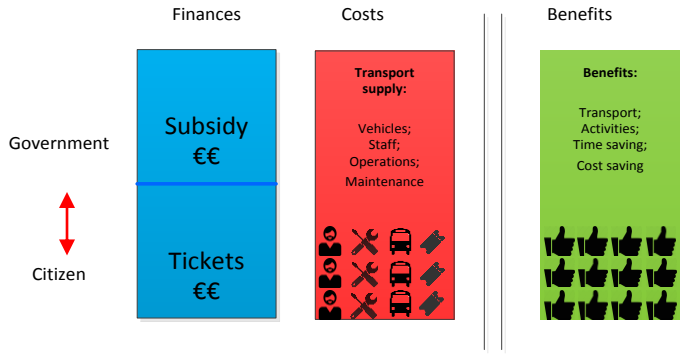


Figure 6.3 User pays more. The icons are illustrative and not scaled (own illustration).

2) Other financial resources: the financial gap is filled by other financers. These solutions are various, e.g. advertisements or private investors. It is not likely that the financial gap can be completely covered by adding extra financers, because this would not use the present opportunities of optimization. Furthermore, this range of solutions is not in the scope of this thesis.

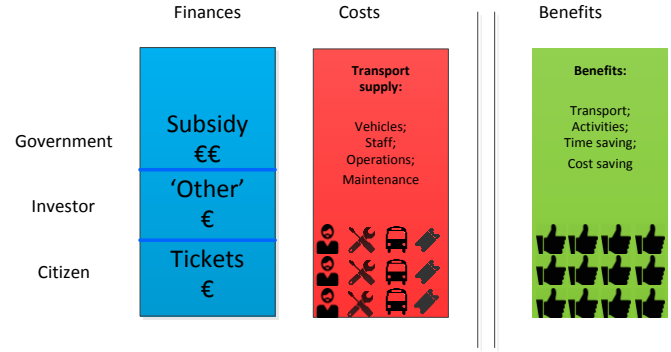


Figure 6.4 Other resources. The icons are illustrative and not scaled (own illustration).

3) Fewer benefits: the most probable option is to lower the benefits, because this process takes place in accordance with the operator, the passengers and the authority. The research focuses on this option.

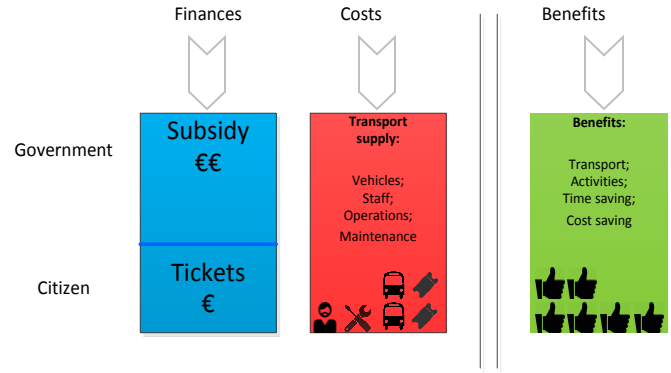


Figure 6.5 Fewer benefits. The icons are illustrative and not scaled (own illustration).

A combination exists between the first and the second option in which a tender-contract is used to select an operator for public transport. Using tender-contracts could lead to higher efficiency and therefore lower costs (Ham & Baggen, 2008). This variant is not addressed in the thesis, since the urge to tender does not exists in the context that this thesis addresses.

The different scenarios of lowering financial resources for public transport have diverse consequences for public transport supply. The first two solutions do not focus on the functioning of the public transport system itself. These two consequences cover a whole range of other solutions, which are note addressed in this thesis.

The focus lies on the third option: less supply of benefits. The third consequence is the most interesting for this thesis, because it contains the possibility to adjust the public transport system itself and to divide and differentiate the benefits towards different user groups. This is not the case in the other two scenarios. No consideration of combination of scenarios takes place in this thesis, because it would distract from the purpose of the research.

The next section links the reduction of finances for public transport to the consequences for the public transport system and thus the supply of transport.

6.5 RATIONALIZING THE PUBLIC TRANSPORT SYSTEM

If less money is available, costs need to decrease or revenues must increase to remain on the same level of service, supply. This concept is the rationalization of public transport systems. Several Dutch transport authorities already affirmed these processes in their policy documents in the last few years (Stadsregio Amsterdam, 2010; Stadsregio Rotterdam, 2012; OVpro [1], 2014; OVpro [2], 2014). The transport authority has and will have to make choices about how subsidy for transport policy goals is divided over the public transport system. The figure below visualizes the aspects that are involved with the costs of public transport systems and thus could be influenced by cutbacks on public transport expenditures.

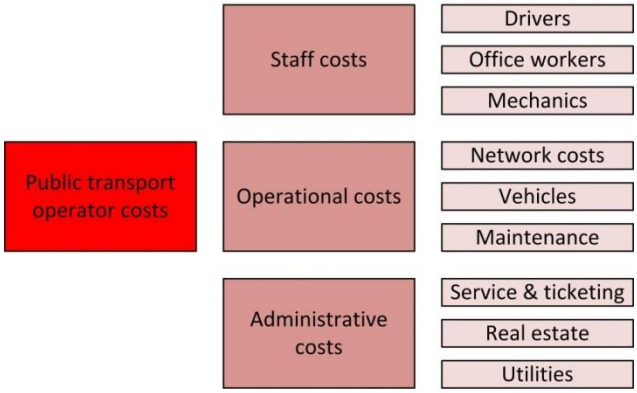


Figure 6.6 Costs that are involved with the operations of public transport (based on Beimborn, n.y.).

This thesis focuses on the network costs. There is a gain to make in network costs. Often, the daily operation speeds do not meet the design speeds. Design speeds of 25 to 30 kilometers per hour do often linger at 18-20 km/h in daily practice (Verweijen, 1992; SRR, 2009).

6.6 RATIONALIZING STOPPING DISTANCES

There is a particular interesting field in which costs reductions can be achieved. There is a gain to make in optimizing stopping distances and thus increasing operational speed (Verweijen, 1992; SRR, 2009; Van Nes & Bovy, 2000, Van der Blij et al., 2010). Stopping distances in the traditional urban public transport network are known for short distances and therefore low average speeds of the vehicles in the system. Short stopping distances reduce the average access and egress time and distance, but a large amount of stops increases the in-vehicle time. Moreover, longer waiting times are expected, since frequencies decrease due to budget limitations (Vuchic, 2005). Optimal stopping distances vary between 500 and 800 meters, depending on the type of optimal network that is chosen, while stopping distances in classic urban networks are 400 meters on average (Van Nes & Bovy, 2000). This means that the network is not as efficient as it theoretically could be.

Moreover, a number of analytical network optimization methods found an opportunity in rationalizing stopping distances (Black, 1978, Furth & Rahbee, 2000; Egeter, 1995; Van Nes & Bovy, 2000). However, these analytical approaches do not succeed in actually implementing longer stopping distances, since the topological network environment is not regarded. If an analytical network design states a stopping distance of 600 meters could result in a situation where a shopping center ends up just between two stops. Therefore, stopping distance rationalization is directly linked to the (urban) built environment.

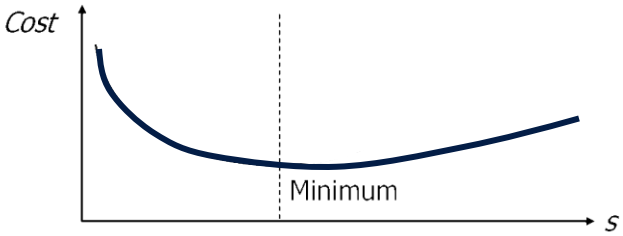


Figure 6.7 Concept of stop spacing (Li & Bertini, 2009).

Adjusting the stopping distance has diverse consequences for the cost and revenue of public transport systems. Figure 6.7 visualizes the total costs versus stopping distance. The optimal stopping distance (s) depends on the type of cost conceptualization and the goal of optimizing (see the network-chapter)

Stopping times at stops vary from tens of seconds to a minute or more. The stopping time is based not only on the actual stand still time of the vehicle, but also on the time that is lost with slowing down and speeding up. The average time spend on stopping is about fifteen percent of the total travel time (Heikoop, 1996). Removing stops thus leads to a gain in travel time. This concept is visualized in the figure below.

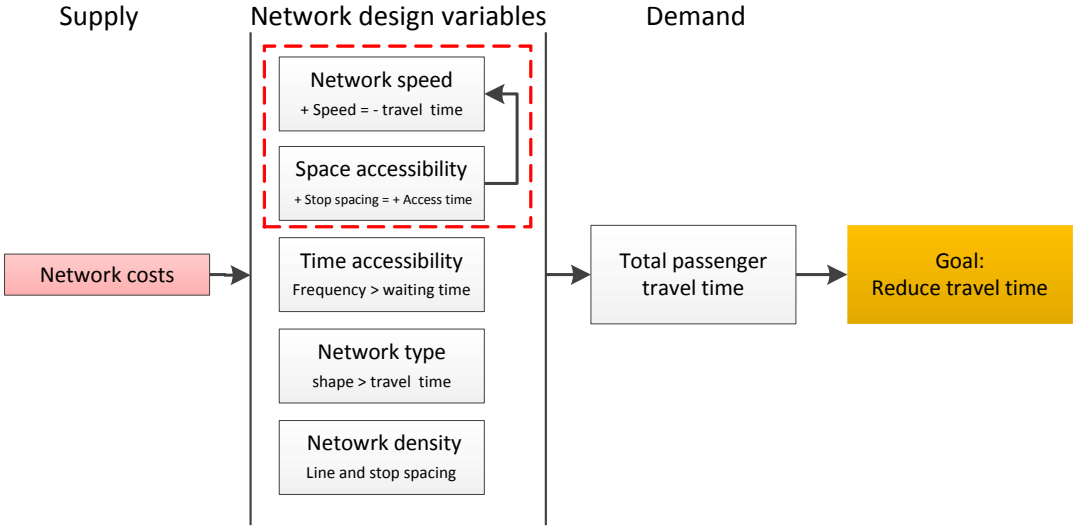


Figure 6.8 Problem area of network function in this thesis (Based on: Van Nes & Bovy, 2004).

The purpose of stop space enlarging is to reduce costs of the operator and to reduce travel time of the passenger (Murray, 2003; Xuebin, Guihaire & Hao, 2008; Tirachini et al., 2010; Xuebin, 2010). An enumeration of the profits related to enlarging stop spacing:

- Less stop maintenance;
- Frequency increase;
- Fewer vehicles needed;
- Reduction of staff deployment;
- Prevent network saturation.

Furthermore, adjusting stopping distances does have consequences for the passenger as well. The total travel time in the vehicle is reduced, which leads to less disutility of time and is seen as a benefit for passengers. On the other hand, enlarging stop spacing could also lead to less supply, since the distance to the stop could become too far for a certain group of passengers. The benefits of shorter travel times are not high enough for them to bridge the longer distance to the stop (Tirachini et al., 2010; Xuebin, 2010). Enlarging stop distances is a trade-off between operator due to less costs and the passenger, benefitting of shorter travel times or loosing transport supply because of too much increased access distances.

6.7 CONCLUDING REMARKS

This chapter set the context for the public transport playing field. The different stakeholders were introduced (operator, authority and passengers). Furthermore, the focus on reducing costs for public transport was introduced. By reducing the costs of the system, the benefits for passengers are changing. This will result in a rationalized public transport network. The third part of this chapter was the focus on stopping distances.

The next chapter focuses on the network and stopping distances, the focus on the network and involved optimizing methods. Thereafter follows the last part of the literature research: public transport passengers and the involved transport benefits. This section aims to exemplify the focus on different passenger groups and their characteristics.

7 NETWORKS

The purpose of this part of the thesis is to find a methodology that helps to decide which stops should be eliminated and which stops should be kept in the system, so that stopping distance is rationalized. According to the problem statement in the first part, there is room for optimization in the PT-network. This part of the thesis discusses different optimization methods. The goal of the method is to enlarge stopping distances.

The premise of the method is to enlarge stopping distance. The method that is selected in this chapter must however also focus on line level and network level, to prevent degradation of transport quality on line and network level. Focusing on the three levels of the system (stop, line and network) serves two goals. It can test and verify the functionality of one of the models per level and it assures that one model can be used without the usage of the other two in a case. Therefore, the method that will initially focus on stop level will be checked by a line level and network level methodology.

This chapter starts with an analysis of the public transport system. The output of this part is used to set criteria for the method. Then, a range of methods is introduced. Subsequently, a method is chosen that will be used in the *network assessment*. This chapter ends with an extensive description of the method, its shortcomings and the adaptations that were made to the method.

7.1 NETWORK CONCEPT

An urban public transport network is a system of transport modes that offers transportation according to a schedule and a route. The different lines that profile the network are designed in such a way that there is interaction possible between the stops of different lines (Lieberman, 2008).

Transit modes like bus, metro and train are dominantly urban transportation modes. The urban environment is very suitable for transit modes, because the urban context provides the conditions for urban transit, namely high density and the high demand for (short distance) mobility. The higher the density, the higher the potential demand for transport (Rodrigue et al., 2006).

The physical network is the underlying context of transit services. Two or more lines constitute a system. The spatial configuration of these lines is called a network. The purpose of the network is to collect and distribute people around a larger area than would be possible with one single line (Lieberman, 2008). Therefore, the network should be designed in such a way that the most people profit from it and so that the most cost-efficient operation is possible. Supply and demand interact in the network.

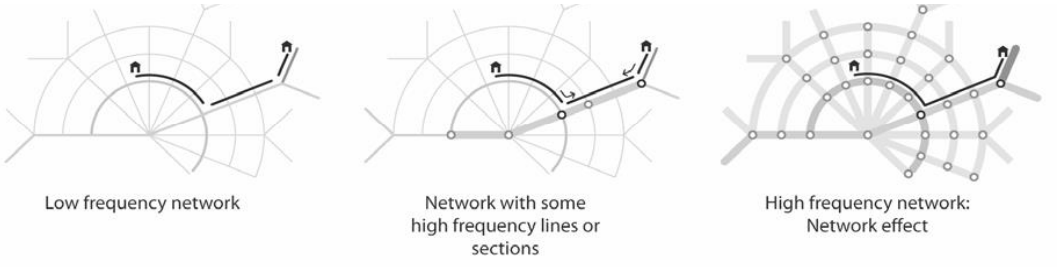


Figure 7.1 The network effect visualized (Nielsen & Lange, 2007).

One speaks of a network with network effect if there is sufficient and consistent supply of transport in such a way that the particular transport mode can compete with other modes and so that all the lines together form a comprehensive system in the city or even in the region (Nielsen & Lange, 2007). Furthermore, crossing lines obviously have interchange stops (Nielsen & Lange, 2007).

7.2 GOALS OF OPTIMIZATION

Public transport network optimizations have differed goals. Fielding (1987), Van Oudheusden et al. (1987) and Black (1995) listed the goals of public transport optimization as follows:

1. user benefit maximization;
2. profit maximization;
3. minimizing total costs;
4. operator costs minimization;
5. total welfare maximization;
6. capacity maximization;
7. energy conservation and protection of the environment;
8. individual parameter optimization.

Removing stops to optimize travel times in relation to the behavior of differentiated passenger groups should be placed in the first category with the remark that 'user benefits' is differentiated towards different passenger groups (as will be exemplified in the next chapter).

Networks are economically seen as a trade-off of costs and benefits. Regardless the underlying purposes of the system, it should function as optimal as possible. As stated in the introduction of this thesis, there is still room for optimization in network, because stopping distances are averagely low. Choices in optimization must be considered carefully. If optimization is not executed on network level, but solely on stop level, the network as a whole will might get corrupted, because costs are only saved on details, while benefits on network level shrink faster (Lieberman, 2008). The next section discusses the premise of the method: stop distance optimization.

7.3 MODELING STOP DISTANCE OPTIMIZATION

Kepaptsoglou and Karlaftis (Kepaptsoglou & Karlaftis, 2009) presented a systematic overview of researches to transit route network design problems. This structured overview is based on design objectives, operating environment parameters and solution approaches. The reviewed methods are not judged on functionality or quality. The paper aims to categorize the addressed researches into a methodological structure. They classify methods into two general methodologies: conventional (analytical) and heuristic (numerical or topological) methods.

Van Eck et al. (2012) distinguishes the network design in two types of approach: the analytical and the topological approach. The analytical approach works with guidelines and uses simplified design rules. The topological method is rather applicable on more complex situation, since they deal with heterogeneous demand, travel behavior, spatial limitations and etcetera. Due to the large variety and the complex network characteristics of the latter, the preference goes to topological methods. A method is sought that can judge a cost and benefit ratio based on passenger usage. Therefore, a numerical or heuristic (topological) approach is preferred over an analytical approach. The figure below visualizes the range of approaches and the focus on methods:

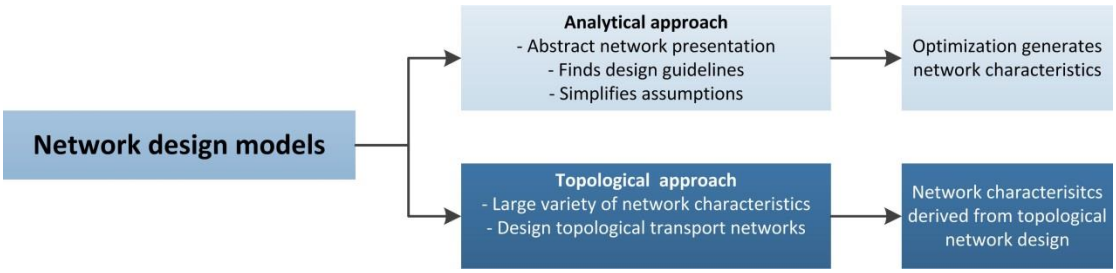


Figure 7.2 Method focus (Based on Van Eck et al., 2012).

7.4 NETWORK ASSESSMENT

By creating a faster network with fewer access points, the efficiency of the network must increase and thence, the costs must be lowered or the supply must increase with equal costs (Tirachini, 2012). Adjusting stopping location affects the access resistance to the system. Adjusting stopping location could lead to higher generalized access costs and thus loss of passengers (Wirasinghe & Ghoneim, 1981; Murray, 2003).

As concluded from the previous section, only topological methods will be addressed. A set of criteria about network rationalization helps to select and compare different methodologies that treat network rationalization. The criteria were formulated in accordance with the purpose of the research: applying differentiated passenger groups on public transport network optimization. The criteria are formulated as follows:

- Possibility to deal with differentiated passenger groups.
- The method must optimize stopping distance.
- The method must deal with passengers' reaction on stop closure.
- The consequences for stop closure must be known on stop, line and network level.
- The method helps the operator to judge on the stop existence.

The table below summarizes different methods and contains the link between the method and the given criteria above. The methods that have been registered are methods that were found by literature research via scientific paper databases (like Science Direct and Google Scholar) and by searching references in previous researches addressing similar problem statements.

Table 7.1 Structured overview of network optimization methods. In each cell, the match between the criteria and the given method is stated.

Criteria/ Literature	Different passenger groups	Optimizing stopping distance	Costs and benefits of passengers	Consequences on stop, line and network level	Helps to judge operator
Furth et al. (2007)	Not included in original model	Yes, based on additional walking time and in-vehicle time	Yes, no groups possible	Only on stop level	Yes
Li & Bertini (2009)	Based on hypothetic passenger loads	Yes	Goal is to minimize total cost.	Only on stop level	Partially
TRB/TRCP 19 (1996)	Does not address passengers	Not necessarily optimizing, but mere relocation	Not addressed, no total optimization	Only on stop level, not on line level	Yes, but no optimization is provided.
Schäfeler (1998)	Focus of research on different goals of optimization. Passenger is not scope.	Optimizes stopping distances for different maximizations	Does treat optimization on total passenger group level	Stop and line level integrated in method	Yes, in a structured way
Furth & Rahbee (2000)	No and difficult to implement	Gives different possible scenarios	Not on passenger level, but on operator level	Only on stop level	Yes
Van Nes (2002)	Yes, with adaptations to method	Concludes generic stopping distance with respect to network hierarchy	Not individually	Does not judge on individual stop but rather on line level	Yes, in a structured way, but results are generic
Van Nes (2003)	Yes	Concludes generic stopping distances	Yes, per group	Only network level	Yes, in a structured way, but results are generic
Wagner (2014)	Yes, with adaptations to method	Yes in a clear and understandable way	Gives the benefits for passing passengers, calculates cost of stop users	Provides overview of stops, but no treat of line and network level	Yes

No method has been found that matches all the stated criteria. However, the methodology of Wagner (2014) matches the most with the established criteria. It is easily adaptable to the non-matched criteria: addressing differentiated passenger groups and functioning on all system levels (stop, line and network).

7.5 SELECTED MODEL

Wagner (2014) developed a method used to optimize stopping distances in an urban environment. The Wagner-method is particular interesting, because it couples both actual passenger usage and stop achievement. The method gives a score per stop based on a benefit-cost ratio that can be used to justify the stop existence. A high score implies a low achievement and the other way around.

The method is furthermore interesting, because it is fairly new and therefore not yet often applied to cases. Using this method creates the opportunity to work with and develop a new method of stop distance optimization.

Since the original method does not fully responds the problem stated in this thesis (the method does not consider differentiated passenger groups), the method is extended and further enlightened.

The chosen and existing method is explained in the section below. The assumptions to the method are discussed thereafter. Since the method does not fully respond to the given criteria, adaptations are proposed as well. Finally, an adapted method overview is given.

7.6 CONCLUDING REMARKS

The public transport environment is changing. Costs and benefits are changing due to political choices. This has consequences for the user of the public transport system. The public transport system in urban environment is the result of years and years of building and planning. According to a number of earlier discussed theories, networks are not as optimal as they could and should be. That means there is room for improving network achievement. This thesis focuses on the relation between different passenger groups and stopping locations. The goal is rationalizing the network according to different passenger groups is useful to create a new way of urban public transport system planning.

There are numerous methods that can be applied for network optimization and so there are for optimizing stopping locations. In this thesis, a method developed by Wagner (2014) is adapted and applied to optimize stopping distances. Stops that are proposed to eliminate are the input for the network assessment.

8 PASSENGERS

The previous section justified a focus on stopping distances and network optimization methods. Passengers do experience the consequences of changed stopping distances. This thesis aims to find a new approach in passenger differentiation that focuses on the process of stopping distances in another way. At first, the possible differentiations are discussed and an approach is chosen. Then the characteristics are discussed that are related to those differentiated groups. Subsequently, a method is selected to apply in the passenger assessment.

8.1 DIFFERENTIATING PASSENGER GROUPS

Passengers have a certain demand for public transport. It is important to know what the travel demand is. If the travel demand is known, the supply of public transport can be adjusted better to the demand. A better adjustment of supply and demand could lead to more consumption of the product, which means more passengers in this particular case.

It is useful to make a distinction between different passenger groups, to get a more detailed view on the demand of public transport. The goal is to match supply of public transport to the differentiated demands of differentiated passenger groups. This should lead to an overall better public transport product that is fine-tuned to the different demands of different passenger groups. Differentiation can be done in various ways. Possible ways of differentiating passenger groups are (APTA, 1992; Mokhtarian & Chen, 2004; Paulley et al., 2006; SEGMENT, 2014):

- travel distance;
- age;
- lifestyle;
- socio-economic data;
- household composition;
- captive and non-captive users;
- income;
- trip purpose.

The focus of this thesis lies at the differentiation towards trip purpose. As stated in the introduction and the problem statement, optimizing stopping distances is often done before from the perspective of one average passenger group (Kocur & Hendrickson, 1982; Chang & Schonfeld, 1991; Spasovic et al., 1994). Several previous researches prove that there exists difference in the way passengers perceive their trip, when differentiating passenger groups, inter alia towards trip purpose (Van der Waard [1], 1988; Koenis, 2008; Van Nes, 2003).

The combination between optimizing stopping distances and involving trip purpose is a gap in science, since the reaction per passenger group on stop distance optimization is still a bit vague if differentiated groups are distinguished. Moreover, there are proves that there is a relation between trip purpose and transport characteristics of public transport passenger groups. By not only applying a rational stop distance optimization method, but rather an assessment on passenger behavior as well, this gap is aimed to close. The next section exemplifies this so-far vague relation.

8.2 DIFFERENTIATION TOWARDS TRIP PURPOSE

Differentiating towards trip purpose is useful, because every group of passengers has identifying characteristics that are related to the trip purpose. For example, work trips are very time restricted and often made during rush hour. The work destination is very fixed as well. On the other hand, shoppers may have a bigger variety in choosing their destination, since different shops are located at different locations. One of the researches that proves the relation between different passenger groups and different valuation of the trip comes from Abrantes and Wardman (2011). The study shows a difference in value of time for different trip purposes. Trips made for leisure were valued lower than trips that were made for commuting. The same counts for shopping versus commuting. The commuting-trip is valued almost 20% higher than the shopping trip. Therefore, a relation is assumed between the trip purpose and the trip specific characteristics.

Furthermore, different previous studies provide information about trip purpose elasticity (elasticity differences for working versus shopping for example), but the underlying reasons what different preferences on travelling mean for travel behavior are not yet clearly mapped (TRACE, 1999). Previous important researches about trip purpose and elasticity were developed by Van der Waard (1988 [1]), Balcombe (2004), Corpuz (2006) and Paulley et al. (2006). This proves the existence of different characteristics in travel behavior. These researches showed singular travel elasticity for different passenger groups, but what remains unclear are the passenger group characteristics on which the elasticity can be based.

This raises questions why elasticity for one group is higher than for another group, since each category of trip purpose comes with specific expectations and demands about the transport (Grotenhuis et al., 2006; Paulley et al., 2006). Those who travel to their work will probably have other transport demands than passengers who are heading to a shopping mall. According to the motive of the trip, different characteristics are applicable for the traveler. When regarding trip purpose, the following groups are often distinguished (Van der Waard, 1988[1]; Van der Waard, 1988 [2]; MON, 2009; Tahmasseby, 2009; OViN, 2013):

- work;
- school;
- shopping;
- others.

This classification is often used when transportation systems are analyzed. The same groups are used in this research, because it is expected that the characteristics are the most marking for these groups. Furthermore, it is expected that the chance that those groups are present in the network is substantial. The next section (8.3) aims give an overview of the different characteristics that are related to the above-mentioned groups.

8.3 CHARACTERISTICS OF DIFFERENTIATED PASSENGER GROUPS

Each group of differentiated passengers has specific characteristics. The mentioned preferences, behavior and interests are based on Van der Waard (1988 [1]), Van der Waard (1988 [2]), Van den Heuvel (1997), Gunn (2001), Wardman (2001), Paulley et al. (2006), CROW (2009) and Koenis (2009).

- Work (workers)

  Passengers that use public transport for work often travel during rush hours. Their trip frequency is often on daily basis. The biggest peaks in the morning and evening are caused by these transit passengers. Costs spend on transport are important for this group. Those passengers want to travel as fast as possible. The time pressure is high and so is their value of time. Transport reliability is coïnciderend high (Van der Waard, 1988 [1]; Van den Heuvel, 1997; Wardman, 2001; Paulley et al., 2006).

- School (students)

  Students and other school-related trips are often made in the morning rush hour and in the afternoon, since school days are often shorter than working days. The school-related trip is often financed by an institution or government. The student often uses PT for free or for a reduced fare. Travel time is considered as important. Study-related trip have a high value of time, but less than work-related trips, because being too late is considered less earnest. The time pressure is relatively high. Demand on transport reliability is high in the morning and less on the return trip (Van der Waard [2], 1988; CROW, 2009).

- Shopping (shoppers)

  Shopping related trips are often made during daytime. Shoppers prefer a seat and short access - and egress distances and times, above costs and travel time. Comfort and convenience are important factors. Costs are not as important as for work-related trips, but substantial compared to other trips. Transport reliability is a less important factor for this group and there is nearly no time pressure (Van den Heuvel, 1997; Gunn, 2001; Koenis, 2009; CROW, 2009).

- Others

  There is no specific description available for this group. Passengers in this group visit a medical purpose, go to a leisure-activity or have other trip purposes. They form a diverse group. Therefore, there is no specific behavior applicable.

The section above proves the existence of different characteristics per group of passengers based on their trip purpose. Each group has identifiable characteristics that are linked to the purpose of their trip. Furthermore, each group of passengers has different valuations of the value of time. When the value of times of access-time versus in-vehicle time are compared, each group has a different value of time.

Wardman (2001) stated that there is a correlation between the trip purpose and the value of time of the trip. This difference is mainly based on discomfort during the in vehicle time. Wardman did found evidence that access time to the stop is differentiable per group. Van der Waard (1988 [2]) found differences in the coefficient of access time ratios. The following value of time coefficients (W_a) were found:

Work = W_{wa} = 1.5
Shop: = W_{sh} = 2.6
School: = W_{sc} = 4
Other: = W_o = 3.8

The average walking time ratio (W_a) is not the average of the four coefficients, because this would imply that every group is equally present in the system. Therefore, the average W_a is set at 2 for the total passenger group (TRB/TCRP 95, 2004; Litman, 2008; Wagner, 2014).

Total = W_a = 2

These VoT-ratios are used in the network assessment to calculate the BC_n-ratio per trip purpose group. As discussed in the problem statement, it is interesting to map their reaction to less stops and to search for possible compensations –if necessary– that should prevent the fallback of transport usage per passenger group. The next part aims to find possible measures that would help to prevent this effect.

8.4 PASSENGER ASSESSMENT

Stop closure is inevitable connected with passenger loss, since longer access times will form a threshold for certain passengers. It is therefore interesting to find possible measures (such as better access, cheaper rides and etcetera). Different compensations are compared to find the best measures per group. The process is called *Passenger assessment*. The passenger assessment methodology should comply with several criteria. Those criteria are formulated in such a way that an optimum method is sought to answer the main question. Those criteria are:

- focus on trip purpose;
- possibility to compare different attributes;
- predict changes in the system;
- valuation of public opinion.

There are numerous methods to evaluate and to predict passenger behavior on changing public transport systems. This thesis seeks for a method that is able to find preferences of passengers about system changes. The level of acceptability of changing supply of public transport is together with possible compensating attributes the most important goal of the passenger assessment. There are different possible methods to apply (Molin et al., 1996; Tuleda et al., 2006; Bryman, 2008). The table below summarizes different possible social research methods. A range of requirements to the methods is listed horizontally. In the rows, a match indication between the requirements and the methods is given. Thereafter, the results of the table are evaluated.

Table 8.1 Methodological overview of social research methods (Molin et al., 1996; Tuleda et al., 2006; Bryman, 2008).

Method/ Requirement	Accuracy	Compare attributes	Predicting changes	Valuation of public opinion

Cost-benefit analysis	Highly accurate method, due to mathematical approach.	Only monetized components can be compared, which requires monetizing of all attributes.	Monetizing benefits could lead to misinterpretation and thus incorrect future scenarios.	Hardly any inclusion of public opinion and mainly economic driven
Multi criteria analysis	High, but confuses personal interest with public interest	Flexible among many attributes	Accurate characteristics of predicting effects of new solutions	Fairly good inclusion of public opinion
Scorecard	Low accuracy, due to simple structure	Rational comparison	Does not include non-quantifiable effects	Not possible
Stated preference survey	Highly accurate, due to series of trade-offs instead of single comparison.	Strong: attributes and values can be analyzed separately.	Method designed for this purpose	Outcome based on choice of user, thus good evaluation
Revealed preference survey	High, but with possible errors	Good, if there are no major changes in the system.	Weak, is based on current behavior	Only if evaluating current situation

Evaluation of methodological overview:

- Cost-Benefit Analysis. The CBA is similar to the MCA, but is more objective due to the usage of purely quantitative data.
- Multi Criteria Analysis. A MCA is useful because it can compare different compensating measures for the stakeholder groups. It also ranks the usefulness for these groups.
- Scorecard. A scorecard is a quick way to estimate the different effects per alternative, but is not very precise.
- Stated Preference Survey. The SP-survey focuses on opinion of the customer. The customer ranks different sets of alternatives. The results reflect the wishes of the customer and gives direct result on possible solutions.
- Revealed Preference Survey. The RP-survey is suitable to find the behavior of passengers. The RP-survey is of good usage if the context of the proposed effects remains the same. On the other hand, the RP-survey requires many respondents and is not suitable to predict reactions on big proposed changes.

According to the evaluation of methods above, the Stated Preference-survey (SP-survey) is the most useful for this research. The SP-survey is renowned for the ability to forecast the effects of changes in systems. Furthermore, the SP-survey is able to find results based on different characteristics of differentiated passenger groups. Besides, the SP-survey fills the gap in scientific knowledge what this thesis aims to close.

8.5 SELECTED METHOD

The passenger assessment is applied with a stated preference survey. The structure of the passenger assessment and the application of the stated preference survey are clarified in the next section. The method is explained in general basis in part C. Thereafter, the passenger assessment is applied to the case in part D.

8.6 ATTRIBUTES OF SP-SURVEY

The candidate attributes for the SP-survey are sought in previous studies and other literature via a qualitative meta-analysis (Dixon-Woods et al., 2006). The purpose of this method is to filter a few effective compensating measures out of a long list of potential compensating methods found in previous studies. This inductive method lists previous main researches on passenger behavior, public transport attributes and quality aspects. Those attributes have been compared in the qualitative meta-analysis to find common attributes that contribute to passenger appreciation. The results of the method constitute a short list of factual compensating attributes. These attributes are used in the SP-survey.

Long list

The table 8.2 below visualizes the long list. This long list is the output of the meta-analysis. The tags, which are mentioned per article per attribute, are conclusions based on the general findings per paper. The short list, containing the attributes for the SP-survey follows behind this long list. Counting the number of tags indicates the importance of the attribute. The most important attributes can be seen at a glance via this list

The found articles are sorted on case study, literature study or another type of study. The articles have been sought via scientific research archives as Science Direct and Google Scholar. Only articles with peer reviews and articles from renowned authors have been used. It must be reckoned that the results depend on the selection of articles. Nonetheless, this analysis gives an overview of the attributes.

Table 8.2 Matrix method to compare different attributes.

	Article/ Attribute	Price	Frequency	Service	Speed and travel time	Comfort on stop	Waiting time valuation	Convenience and accessibility
Case	Falzarano et al. (2001) *Quantifying the value of transit station improvement*					Proper protection from weather and decent lightning are the most important stop attributes		
	Pucher et al. (2005) *Public transport reforms in Seoul*						Priority for public transport increases average speed and contributes to ridership	
	Beirao & Cabral (2007) *Understanding attitudes towards public transport and private car*			Key finding is that service should be designed so that it accommodates levels of required service		Comfort is very important for users		The PT-system is often perceived as inconvenient and difficult
	Nielssen (2007) *Network design for public transport success*		Multiple lines forming a network increase the usage of each line					
	Wall & McDonald et all (2007) *Improving bus service quality and information*	Simple price structures increase willingness to travel	Increasing frequency can lead to significantly more passengers	Providing clear information contributes to quality percipience		Modern and new furniture at stops leads to higher appreciation. Shelters are highly appreciated		PT-information at stop does not necessarily leads to higher ridership
	Eboli & Mazzulla (2008) *A stated preference experiment for measuring service quality in public transport*	Price and frequency most important quality attributes						
Literature	Andreassen (1995) *Dissatisfaction with public services: the case of transportation*	Price critical for passenger satisfaction			Higher speeds lead to higher passenger satisfaction	Platform lay-out is considered as important		Frequent passengers attach more value to attributes than non-frequent passengers
	Hensher (2003) *Service quality-developping a service quality index*	Reducing price is not the best solution to improve service. Improving other attributes and maintain ticket price	The frequency of the service is considered important by all passenger groups		Travel time is not considered as the most important negative transport attribute	A shelter with a seat at the stop is highly appreciated.		

	Del Castillo & Francisco (2012) *Methodology for modeling and identifying users satisfaction*		High service frequency is highly weighted.					Stopping locations must be adequate.
	Litman (2008) *Valuing transit service quality improvements* and (2013) *understanding transport demands and elasticity*	Work and school travel are less price sensitive than other purposes		High-end service is appreciated, but almost never offered		Commuters are expected to pay more for better service and higher quality		Inconvenient PT causes higher unit travel time costs
	TRB TRCP 165 (2013) *Quality of service concepts*			Real time information at stop reduces perceived waiting time significantly		Presence of information at stop is essential	Dirty stops cause IVT-equivalent to triple.	Is there a stop near the origin and destination?
	Dell'Olio et al. (2011) *The quality of service desired by public transport users*					Casually passengers will value high comfort as very important attribute.	Waiting time is the most important factor. Frequent users will try to reduce waiting time as much as possible	
	Redman et all (2012) *Quality attributes of public transport*	Reduced fare promotion measures can succeed in encouraging public transport usage		Service is more important than physical attributes				Improving accessibility to the stop leads to increasing usage
Other	Rietveld et all (2001) *Coping with unreliability in public transport chains*	Price and travel time are strongly related				Proper cycle parking at a stop is very wanted		
	Levinson et all (2003) *Bus rapid transit volume 1: case studies in bus rapid transit*		Offering a frequent-all day service is important for quality of PT. Increasing frequency leads to more passengers					
	Rietveld (2005) *Six reasons why supply-oriented indicators Systematically Overestimate Service Quality in Public Transport*			Service is often overestimated by operator compared to customer evaluation			Solely observing waiting time from supply side leads to underestimation of waiting time	
	Count	7	5	6	2	9	4	7

This section lists the attributes that are the most convenient to implement in the SP-survey, according to the results of the meta-analysis:

- Comfort is the most important factor at a stop.
- Price compensation is a feasible way to attract passengers.
- Convenient access leads to higher appreciation.
- An extra attribute that is added to the SP-survey is travel time profit that was calculated in the network assessment. The travel time profit is applicable on all measures.

Based on those three conclusions, the SP-survey contains three compensation measures based on those conclusions. The measures are discussed in the next chapter.

Selecting attributes for SP-survey

The meta-analysis showed that three compensating directions are the most feasible to use for compensation at adjacent stops to attract passengers to those stops. These are price, comfort and convenience. The goal of this

analysis is to seek for attributes that are usable for each compensating direction. The price-compensation is not part of this analysis, since the price is much related to each case individually.

The analysis is based on benchmarks of other urban public transport systems. The analysis is based on European cities that recently implemented or changed an urban transport system. It is expected that the stop attributes in those systems were carefully selected in the recent design stage to attract (potential) passengers. By analyzing these systems, attributes are sought that contribute to a higher passenger satisfaction level (Henning et al., 2011). So high, those passengers are willing to bridge the *extra* distance from the original (closed) stop to the adjacent stop.

The table below summarizes a few modern and recent tram projects and lists the amount of attributes that belong to one of the three compensating directions subtracted from the meta-analysis. The attributes are found via the websites of the operators.

Table 8.3 Compensating attributes.

City	Year	Comfort at stop	Convenience
Le Havre (France)	2012	Shelter with wind and rain protection; 4 or more benches Bins	Digital information system Travel information Limited bicycle parking
Mulhouse (France)	2006	Limited sheltering 1 to 3 benches Bins	Digital information system Travel information
Edinburgh (Great Britain)	2014	Limited sheltering 1-3 benches	Digital information system Limited travel information
Innsbruck (Austria)	2012 (new section)	Limited sheltering 1-3 benches	Digital information system Travel information
Paris (France)	2014 (new section)	Extensive sheltering 4 or more benches	Bicycle parking at few stops Digital information system Travel information
Dublin (Ireland)	2004	Limited sheltering 1-3 benches	Bicycle parking at most stops Limited travel information
Bergen (Norway)	2013 (new section)	Extensive sheltering 4 or more benches	Bicycle parking at few stops Digital information system Travel information

The most mentioned compensating measures are shelters, although in limited performance, digital information and convenient cycle storage places. Per case should be determined which compensating attributes are feasible to implement. If there is already digital travel information, this compensation is useless to propose. If the adjacent stops do already have (limited shelters), it could be useful to update them. Cycle storage is often suggested as feasible solution to attract more passengers (Martens, 2007).

When comparing these outcomes with the results of the literature research, some preliminary conclusions could be drawn. Passenger groups as commuters and students value travel time high. Accessing a stop by bike could reduce the travel time. Therefore, the convenience measure that is proposed is bicycle parking at stops. Shopping passengers prefer more comfort during their journey. Therefore, proper waiting facilities (with sufficient wind and rain protection) are proposed as comfort-attribute. The price-attribute is expected to be interesting for all passenger groups, except the school-going-group, since this group often benefits of free transportation. The compensation measures that are used in the SP-survey are visualized at the generic passenger assessment section (chapter 13).

8.7 CONCLUDING REMARKS

This chapter proves the existence of different characteristics related to passenger groups that are differentiated on their trip purpose (work, school, shopping and others). The characteristics are of such nature that they do distinguish passenger groups in a very fundamental way related to how the trip is made.

The different values of time ratios prove that there is a difference in the willingness to bridge a certain distance. By using these values in the network optimization part (next chapter), results about stop use are obtained.

By applying a method (in the passenger assessment), the research aims to find reactions of passenger groups on stop closure and stop distance optimization. Furthermore, the passenger assessment seeks for measures of compensation that could be linked to the differentiated passenger groups. By applying those measures on adjacent stops of closed stops, the specific passenger group is teased to bridge a higher access time.

9 CONCLUSION

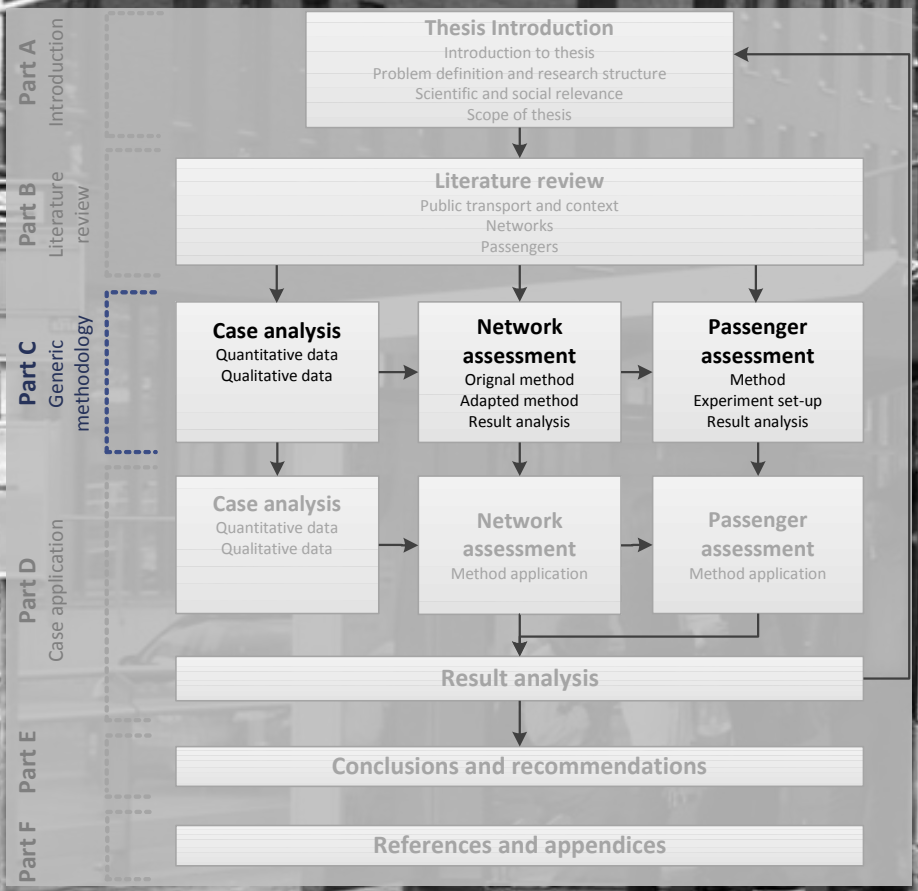
The purpose of the literature framework was plural. At first, the institutional context for public transport was stated. The need to optimize stopping distances was proved by this section. Furthermore, the most important actors (authority, operator and passengers) were introduced in this section. Their mutual relation was briefly described.

The second chapter sought for network optimization methods. An existing method was chosen and adapted to the demands that were set in this research.

This part ended with a chapter about passengers that aimed to find and justify differences in travel behavior between differentiated passenger groups. By applying the differentiation on trip purpose, evidence was found that the characteristics and preferences differ per trip purpose.

The next section treats the methodological roadmap that is created in this research. The roadmap is applied in a general way, so that is applicable on other cases as well. Moreover, with the general appliance of the methodological roadmap, the operation and the steps that are taken are clarified.

PART C – GENERIC METHODOLOGY



The third part of the research (part C) contains the general methodological overview of the different methodological steps that were taken in the literature review (part B). The purpose of this part is to introduce and explain the methods that form the methodological roadmap together. By applying the method on generic level, each step is justified. The next part (part D) applies the generic roadmap to a case.

10 GENERIC METHODOLOGY OVERVIEW

In imitation to the literature research, this chapter gives an overview of the methods that will be applied. At first, the methods are summed up. Thereafter, each method is extensively explained. In the next part (part D), the methods are applied to the case study.

10.1 CASE ANALYSIS

The case analysis has the purpose to understand which specific data is relevant in the case. The case analysis treats the network layout, passenger usage, policies, and etcetera. The case study is discussed on generic level in this part and applied to the case in the next part.

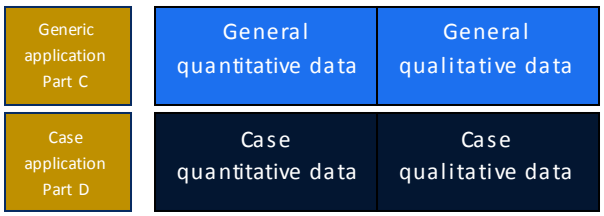


Figure 10.1 Structure of case analysis.

The case analysis consists of two sections. The first part is a quantitative analysis about stopping distance, passenger and load information and main origins and destinations near stops. The second section of the analysis is qualitative oriented, about network costs, trip purpose differentiation and specific policies from stakeholders. The result of the case analysis is an overview of transport policy and an overview of network characteristics about stopping distances, stop function and network usage

Required data: policy documents, policy on public transport by authority and previous researches.

10.2 NETWORK ASSESSMENT

The network assessment method generates an advice based on stop performance for each of the differentiated passenger groups. The precise method was not found in literature. However, a well-structured method about stop performance has been made by Wagner (Wagner, 2014). This method was considered a proper base method and extended to the demands of this thesis. The method selection is justified in chapter 7. The extensions to the method were explained in the same chapter. The method is applied to the case in part D. Testing the method on a case study creates the ability to test the method and to generalize the results. The result of this method is an overview of stops with a certain critical level of performance.

Required data: differentiated passenger usage loads, stopping distances, value-of time-ratios, walking speed, walking resistance.

10.3 PASSENGER ASSESSMENT

The last step of the methodology roadmap is the passenger assessment. The goal is to find out how the loss of transport supply due to stop closure could be compensated. Since this thesis focuses on differentiated passenger groups, the purpose is to find compensating measures per passenger group. In literature are numerous attributes explored about comfort, service and making public transport more attractive. This part of the methodology aims to find measures that match the travel behavior and demand of the selected passenger groups, based on a meta-analysis and a stated preference survey.

The stated preference survey is conducted on a range of selected stops. The SP-survey answers the question what solutions would keep differentiated passenger groups still travelling with the public transport system, even when the stop is closed (and thus the distance to adjacent stops is bigger).

The result of this assessment is an overview of which compensating measures fit to the passenger groups that are hit the hardest by the stop closure. This should prevent fallback of public transport use due to the reduced supply of transport.

Required data: travel behavior of differentiated passenger groups from literature review, transport policy of transport Authority (subtracted from the case analysis) and a list of stops that are candidate for closure.

The next part continues with the first mentioned methodology: the case analysis. Thereafter follows the network assessment. This part finishes with the passenger assessment. All these methodologies are applied in a generic way.

11 GENERIC CASE ANALYSIS

The case analysis contains case specific information. This knowledge is mostly important to perform the next step, the network assessment. The generic case analysis gives answer to the question which aspects of the case are important to involve in the network assessment.

The results of the case analysis are necessary for the network assessment and passenger assessment, because the case analysis will provide knowledge on case specific network design and policies from operator and authority. The case analysis also generates an overview of transport policies made by the operator and/or the authority.

The case analysis both encompasses quantitative and qualitative data. In the section below, the content of both parts is briefly explained. In part D of this thesis, the case analysis is applied to the chosen case.

11.1 QUANTITATIVE DATA

The quantitative data is about stopping distances, network speeds and passenger usage. Those three network elements are important to conduct the network assessment ant the stated preference survey (see the network assessment and SP-survey in this part).

The network stopping distances are needed for the network assessment. They can be measured via tools as Google Earth, if this data is not available by the operator. It is important to measure constant and accurate. The stopping distances are rounded to ten meters. Lower units (on meters) causes measuring errors, higher units (hundred meters) are not accurate enough. The distance is measured from the middle of one stop to another. If stops are not synchronically located, for example on both sides of a crossing road, the middle of the two opposite stops is given. This concept is visualized in figure 11.1:

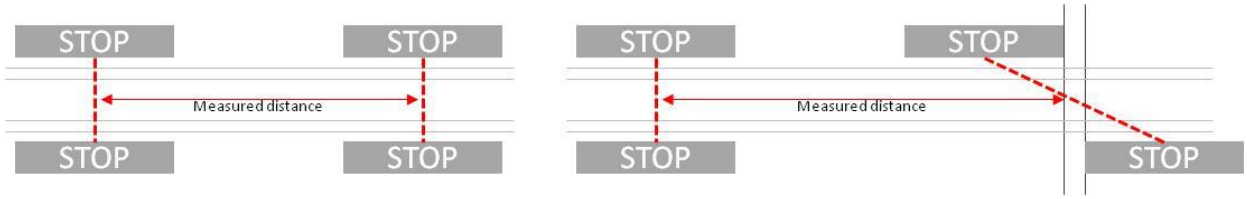


Figure 11.1 Measuring methods for stopping distances.

Network speeds give an overview on the places in the network where speeds are higher or lower than the design speeds. They are calculated with the information on stopping distances and the travel times between stops. The network speeds can be calculated in different ways. The information about travel times is available in the schedules published by the operator and these travel times are combined with the stopping distances to obtain the network speeds.

Another way to obtain network travel times is to use real time vehicle data. Operators offer more and more open data about actual vehicle locations. This information can be used to extract travel times. Extracting travel times from real time vehicle location is more accurate (on seconds) than schedule information (on minutes). However, calculating in minutes is often accurate enough. Sometimes the specifically information on speeds between stops is known by the operator.

Passenger usage is often the most difficult to obtain. There are various ways to obtain passenger usage numbers per stop. This information is needed so that an image can be obtained on the differentiated passenger group usage per stop. Besides, with passenger usage figures, the use of the stop can be judged. Data on passenger usage can be obtained via the operator, from traffic model systems or out of sample data.

11.2 QUALITATIVE DATA

The second part contains information about the share of passenger differentiation, policies from the operator and stop attributes

The **Share of passenger differentiation** says something about the use of different passenger groups. Since this thesis is focused on differentiated passenger groups towards trip purpose, a significant share of different passenger groups must be present in the network. If only one differentiated passenger group is dominantly using the system, it would not be justified to use the trip purpose segmentation, since a distinguishing factor would not be found. The data about passenger differentiation can be obtained via samples among passengers or via the operator.

The **Policy from authority** provides information about the goals and targets from the authority for the operation of public transport. By analyzing these policies, the right of existence for certain stops could be justified. Policies can contain demand on stops near hospitals, schools, shopping centers, and so on.

Specific network policy provides information about special parts in the network. An optimization method creates a simplified model of the reality. In this model, important functions of the network may get lost. For example, a stop near a school is only used before and after school time. The stop could be underused during the rest of the day. The model might suggest removing the stop, while the function of the stop is considered as important. Therefore, analyzing the stops for important nearby destinations can help to decide whether a stop should be removed or not.

Stop attributes: suggesting stop removal demands knowledge of the conceptual design guidelines behind the stop. When a public transport line is planned, the stops are the access- and egress points of the provided transport service. The location of a stop has a major impact on the total travel time of the passengers, because of the time it takes to reach the stop (Murray et al., 1998). The environment of a stop is the catchment area of the stop. The catchment area is the area in which people consider the transport service that serves the stop as a feasible transport mode for their trip. In other terms, people that live in that area, are potential passengers of the system (Wibowo & Olszewski, 2005; Landex & Hansen, 2006).

There are different methods to determine the stop catchment area. In this thesis, the space around the stop is considered as a square. Using squares is the most accurate method of considering the urban structure around stops, since overlap is prevented. Using circles around stops would cause overlap and give difficulties in determine the influence areas of the stop.

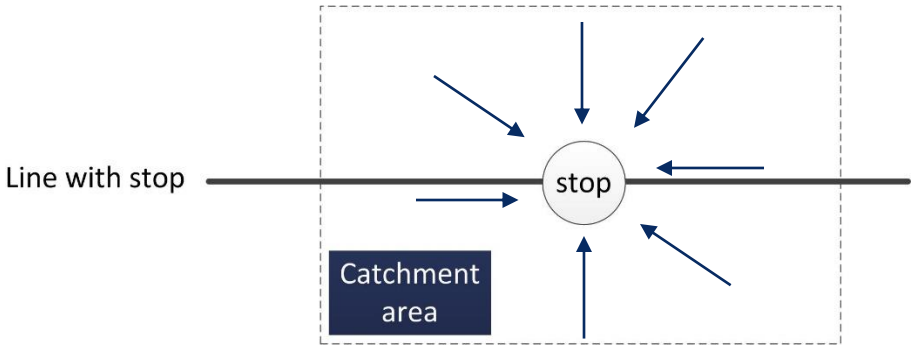


Figure 11.2 Catchment area of the public transport stop (based on Landex & Hansen, 2006).

There are limitations to this approach, because using squares assumes that the distribution of passengers is evenly spread over the square. In urban environments, it may be accepted that this simplification is accepted.

This thesis assumes that passengers only walk parallel to the line and not in perpendicular direction. The assumption means that the actual walking distance to the stop is underestimated (Von Lupke, 1983). This underestimation is accepted and negated in the network assessment.

Furthermore, considering a perfect square does not take the geographical surrounding is account. The geographical surrounding often causes the actual access distance to the stop to be bigger than the theoretical catchment area (Landex & Hansen, 2006). Obstructions that prevent the most ideal and direct access are for example rivers, bridges, railway lines, building blocks and etcetera. This limitation to the method is visualized in figure 11.3.

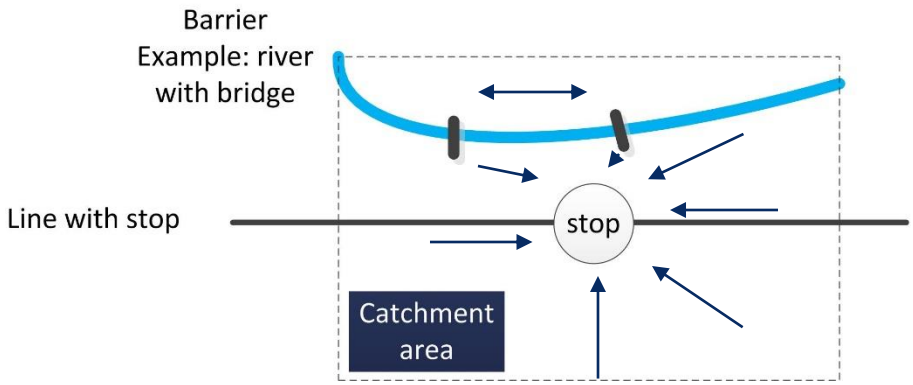


Figure 11.3 Barrier in catchment area (based Landex & Hansen, 2006).

Nonetheless, it is assumed that the chosen method is accurate enough, since the focus of this thesis lies at the behavior of passenger groups and not on the relation between the stop and the urban physical structure.

12 GENERIC NETWORK ASSESSMENT

This chapter explains the network assessment in a generic way. The selection of the method applied in the network assessment was exemplified in the literature research.

The method was considered incomplete, as concluded in chapter 7. The original method only treats passenger groups as a whole. The purpose of this thesis was to differentiate passenger groups. Therefore, the method is extended, so that it can cope with different passenger groups. Furthermore, the method is works on stop level, but does not cope with line level and network level. Therefore, two extra levels were added to the method.

Some assumptions that were made in the original method are considered too simple. Those shortcomings will be discussed in the next sections. Subsequently, the parameters of the new model are treated. Finally, the expectations are given. The network assessment ends with an example to illustrate the process.

12.1.1 METHOD DESCRIPTION

The applied network rationalization method for this thesis is a Benefit-Cost evaluation method for transit stop removal that was developed at the Portland State University by Wagner (2014). The method was published and presented for the first time at the Transportation Research Board 93rd annual meeting.

The general idea behind the method is that removing stops leads to faster transit on a given line. Stops can be removed if the benefits for passing passengers are higher than the costs for stop-using passengers according to this method. The method uses quantities of boarding and alighting passengers and in-vehicle passengers. Eliminating a stop is considered as being positive (benefits) for the in-vehicle passengers and negative for the stop-using passengers (costs).

The method calculates a benefit cost-ratio (BC-ratio) for eliminating a stop in the network. This BC-ratio is based on costs and benefits. The costs are expressed in walking distance and time for passengers that have to use another stop. The benefits are expressed in travel time gain for passengers that have reduced travel times. Goal of the method is to find stops that perform bad and could be eliminated to rationalize the operation. The steps and associated formulas are given below.

Benefit-Cost Ratio = B/C (BC-ratio) [1]
Where
B= Total Benefit
C= Total cost

The stop is evaluated as follows:

If B/C> 1, the stop removal should be approved
If B/C< 1, the stop removal should be rejected

The benefit of removing a stop is a function of passengers riding through the stop and gain time for skipping the stop:

$$B = P_r * T_r \quad [2]$$

Where
B = generalized benefit
P_r = passengers riding trough (number)
T_r = additional travel time due to stop (constant)

The cost for removing a stop is a function of the number of passengers that is using the stop. These passengers experience an increased travel time, because they have to access the network via another stop.

$$C = P_a * T_a * W_a \quad [3]$$

Where
C = generalized costs
P_a = passengers accessing or egressing at stop

T_a = net increase in travel time per person to use adjacent stop
W_a = weight for access time

T_a is the average additional travel time experienced by passengers whose stop is removed and have to access via another stop.

$$T_a = D_{aw}/V_w \quad [4]$$

Where
D_{aw} = average additional walking distance to remaining stops
V_w = average walking speed

The stop's service area is assumed half the distance to the nearest stop in each direction. The method assumes passengers to migrate to the nearest remaining stop after elimination.

$$D_{aw} = (D_n * D_f)/(D_n + D_f) \quad [5]$$

Where
D_n = Distance to near stop
D_f = Distance to far stop

The calculation for the additional walking time as discussed above needs extra elucidation to prove the correctness of the formula. The formula calculates the extra walking distance from the middle of the influence area left or right at a stop towards the next stop. The concept is of the additional walking distance is explained in annex 1.

12.2 ORIGINAL ASSUMPTIONS

The model as explained above is based on the following assumptions that are considered correct. It is assumed that all stops are being served. There is no probability taken into account that any-one wants to board or alight at a stop so that the vehicle does not has to stop at all. This assumption can be justified, because on-board passengers do not experience an unplanned stop-skip as overall gained travel time, since they could not know on forehand that the stop would be skipped. Besides, on busy main lines, it is unlikely that many stops are skipped. At quiet branches of the network, this may happen more often, but fewer passengers benefit from it, causing the gain negligible.

Furthermore, the original method assumes a perfect street grid around the stop. This assumption is justified, since the method just needs passenger usage data and does not regard the urban environment itself on stop level. Furthermore, it may be assumed that a dense urban structure knows a well-organized infrastructure with proper access-possibilities.

Confined assumptions: The following assumptions are considered incomplete.

The most important assumption is that stop removal has no effect on usage of the overall system, both for the passengers that experience longer travel times (walking to other stops) and passengers that experience shorter travel times (due to reduced travel times). This assumption is too simple for the method and can be considered wrong (TRB/TCRP, 2013). Therefore, a certain method to calculate passenger loss is introduced.

The method assumes that stops on either side of candidate elimination stop remain. This assumption is too simple, since three or four stops in a row could have a BC-ratio higher than one. The next section contains an adjustment to this assumption. Furthermore, no limitations are made on the direction of the stop. According to the original method, a stop may be eliminated in one direction, but could remain in the opposite direction.

12.2.1 LIMITATIONS OF ORIGINAL METHOD

The assumptions mentioned above are considered too shortsighted. In the next part, extensions to those limitations are proposed. As mentioned in the method-selection section, the method has two other important shortcomings. Those limitations are discussed below.

Line and network level: The original method is only treating the system on stop level. As explained in the first part of this chapter, this could harm the line and network level, because removing stops has consequences for the line and the network. Therefore, two additional steps must be added to the method to prevent impoverishment of the whole system due to nearsighted system optimization.

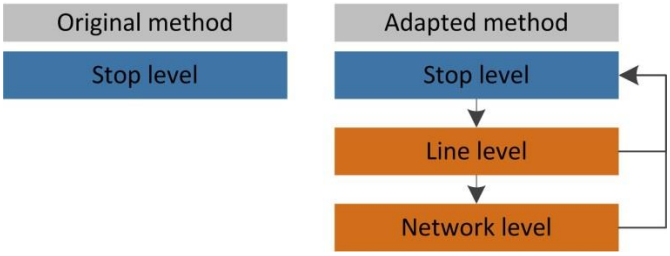


Figure 12.1 Suggested adaptations for system levels.

Differentiated passenger groups: The BC-ratio is originally only calculated for the passenger group as one whole. Due to the focus on differentiated passenger groups, the adapted method must also treat BC-ratios for differentiated passenger groups. In the next section, the adaptation is further explained.

Passenger loss: the original method assumes that the use of public transport remains constant. One can expect a change usage if a certain stop is closed. Therefore, the method is extended with a module that calculates passenger loss on stop level.

12.3 ADAPTATIONS TO ORIGINAL METHOD

The original method does have shortcomings that prevent the model to generate the desired results: In this section, the adaptations to the original method are explained. A short summary of shortcomings that where discussed in the previous sections:

1. No differentiated approach of passenger groups;
2. No effect of changing transport usage by stop removal;
3. No line approach
4. No network approach

12.3.1 DIFFERENTIATED APPROACH: BC_N-RATIO

The calculation method of the BC-ratio is the same as in the original method, except for the fact that in the adapted method, the calculation is made for every passenger group (work, school, shop and others). Thus, the BC-ratio is given for all groups. This ratio is called the BC_n-ratio, in which n is the specific passenger group. The related formula to calculate the BC_n-ratio is given below.

$$Benefit_n\text{-}Cost_n\ Ratio = B_n/C_n \quad (BC_n ratio) \qquad [6]$$

Where

B_n = Benefit for passenger group n

C_n = Cost for passenger group n

12.3.2 STOP LEVEL: CHANGING TRANSPORT USAGE

It can be expected that stop closure cause loss of passengers. The existing method is extended with a module that calculates loss of passengers on a hypothetical way with parameters in literature on stop level. The actual loss of passengers is not part of the original BC-ratio. This addition aims to complete the figures of passenger loss in the stop level method.

An important subject in these theories is the distance that one is willing to bridge from their current location (a house for example) towards an access point of public transport. Depending on the type, frequency, level of hierarchy, etcetera of transport, this distance that one is willing to bridge, differs (Meyer, 1971; Gerland & Meetz, 1980). Based on these characteristics, the influence area of a stop is determined. Previous studies on influence

areas and walking resistance help to determine the walking resistance (K) for this thesis come from O'Neill et al. (1992), Zhao et al. (2003), Kuby et al. (2004), Schlossberg et al. (2007), Van der Blij et al. (2010), and El-Geneidy et al. (2013).

The module is programmed so that an increase of X meters walking distance leads to a decrease of Y passengers. The total expected loss of passengers is then showed. The calculation on this method is as follows:

$$P_l = P_a - P_r \quad [7]$$

Where:

P_l = loss of passengers

P_a = number of passengers boarding or alighting at stop

P_r = remaining passenger number

The amount of lost passengers (P_l) is calculated based on a distances to the next stop and percentages of passengers that will walk the distance (which is given by K). The longer the distance, the fewer passengers will walk to the next stop (ASVV, 2012). The calculation for loosing passengers is described below:

$$P_l = K * P_a \quad [8]$$

Where:

P_l = loss of passengers

K = parameter walking resistance (specified below)

P_a = passengers using stop

The factor assumes the density around stops is equally spread over the urban environment. This method was considered to be incomplete, since it does only take the average distance to the adjacent stops into account, which implies that only horizontal distances are used. Therefore, vertical distances should be applied as well. This results in bigger rates of passenger loss, since the distances from each cell is also calculated vertically. This concept is illustrated in the figure below.

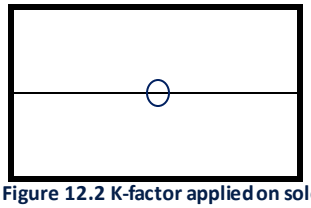


Figure 12.2 K-factor applied on solely horizontal basis.

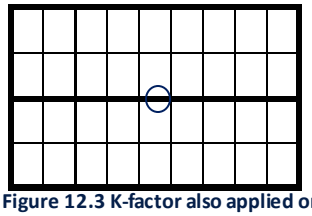


Figure 12.3 K-factor also applied on vertical basis.

The figure on the right side assumes that all passengers spread equal and that the willingness to access is only present horizontally along the line. The figure on the right visualizes a grid that also takes vertical access into account.

The Transport Research Board or TRB (2013) published an overview of different walking resistances to stops. The information in this paper is used to determine the walking resistance (K), because of the clear description of the walking resistance. It is assumed that the walking behavior of passengers is comparable for this case in the Netherlands, although the TRB-survey uses data from other countries. The data is assumed accurate enough to use in this case. The values of (K) are:

If $D_{aw} < 100$ meters, then K = 0.9,
If D_{aw} 100 < 150 meters, then K = 0.8,
If D_{aw} 150 < 200 meters, then K = 0.7,
If D_{aw} 200 < 250 meters, then K = 0.6,
If D_{aw} 250 < 300 meters, then K = 0.5,
If D_{aw} 300 < 350 meters, then K = 0.4,
If D_{aw} 350 < 400 meters, then K = 0.3.

K is an incremental parameter. A small comparison was made with an integral-approach in which the loss for each section around the stop was calculated. The results of this approach are comparable with the above-

mentioned method. Annex 10 contains a calculation example of this more detailed approach. The case assessment will test the feasibility of this method.

Furthermore, in this thesis, stops are only proposed for elimination if elimination is applicable in both directions.

12.3.3 LINE LEVEL: GREEDY ALGORITHM

The original method does not provide a module that deals with rows of stops with a BC-ratio bigger than one. According to the method, all the stops should be removed, but removing one stop has consequences for other stops. Passengers that will shift to another stop, cause a change in degree of the BC-ratio of that stop. The original method states that it is not preferable to remove more than one stop in a row. The extended method provides a more structured approach for this problem, which is explained in the next paragraphs.

There are different methods that could be used to deal with this problem. An expert of public transport could judge on which stop should be removed. This requires detailed knowledge of the PT-system. Therefore, an expert's judgment is not, by definition, the best solution. An algorithm for sequential decision-making is preferred, because the rational decision process generates accurate results (Lederman, 1996). The problem addressed in this section is the search for a local optimum that optimizes the elimination process of stops in a row, because the affected stops are in a local area. The search for a global optimum is needless, since stop elimination in area A minimally affects the same process in area B (only applicable if a passenger uses both stops A and B). The use of a greedy algorithm suits this requirement, since it searches for a local optimum, which is not necessarily the most optimal solution. The greedy algorithm is able to find local optima.

The use of a greedy algorithm is a heuristic. This heuristic contains a criterion that is used to determine the choice that is most likely to make to lead to an optimal solution (Cormen et al., 2009). The criterion used in this algorithm is to keep as many as passengers possible with the least amount of eliminated stops possible. This step does not distinguishes stops with BC > 1 and stops with BC > 1, $BC_n < 1$, since both types of stops are candidate for elimination. Therefore, the greedy algorithm does not make distinction between stops that perform overall badly and stops that perform badly, but have at least one group of passengers that do has stake in keeping the stop. Stops that are eliminated by the greedy algorithm are also candidate for compensation measures (discussed in the passenger assessment).

The process of removing stops in a row of stops with BC higher than 1 is conducted as follows

6. Select the stop with the highest BC-ratio;
7. Change the stopping distances between the selected stop and the adjacent stops in such a way that they become new consecutive stops;
8. Calculate passenger distribution over adjacent stops;
9. Eliminate original stop and check the new BC-ratios of the former adjacent stops;
10. The process stops when all stops with BC-ratio > 1 are gone either through removal or due to passenger increase.

This method is only applied to strings of stops that exist in both directions. The process is visualized in the next table:

Table 12.1 Greedy algorithm.

Name	Dist. near	Dist. Far	BC-total	Usage
Willem Ruyslaan	390	540	0,8	538,57
Avenue Concordia	390	670	2,5	146,25
Woudestein	250	670	1,8	219,1
Oude Plantage	250	330	3,1	136,89
Lage Filterweg	330	490	0,2	456,33

Name	Dist. near	Dist. Far	BC-total	Usage
Willem Ruyslaan	390	540	0,8	538,57
Avenue Concordia	390	670	2,5	146,25
Woudestein	580	670	1,8	219,1
Oude Plantage			3,1	136,89
Lage Filterweg	490	580	0,2	456,33

Name	Dist. near	Dist. Far	BC-total	Usage
Willem Ruyslaan	390	540	0,8	538,57
Avenue Concordia	390	670	2,5	146,25
Woudestein	250	670	0,8	297
Oude Plantage			3,1	
Lage Filterweg	330	490	0,1	515

1: search stop with highest BC-ratio *2: change stopping distances* *3: calculate distribution and eliminate stop*

The example shows how the BC-ratio changes when stops are removed. By applying this method, the range of stops that initially should have been eliminated, is reduced to a minimum. By incrementally removing the stops with the highest BC-ratio, other stops get the 'opportunity' to reduce their BC-ratio, because passengers redistribute over the adjacent stops. The calculation of passenger redistribution is done via a ratio based on the stopping distances between the near stop and the far stop. This ratio is calculated as follows:

- Near stop ratio: (additional walking distance / near stop distance) * 100%
- Far stop: (additional walking distance / far stop distance) * 100%

This process is one way of redistributing the passengers. The process assumes that passengers distribute according to this ratio over the adjacent stops. It is assumed in this thesis that the results are accurate enough.

The greedy algorithm neglects the fact that the level of in-vehicle passengers also changes due passenger redistribution. Passengers using a specific stop are becoming in-vehicle passengers when passing an adjacent stop. Changing stop location changes therefore the level of in-vehicle passengers as well. This effect is neglected, since it expected that the changes are not significantly contributing to the level of in-vehicle passengers. The stops that are proposed to be eliminated have after all low contributions to the total ridership.

12.3.4 NETWORK LEVEL: OMNITRANS

The effects on network level are not part of the original method as well. Therefore, the stops that are proposed to be eliminated (based on the BC-ratio, which includes also stops with a BC_n-ratio, and the greedy algorithm) are put in an omniTRANS model. This program is a transport modeling software tool. By running the model, load factors are allocated to stops and lines. By applying this action, the differences in passenger usage can be checked and compared with the expectations of lost per stop as calculated in the first step on stop level.

The purpose of the network level-model is twofold. This method aims to verify the passenger losses that are generated in the stop level-method. Furthermore, this method shows the effects on passenger usage on network level per line.

The network level check does not incorporate the verification on line level. That implies that strings of stops that are removed (what could be the result of the stop level-method), are not modeled in omniTRANS. One could argue that removing a row of stops would eventually lead to the fallback of transport use.

The results of this model is a list of data per stop and usage. This data is compared with the original input for the BC-ratio method to observe differences in stop usage.

12.4 NEW ASSUMPTIONS

In this section, new assumptions to the adapted method are given. The new extended method agrees with two of the original assumptions (12.2): the perfect street grid and the operation of all stops on the line. The following assumptions are added to the adapted method and per assumption a justification is given.

Maximum stopping distance

The greedy algorithm aims to find optima in removing rows of stops. However, the greedy algorithm does not prevent the fact that according to this method, a row of stops should be removed, because the BC-ratio remains higher than one, even after removal. Therefore, an extra constraint is proposed on maximum stopping distance. The maximum acceptable stopping distance should be determined per case.

Adjacent lines

The method does not consider adjacent lines. Passengers that used a removed stop are expected to shift to adjacent stops on the same line. In practice, another nearby stop of another line could also become an attractive alternative. This concept is neglected in this method. The passenger assessment aims to find out if significant differences would be found in the case study.

Urban environment around stop

The original method assumes that all the passengers have the stop as their origin and destination of their journey, which is obviously not true. This can be proven by an easy example: nobody lives at the stop, so one should always walk from home to the stop (if the trip is home-based). Depending on the location of the activity, this distance may vary. The longer the distance is, the more users will drop out (Furth & Rahbee, 2000; TRB/TCRP report 165, 2013). For practical purposes, using geographical information would be helpful to adapt a user-oriented approach, instead of solely focusing at stopping distances from operators' perspective (Rietveld, 2005).

Stops may be important for the urban context. For example stops near schools: they may have limited usage (only before school begins and when school is out), but they have an important function. It could might be suggested by this applying the method that a stop should be removed from network perspectives (low usage), although the function of the stop could be considered as important. Therefore, it is suggested that a list of all important functions around stops is being made, so that decision on stop removal can be made more carefully than only based on usage.

Therefore, an extra check on the urban environment takes place right after the network check.

Network function

Stops that have a network function (interchange with other lines) could have a BC-ratio that would suggest stop elimination. To prevent the elimination of network stops (which would cause impoverishment of the network), right after the network check, stops are checked on their network function if closure is suggested.

End of the line

The last new assumption states that stops at the begin/end of the line cannot be skipped. The dedicated infrastructure for tram systems requires special facilities at the end of the line to turn the vehicle, either via switches or with a loop. In the next section, the new method overview is given.

12.5 ADAPTED METHOD OVERVIEW

In this section, the adapted model is explained systematically. The model is based on the new assumptions that were described above.

1. The passenger data per trip purpose is put in the model. The amount of access time to the adjacent stop, based on walking speed and distance and calculates a BC-ratio and a BC_n-ratio. This is the model on stop level;
2. The line level-model (greedy algorithm) solves the problem of rows of candidate stops. All stops with a BC-ratio > 1 are taken into account, regardless the BC_n-ratio;
3. On network level, the whole transport system is modeled. Modeling proposed closure stops with omniTRANS to check the results generated by the BC-ratio and passenger loss assignment;
4. A final check takes place that compares the stops -proposed for elimination- with a network-function and an urban environment function to prevent the network from getting corrupted and to prevent that urban functions lose their public transport connection;
5. The result is a list of stops that should be eliminated. This list is the input for the passenger assessment (chapter 13). The others stops should remain as they are, since they perform well.

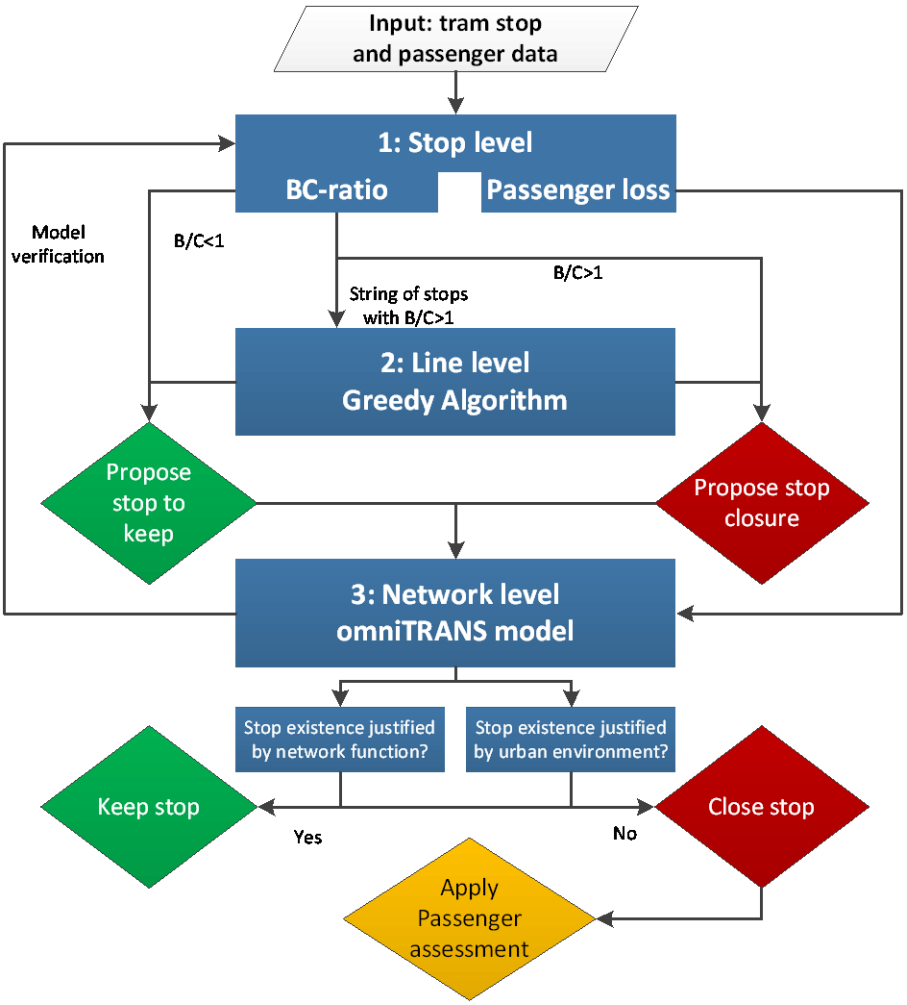


Figure 12.4 Network assessment overview.

12.6 PARAMETERS

The following parameters must be known for the model. The constants are explained below this overview.

D_{ab}	Distance between stop a and b	meters	
D_{bc}	Distance between stop b and c	meters	
V_w	Walking speed user	meters per second	constant
P_{aa}	Passengers accessing network by stop		
P_{ae}	Passengers egression network by stop		
P_r	Passengers riding through stop		
W_a	Value of time walking to (an adjacent) stop		constant per diff. pass. group
T_r	Stopping time	Seconds	constant
K	Constant for loosing passengers		constant

The parameters P_{aa}, P_{ae} and P_r must be known per trip purpose group.

Passenger walking resistance (K)

The values of this parameter were already discussed in 12.4.

Walking speed (V_w)

The walking speed V_w of a passenger that walks to a stop gives information about the time the passenger spends on walking. If the stopping location is replaced, the new walking distance says something about the extra effort a passengers must make to access the system. There range of acceptable walking speed lies approximately between 4 and 5.5 kilometers per hour (Transafety, 1997; Levine & Norenzayan, 1999; Mohler et al., 2007; ASVV,

2012; Bunschoten, 2012). The walking speed in this thesis is set at five (5) kilometers per hour. This value is the most used in related surveys.

Value for walking time ratio (W_a)

The value of time ratios were found in the literature review. The following values are used (justified in chapter 8):

Work = W_w = 1.5
Shop: = W_{sh} = 2.6
School: = W_{sc} = 4
Other: = W_o = 3.8

The average W_a is set at 2 (justified in chapter 8)

Total = W_a = 2

Vehicle stopping time (T_r)

Another important aspect of the model is the stopping time of the vehicle at the stop. The stopping time depends on different factors. The amount of passengers that use the stop, the level of crowding on the platform, the amount of doors, height difference between vehicle and platform, etcetera (Heikoop, 1996). The time the vehicle takes to slow down and to accelerate before and after stopping should also be seen as time loss. The time lost per stop is estimated (from observations at different stops) on approximately 40 seconds per stop (20 seconds actual stopping time and 20 seconds braking and accelerating). There is no variance applied on the stopping time.

12.7 EXPECTATIONS

Before the method is applied, expectations about the results are formulated. By comparing these expectations in this paragraph with the results generated by the case study, the final case results can be generalized and applied to other cases.

At first, the stop achievements for stops that are near very busy stops (like a train station or an important interchange stop) are considered low. The amount of passing passengers is very high (busy stops have many access and egress passengers). Therefore, the BC-ratio for these stops is expected to be rather high. This concept is visualized in the figure below:

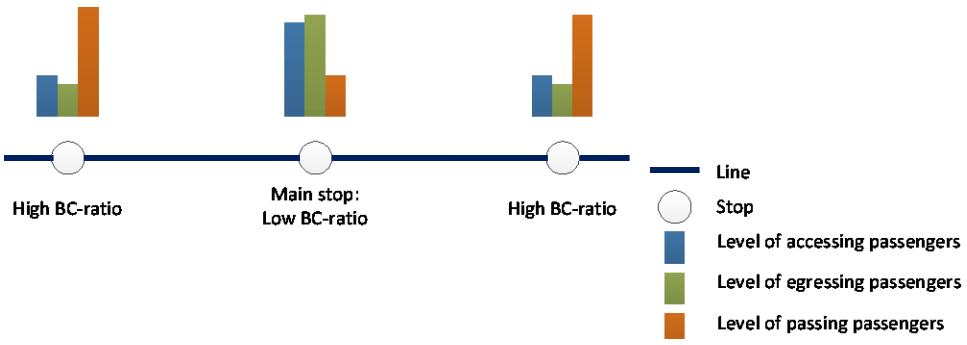


Figure 12.5 Consequences of BC-ratio for adjacent stops near main stops.

Secondly, the data that is used is based on a twenty-four hour day cycles. There is no specification made for peak hours and off-peak hours. This results in an average distribution of trip purpose over the network. Nonetheless, it is expected that based on the chosen trip distributions, conclusions can be drawn about time slots, since the literature review learned that some groups are mainly present inside or outside the rush hours.

At last, it is assumed that stops near important destinations (schools, hospitals, shopping centers and etcetera) have a high-related trip purpose.

12.8 RESULT EVALUATION

The outcome is the BC-ratio. The BC-ratio says to what extend it would be acceptable to close a stop per trip purpose. The results should first be selected on the total BC-ratio. If the BC-ratio > 1, the stop could be candidate for closing. The benefits of closing are indeed higher than the costs. Then the stop must be compared in Trip Purpose BC-ratio. If all individual Trip Purpose BC-ratios are > 1, then the closure should be approved (unless the case analysis does not allow the stop to be closed). If one of the BC-ratios is <1, then apparently one of the passenger groups benefits of the existence of the stop.

Example

Table 12.2 Example of outcome Network Assessment. Tramline 4 towards Hillegersberg.

Stop	BC Total	BC Work	BC Shop	BC School	BC Other
Ruilstraat	0,5	0,49	0,44	0,51	0,41
Mahtenesserlaan	1,6	0,86	2,47	2,88	2,73
s-Gravendijkwal	2,1	2,35	3,32	4,11	3,44

The Ruilstraat-stop has an overall BC-ratio lower than one. All differentiated passenger groups have a BC_n-ratio lower as one as well. This implies that all passenger groups benefit from the stop and that closing would mostly harm passengers.

Mathenesserlaan has a BC-ratio>1. The BC-ratio for the motive *work* is lower than one, which implies that closing the stop would have mostly negative impact for commuters, while most other passenger groups do profit of stop elimination. It is important to keep in mind that the affected passenger group (work in this case) should be compensated according to the thesis. How and which

The stop 's-Gravendijkwal stop has a BC-ratio higher than 1. All BC_n-ratios are bigger than one as well. This implies that –solely regarding this stop- most passengers would benefit if the stop would be closed.

12.9 SENSITIVITY ANALYSIS

In order to test the results, it is useful to conduct a sensitivity analysis. In this analysis, the parameters are systematically changed to assess the effect on the outcome. The sensitivity analysis identifies alternative outcomes generated by the same course of action. If the results (the BC-ratio) remain comparable with the original result, the method is stable.

The VoT-ratio and the vehicle stopping time are the most critical parameters. Since the VoT-ratio was already specified per passenger group, it would not make sense to vary this parameter again, until another study finds significantly differing results from those used in 4.3.3. Varying stopping time could make a proportional difference in the BC-ratio. Therefore, it is useful to vary the stopping time of the vehicle. This analysis is performed in chapter 17.

12.10 CONCLUDING REMARKS

The method that was proposed in this section, rationalizes public transport stopping distances. On stop level, closure of stop is suggested. The line level-approach prevents rows of stops from being closed. The network level-methodology verifies the first two methods. The on stop level proposed passenger loss methodology is not applied, since the found parameters overestimated passenger loss.

The method is applied to a case study in the next section (section D). The purpose is to test the method and to generate results. The next section is related to this method, because it aims to find compensating measures per passenger group.

13 GENERIC PASSENGER ASSESSMENT

The passenger assessment aims to find the reaction of passenger groups towards stop distance optimization. In addition, it brings on a range of solutions to implement in the public transport system to compensate the loss of supply of public transport if a certain stop is proposed for elimination. As concluded in chapter 8, the used method to find suitable compensation methods is a Stated Preference-survey.

In the next sections, the attributes that are part of the SP-survey, the research structure, the stop selection and the experimental layout are explained. The last part of this section is a result evaluation.

13.1 STATED PREFERENCE SURVEYS

Stated Preference-surveys are useful to perform in the public transport field when the researcher would like to know more about the user's preferences. Past researches on SP-surveys mainly focused on time and costs (Ghali et al, 1997; Van der Heijden & Molin, 2002). Polydoropoulou and Ben-Akiva (2001) applied a SP-survey and included comfort attributes as well.

The Stated Preference survey is a technique concerned with measuring and understanding the preferences of stated choices, based on hypothetical but realistic situations. Choices are presented with attributes that describe the character of the choice (Molin et al, 1996; Bos et al, 2004). SP-surveys refer to a family of research techniques that uses the individual response from the respondents to measure the preferences. Utility functions can be based on those preferences (Kroes & Sheldon, 1988). By applying a stated preference survey, the researcher is able to make a preference evaluation that helps to advice on compensation measures for stop removal.

Most SP-surveys aim to estimate parameters for choice models. This SP-survey aims to find passenger reaction on transport usage, if stop distances are optimized, based on differences in preferences related to trip purpose as distinguishing factor. The purpose is not to build a model based on the results.

13.1.1 SP-SURVEYS AND DIFFERENTIATED PASSENGER GROUPS

Van Hagen, Boes and Van den Heuvel (2009) concluded in previous studies on needs and requirements of public transport passengers. Those studies are about passenger experiences and how to improve those experiences. Hine and Scott (2000) performed a research on seamless accessible public transport, both from the point of view of car drivers and PT-users, highlighting the differences in service and comfort perception. Dell'Olio (2011) delivered an extensive research on the quality of public transport service as desired by the user. Waiting time, cleanliness, comfort and occupation rate were valued as very important for users. Via a SP-survey, Dell'Olio found differences in desired services among different passenger groups. Those groups were differentiated towards age, gender, income and mode use. This confirms that different passenger groups can have different preferences on the public transport.

13.1.2 METHOD OVERVIEW

This assessment starts with the output of the previous step. The list of stops that are candidate for elimination is the input for this assignment. Based on the BC-ratio and the BC_n-ratio, a range of stops is selected on which the SP-survey takes place. Simultaneously, a long list of compensating attributes is generated. Via a meta-analysis on previous studies, the most realistic attributes are filtered. The compensation measures are the basis of the actual stated preference survey. The results of the SP-survey are evaluated and finally the conclusions about which measures are useful and which are not, are drawn. The figure below visualizes the method overview.

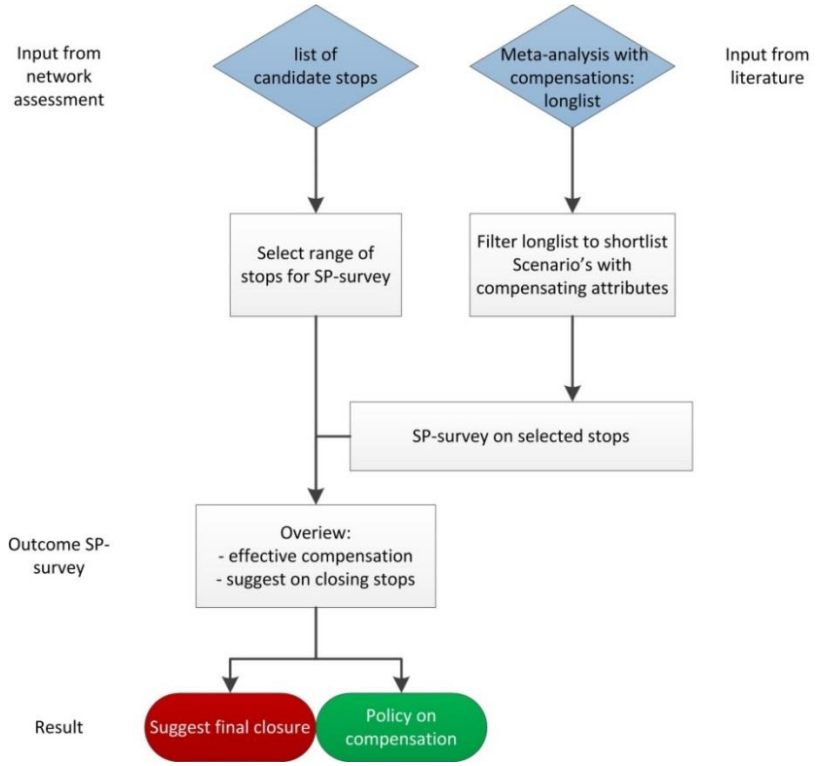


Figure 13.1 Passenger assessment overview.

Based on the method description given above, the following method overview is applicable:

1. The list of poorly performing stops that is retrieved from the network assessment is the starting point for the passenger assessment;
2. The BC-ratio's per passenger group are analyzed. Stops with an overall BC-ratio bigger than 1 and a differentiated BC-ratio smaller than one are candidate for the passenger assessment;
3. The stop that has the biggest difference between the general BC-ratio and the differentiated BC-ratio is selected for the passenger assessment. For each passenger group, a stop is selected. That means that four stops are selected. A fifth control stop is selected that hat has BC-ratio>1 for all groups.
4. By analyzing the trip purposes with the compensation choices, the compensating measures per passenger group are known. Furthermore, the expected loss of passengers that was retrieved from the network assessment is validated. The results of the stop selection for the case study are in part D.

13.2 ATTRIBUTES OF SP-SURVEY

The passenger engagement plan focuses on differentiated passenger groups. The theories discussed in chapter 6 and 8 stated that different passenger groups do have different behaviors according to accessing another stop. This theory stated furthermore that certain comfort and quality improvements on stops reduce the resistance of using that stop, what could imply that passengers would use another (further) stop, if the level of comfort to reach the stop and the level of comfort at the stop is of a certain level (Litman, 2013).

According to the literature and the meta-analysis discussed in chapter 8, the following attributes are important to incorporate in the compensations that form the SP-survey:

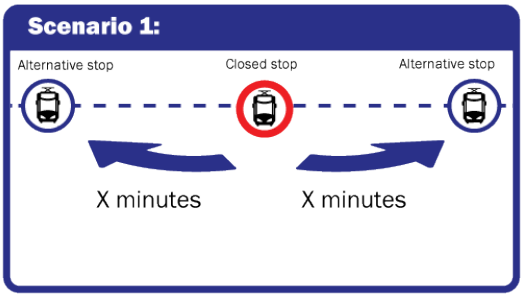
- Comfort is the most important factor at a stop
- Price compensation is a feasible way to attract passengers
- Convenient access leads to higher appreciation.
- An extra attribute that is added to the SP-survey is travel time profit that was calculated in the network assessment. The travel time profit is applicable in all cases.

The compensation measures are exemplified in the section below.

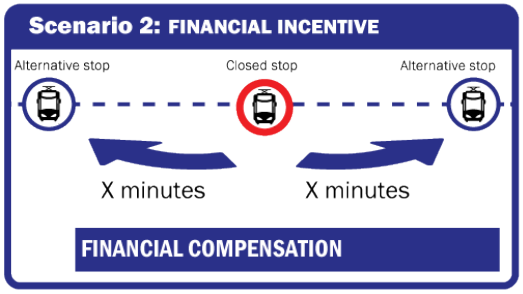
13.3 SP-SURVEY COMPENSATION ATTRIBUTES

The different attributes that are selected in the matrix method are visualized in small frames. These compensations are based on the outcomes of the meta-analysis and not yet applied to the case. The compensations are applied to the case in section D.

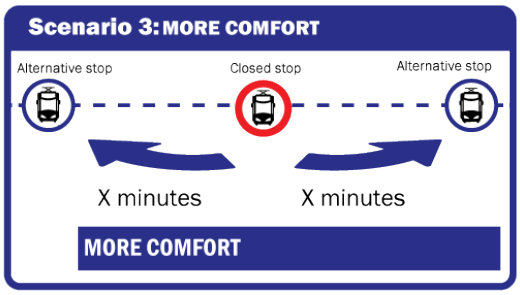
Previous SP-surveys demonstrated that solely using numbers often leads to a mathematical choice rather than a proper consideration about different choices (Bunschoten, 2012). The compensations are disused below.



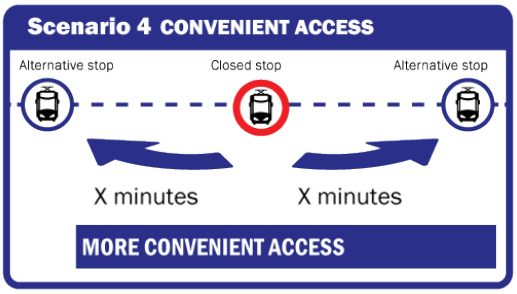
1: only stop closure



2: as 1 and financial incentive



3: as 1 and more comfort.



4: as 1 and more convenient access.

13.4 RESEARCH STRUCTURE

The SP-survey must be designed so that all the required information can be subtracted from the results. According to the core of this research, is the most important discerner is differentiated trip purpose. Nonetheless, it is recommended to also observe other aspects, so that correlation between other aspects is found, if trip purpose doesn't seem to be a proper distinguisher.

13.4.1 OPERATIONAL CONSTRAINTS

The most important constraint on the SP-survey is a limited time slot in which it should take place. The SP-surveys are conducted at stops. The interviews must be short and compact, to interview as many passengers as possible. The aim is to reserve approximately 60 seconds per passenger.

The amount of passengers that should be interviewed depends on the stop usage. This should be determined per case. The sample size of this case is determined in the case-part (part D).

The SP-survey is conducted on a selected amount of stops and only among waiting passengers, since the natural reaction of respondents is expected to be the most natural when confronted with the possibility that the current stop could be eliminated. It is furthermore expected that in-vehicle passengers do not object against removing stops that they do not use. Furthermore, from operational view, waiting passengers are expected to be more willing to cooperate in the survey than egress-passengers.

Only interviewing waiting passengers could influence the results. They could be biased towards waiting time since they are experiencing waiting time at that particular moment. Therefore, it is recommended to incorporate a limited amount of egress-passengers as well.

Furthermore, other factors may also influence the test results. It is expected that the day of the week, the time of the day and the weather could also influence the test results. The SP-surveys is therefore conducted on weekdays in a given time slot that should be determined per case. It is expected that only on weekdays all differentiated passenger groups are present, since the work-group is largely absent in the weekend.

Other influencing factors could be market days, holidays, big events and etcetera. The researcher should be alert to these circumstances when analyzing the results.

13.4.2 PROFILE DATA

The SP-survey starts with a few personal questions. The purpose of these questions is to have general information about the movement pattern. Besides, having more results than just trip purpose creates the possibility to draw conclusions that are more detailed. Furthermore, it is expected that trip purpose is not the only distinguishing factor. By collecting other profile data as well, other relations and influence could be found (Webster & Bly, 1982; Bunschoten, 2012).

The attributes are:

- Age;
- Gender;
- Income;
- Daytime activities (student, working, retired, other);
- Dependency on public transport (low, middle, high);
- Type of ticket.

Other important aspects for the SP-survey are:

- Trip purpose;
- Destination (tram stop and trip purpose);
- Mode choice (could this trip have been made with another mode);
- Frequency of the trip;
- Trip length (minutes).

13.4.3 RESEARCH BIAS

One of the biggest biases of SP-surveys is the chance that the passenger would not make the same choice in real life as in the SP-survey (De Keizer & Hofker, 2013). By conducting the SP-survey at a stop, the circumstances in which the survey takes place refer to the circumstances of the proposed situation. Therefore, this bias is minimized.

Willingness to pay is often overestimated in SP-surveys. The hypothetical values are valued too high by the respondents of the survey (Murphy et al., 2005). This can be solved if real values of prices are used. That means that the only monetary part of this SP-survey are the prices that passengers pay for their public transport. They are based on the willingness to pay for a trip. The prices used in the case study are given in chapter 18.

13.4.4 STOP SELECTION

The process of stop selection for the SP-survey is explained in the next section and visualized in the figure below.

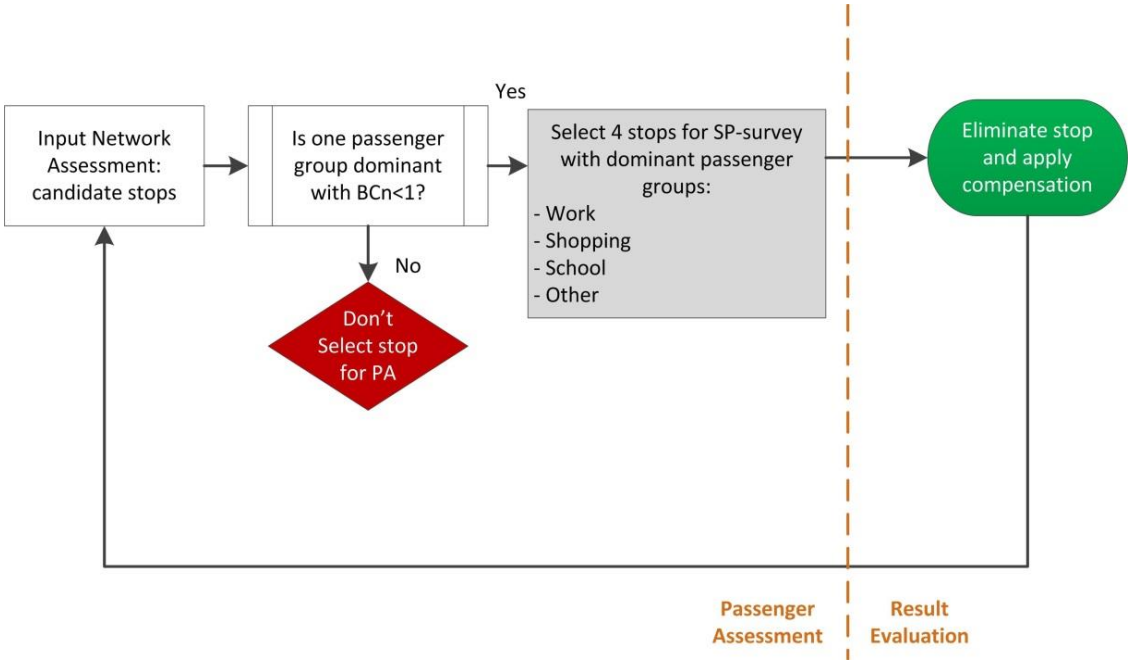


Figure 13.2 Stop selection process.

A stop is selected if the BC-ratio is bigger than one and the BC_n-ratio is smaller than one. The stop with the biggest difference between those values is the most ideal for the SP-survey, because the stop is candidate for closure and chance that the dedicated group for compensation is part of the sample, is the highest.

13.4.5 SAMPLE SIZE

The share per passenger differentiation group is based on quota sampling. This type of sampling assumes no probability and searches for a designated group of respondents. This fits the purpose of the SP-survey. The sample size per group is determined as follows:

- N = all tram passengers;
- n = sample size;
- n_n = sample size per passenger group;
- Hx_n = strata (amount of groups) = 4;
- X_n = percentage passengers present in the network.

Sample size

- $n_1 = X_1 * n$
- $n_2 = X_2 * n$
- $n_3 = X_3 * n$
- $n_4 = X_4 * n$

These numbers are specified for the case in chapter 18. A desired number of respondents lies between then 200 and 220 based on previous researches (Molin et al., 1996; Bos et al., 2004 and Bunschoten, 2012).

13.5 EXPERIMENT LAY-OUT

An example of a Stated-Preference survey is enclosed in annex 2. The compensation to which the document refers are visualized in section 13.3. The compensation measures as used in the applied SP-survey (in part D) are visualized in 18.1. These attributes are described in Dutch, since the SP-survey is conducted among Dutch-speaking respondents.

13.6 EXPECTATIONS

Before the method is applied, expectations about the results are formulated. By comparing these expectations in this paragraph with the results generated by the case study, the final case results can be generalized and applied to other cases.

1. It is expected that stop removal is more tangible for shoppers than for work and school related trips. Therefore, it is expected that the most compensation measures must be applied on this group.
2. It is expected that compensating measures are mainly appreciated if the accessibility for adjacent stops is enlarged, because this eases the resistance to access the stop. Furthermore, the level of comfort and service on adjacent stops should be increased to keep the transport attractive.
3. Mode use is part of the SP-survey. It is expected that stop removal is less objectionable for non-captive passengers than for captive passengers.

13.7 CONCLUDING REMARKS

The results of the SP-survey give an idea of passenger behavior on stop optimization. By applying this method, the potential gain or loss of passengers is mapped per passenger group. Furthermore, the method analyzes and maps the reaction on different compensating measures that could be applied for which groups on stops that are candidate for closure. The suggested compensations are also useful for the operator and authority to discuss the stop existence, even if the stop is required by a transport policy.

In the last chapter, the results of the SP-survey are used to justify the model that was used in the network assessment. Furthermore, the results of the SP-survey are used to link trip purpose to certain transport behavior and to compare the effects of alternative mode use and trip purpose.

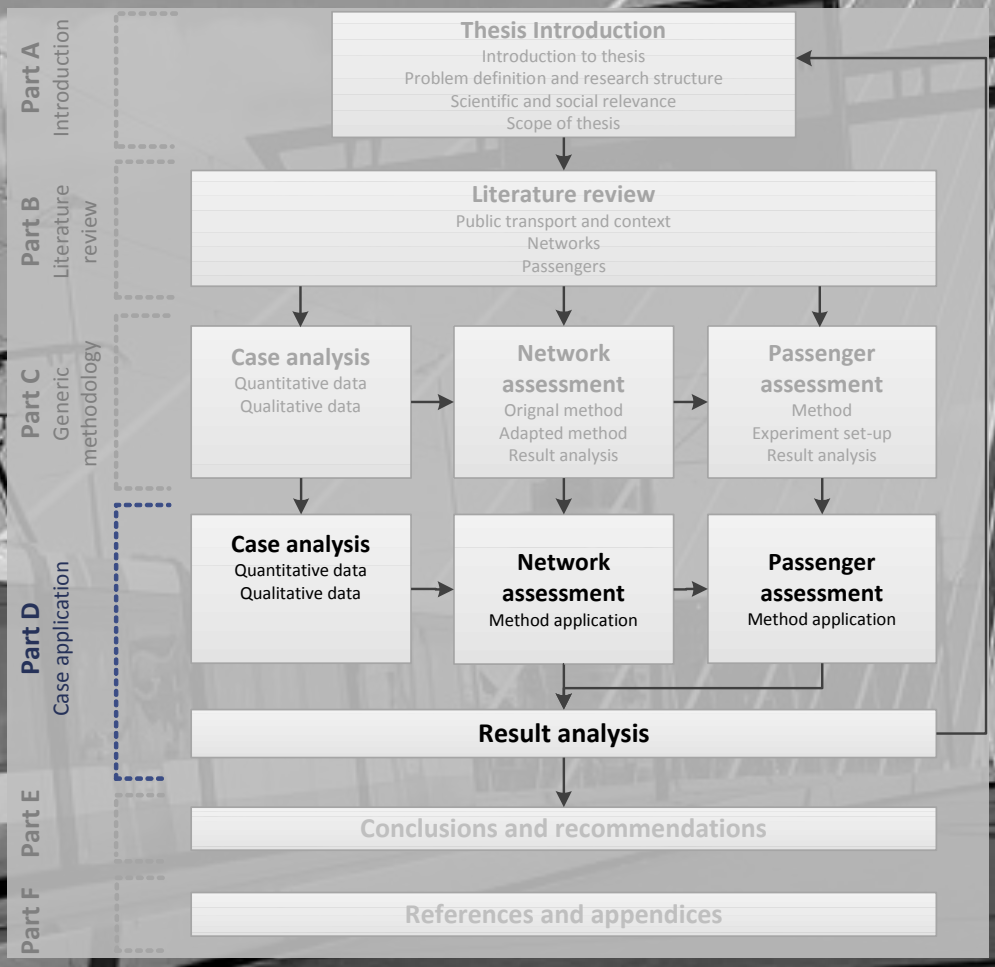
14 CONCLUSION

Part C performed the methodological roadmap in a generic way. At first, all important elements of the case were discussed in the case analysis. All side information that is necessary to perform the network assessment and the passenger assessment was given in this part.

The network assessment subsequently treated the adoptions to the original method and focused on the results of the method. At last, the passenger assessment introduced the stated preference survey to find actual passenger reactions on stop closure and possible desired compensations to prevent fallback. All methodological steps necessary to perform this survey were treated in this chapter.

The next part (part D) will focus on the case application. In this part, the above-discussed methodology is applied to a case. The goal is twofold. The suggested network assessment methodology is applied to generate results for the public transport operator. The other goal is to test the methodology, so that it is assured that, the results are valid and that the outcomes can be generalized and applied to other cases as well.

PART D – CASE APPLICATION



In imitation of the generic methodological approach that was explained in the previous part, this part applies the methods to a case. The results of the case can be used by the operator of the case to make decisions. Another purpose of the case application is to test the functionality of the method. Furthermore, the results of the case study are used to generalize the outcomes and to draw recommendations on generic level. This process is performed in the next part (part E).

15 INTRODUCTION TO THE CASE: ROTTERDAM TRAM NETWORK

As explained in the introduction (part 1), the methodological roadmap as discussed in part C is applied on a case study. This section selects the case and justifies the choice. The network assessment and passenger assessment are applied to the case in the sections thereafter.

15.1 CASE REQUIREMENTS

The most important requirement for selecting the case is that all the differentiated passenger groups are present in the network. That means that the urban context in which the system is operating, has a diverse range of activities: housing, work, shops, schools, and etcetera. The second requirement on the case study area is an urban public transport tram system in that particular area. Besides, there must be an opportunity to rationalize stopping distances.

15.2 CASE SELECTION

As explained in the introduction, this thesis is conducted for the Dutch context. Therefore, a Dutch city is chosen to perform the case study.

Three Dutch cities have a tram network; Amsterdam, The Hague and Rotterdam. Those cases are particular interesting, because of the presence of the problem of traditional stopping distances. The chosen case is Rotterdam because the physical appearance of the network is known on a very detailed level by the researcher.

The problem of traditional stopping distance in Rotterdam is present. The public transport company Rotterdamse Elektrische Tram (RET) and the transport authority Stadsregio Rotterdam (SRR) have targets to speed up the public transport rail network in Rotterdam and to enlarge stopping distances (SRR, 2012).

15.2.1 THE CITY

This thesis is focused on the tram network of Rotterdam. The Rotterdam region (mainly in the municipality of Rotterdam and some branches in adjacent municipalities) has a tram network of approximately 100 kilometers. The tram is mainly center oriented. From the city center and the central station, the lines do converge over the city. One line is tangential and does not serve the city center.

15.2.2 FILTER TO AREA

The case study is done in an area with the highest variety in trip purpose. The first filter in the case study that has been made is to explore solely the northern bank of the city of Rotterdam. The northern bank is known for a highly urbanized structure with all sorts of functions present that cause different trip purposes. There is a mixture of different urban activities and therefore the variety of trip purposes is expected to be higher, compared to the south bank, where the urban structure is less diverse. The figure below visualizes the part of the tram network area that is selected in this thesis.

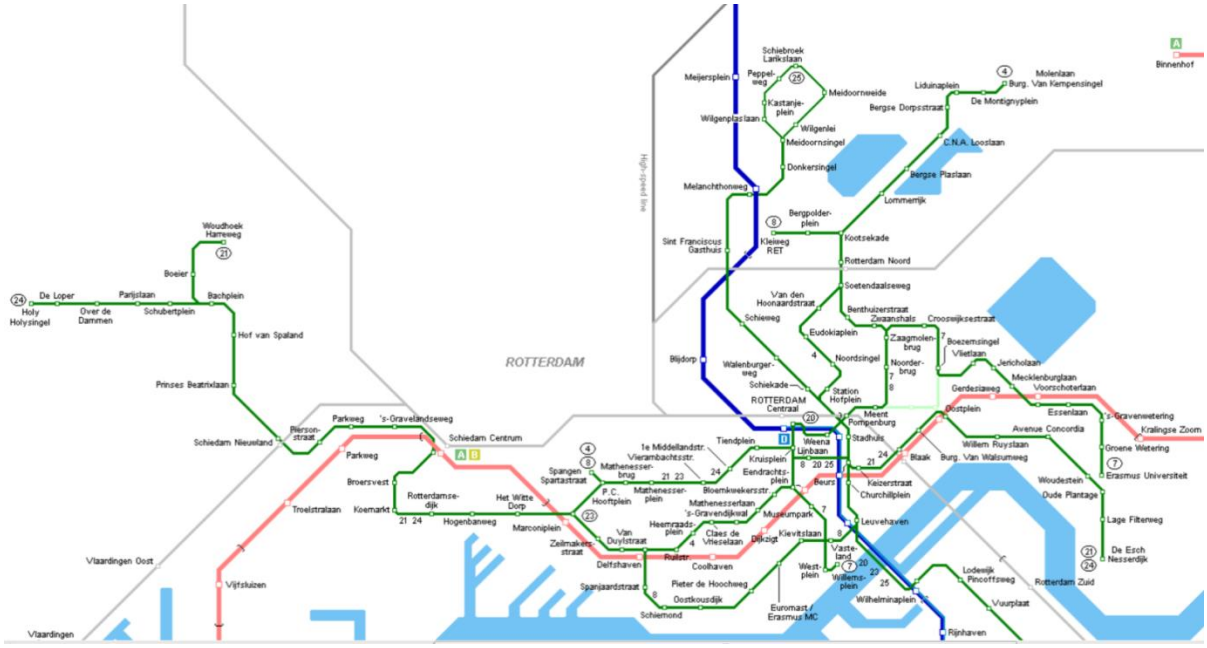


Figure 15.1 map of the selected area. The green lines are the tramlines (Schwandl, 2011).

15.2.3 FILTER TO STOP

The result of the network assessment is a list of stops that have a certain achievement. Based on the outcome of this method the stop remains or is candidate to be closed. The passenger assessment is twofold: it should justify the results of the network assessment and it should generate a range of solutions to compensate the decrease of transport supply.

For all the lines on the northern bank, a network assessment is used to determine the achievement per stop. The lines 4, 7, 8, 21, 23 and 25 are part of the assessment. Lines 23 and 25 operate on the south bank as well. To prevent errors in load data, the first stop on the south bank is also part of the network assessment. Line 20 is not taken into account, since this line only has limited operation hours. The same reasons apply for line 12, which is only operating during football matches in one of the stadiums.

The stops that are part of the SP-survey are stated in the designated passenger assessment-chapter.

16 CASE ANALYSIS OF ROTTERDAM TRAM NETWORK

The case analysis is the first part of the methodology roadmap that is necessary to perform the passenger assessment and network assessment. In this part, the network characteristics are discussed that will be used in the two following assessments.

16.1 QUANTITATIVE DATA

At first, the case specific quantitative data is given below. Some of the detailed information can be found in the summary.

Network stopping distances: The stop distance varies over the network. Some lines are entirely known for short stopping distances. These lines mainly serve the inner city center and the adjacent urban areas. Stopping distances are traditionally between 250 and 400 meters on these lines. The involved lines are lines 4, 7 and 8.

Several years ago, some tramlines were upgraded. One of the features of this upgrade was to increase the speed of the network and therefore some stops were consolidated or abrogated. The stopping distances on these lines are somewhat longer. These lines mainly serve the city center and the more remote suburb districts. The stopping distances vary from 300 to 500 meters, with outliers to 800 meters. These lines are 20, 21, 23, 24 and 25. Annex 5 contains an overview of stopping distances and speeds per line. This data was collected with aid of a measuring tool in the application Google Earth. The data was also available in the RVMK-model, but more difficult to abstract, since omniTRANS makes small tours at certain points, due to the structure of the network. The data is equivalent in accuracy. This was checked for a few stops distances.

Network speeds: The network speeds vary over the network. In the outer suburbs, the speeds are generally higher, while speeds are generally lower in strongly urbanized areas. The network speed is related to the amount of stops. Annex 5 contains an overview of network speeds in the different network parts. The network speeds are based on the travel time distracted from the schedules delivered by the operator and the information on stopping distances from annex 5.

Via this analysis, different speeds in the system can be found. This analysis gives ideas which parts of the network have the lowest speeds and thus are attractive to adjust. Some examples:

- Woudhoek-Schiedam Centrum (line 21, suburb, average stopping distance 500 meters): 20,2 km/h;
- Meent-Voorschoterlaan (line 7, dense urban area, short stopping distance 350 meters): 14,5 km/h.

The analysis is based on analytical measured distances between stops (via Google Earth) and schedule information from the operator. Combining this information leads to the average speed on the network.

The travel times are subtracted from the operators' schedule. The travel time per stop is given in minutes. At sections with short stopping distances (below 300 meter), the travel time is defined in half minutes, to give more accurate travel times. This is only done if the situation requires adaption, to prevent unrealistic results. Adjusting half-minute-accurate travel times over the whole network is unnecessary detailed.

Passenger usage per stop: The passenger stop usage data is gathered via the modeling program omniTRANS and the traffic model RVMK. This model, which is owned by the municipality of Rotterdam, contains the complete infrastructure of the whole region Rijnmond (the city of Rotterdam and adjacent municipalities) and parts of neighbor region (The Hague, provinces of Zuid Holland, Utrecht, Zeeland and Noord Holland) infrastructures. The model is based on different sources of data. The model uses socio-economic data to calculate flows of passengers in the network. These flows use different modes. The mode use, route choice and other choices that are made by the virtual traveler, are based on parameters in the model. These parameters represent travel resistances.

By running jobs in the model, omniTRANS calculates the usage per link and mode, the chosen destination and the time of departure. To collect data about trip purpose, four additional job script were made for omniTRANS. OmniTRANS already has the resistances per trip purpose per mode choice. The missing part of the model was

the distribution per trip purpose per mode. Annex 6 contains the scripts that omniTRANS used to calculate public transport use per trip purpose.

Validation: The data that omniTRANS uses to determine the usage of the public transport network is based on counting data performed by the public transport company (operator). OmniTRANS uses that data to calculate network usage over the whole network. Both results have been compared by a transportation engineer of the operator. It was concluded that the data match. Therefore, the output that omniTRANS gives on public transport network usage, is validated. The researcher of this thesis has not seen the actual counting data. This is confidential information.

16.2 QUALITATIVE DATA

This part of the analysis is about qualitative data. The information in this part is processed via document analysis and contact with key persons.

Share of passenger differentiation: The public transport operator collects information on the share of usage of different travel purposes. In general, the travel purpose on all lines is quite comparable. The differences in share per trip purpose are solely about a few percent. This analysis is part of a survey that is yearly conducted by the operator. The figure below visualizes the share per trip purpose. The major groups are the commuters, students and shoppers.

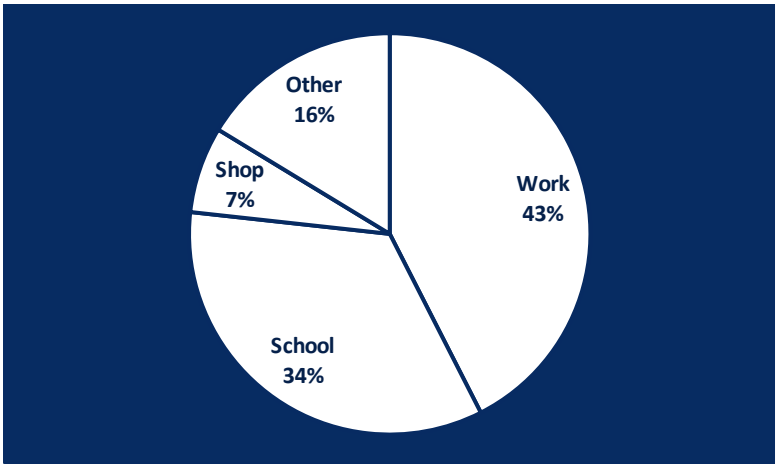


Figure 16.1 Share per trip purpose for al tramlines in Rotterdam in 2013 (RET, 2014).

Policy from Authority: The transport Authority of Rotterdam already has policies to extend stop distance. This policy has the purpose to speed up the system. This policy is not based on the differentiation of several passenger groups. Therefore, it is interesting to model this policy as well in the network analysis, to discover if there are differences between various stop distances and passenger group usage intensities.

According to the authorities policies, stopping distances are preferred between the 400 and 800 meters for the tram in Rotterdam. Besides, the stops should easily be reached by foot and bike at least. Bike parking places at the stops are highly desired, so that the influence area can be expanded to even 800 meters (Stadsregio, 2011). In this case, stopping distances bigger than 800 meters should thus be prevented. That means that the greedy algorithm applied in chapter 17 is constrained in removing stops that would cause stopping distances bigger than 600 or 800 meters. This is manually applied by observing stopping distances and increasing distances by stop removal.

Specific network data: Although some stopping distances are low -which can be seen from the stopping distance analysis (see annex 3, 4 and 5)-, the function of both of the stop could be considered as being important. This could be the case when the stop serves an important network function with interchanging possibilities to other lines or other modalities. Other important stopping locations are for example stops near hospitals, shopping centers or schools. Not removing these stops should not be concluded on forehand.

An overview of important functions of stops is given in annex 3 and 4. For every stop, the amount of changing possibilities is calculated and important functions are listed.

Urban environment

As stated before, each stop serves particular functions. Furthermore, the authority often has policies about which functions should be served by public transport. This results for example in the demand that each hospital has a tram stop within a certain distance range. That means as well that if the stop is demanded by the authority's policy (based on social motives) or because the stop is considered an important interchange point (based on network policies), the stop could not be eliminated.

This thesis aims to suggest that stops near important functions must be part of the network assessment as well. Only in the last step of the passenger assessment, there is an *escape* so that stops that perform badly, can be saved.

The input to check the urban environment is based on the functions near the stops. The functions that are distinguished in this thesis are *schools*, *shops* and *working areas*.

The process allows a stop to be removed if within a certain acceptable distance, a nearby transport facility is present. This could be another stop on the same line or another transport line. The maximum acceptable walking distance should be determined per case. In this case, 600 meters is considered as maximum distance, based on policy of the operator (Stadsregio, 2011).

Stop attributes: The stops in the Rotterdam Network do generally have three types of layout. The most basic stop is solely a stop sign and occasionally a shelter. The extended stop has an elevated platform providing easy access to the vehicle, shelters and bins. The third type of stop has big shelters, multiple units of seats, handrails and several bins.

Almost all stops have digital travel information, the stops also have voice recorders pronouncing the estimated time of arrival of the next tram and the destination, but this system is hardly used. Every stop has at least a schedule and the bigger stops have maps of the network, the urban environment and other general information about the operation.

16.3 CONCLUDING REMARKS

There are several places in the network where the speed of the vehicles is fairly low. Compared with the stopping distance, a relation between stopping distance and average speed can be found. The case analysis generated information that is necessary to perform the network assessment and the case assessment. This information is either quantitative or qualitative.

The next chapters (network assessment and passenger assessment) use the above-generated data to perform the steps that are required to obtain results.

17 ROTTERDAM CASE NETWORK ASSESSMENT

The network assessment was explained in a generic way in the previous part (part C). The network assessment is applied to the case in this part of the thesis. In order to test the network assessment and to genera te results, the method is applied to the tram network of the Dutch city of Rotterdam, as explained at the beginning of this part.

17.1 MODEL APPLICATION

The used data for passenger loads is extracted from the RVMK. The RVMK is a traffic model comprising the infrastructure of the city of Rotterdam and adjacent municipalities. The data was processed so that per stop the amount of passing, access and egress passengers for all the distinguishable trip purpose groups. The steps discussed in the model in 7.5 were applied to the data. The results are discussed in the next paragraph.

17.2 MODEL RESULTS

The results of the network assessment are discussed in this part. A total amount of 335 stops was analyzed. Some stops are counted double, since each stop is counted on each line. Some stops are served by more lines and are thus counted double or even multiple. The process of analyzing is followed as described in the generic network assessment. At first, the BC-ratios are given for the stop level-method. Then the results of the line level-methodology follow. Subsequently, the evaluation of the network level-method is given. Then, the check on network and urban environment is given.

17.2.1 STOP LEVEL: BC-RATIO AND PASSENGER LOSS

The BC-ratio found 172 stops that have a BC-ratio > 1. 111 of those stops have a BC_n-ratio for at least one specified trip purpose smaller than one. This means that 172 stops could be eliminated based on the stop level methodology (without considering any other constraint). 111 of those stops are nonetheless substantially used by at least one group of differentiated passengers. 69 stops have a BC-ratio>1 in both directions.

The involved stops are all listed in annex 7.

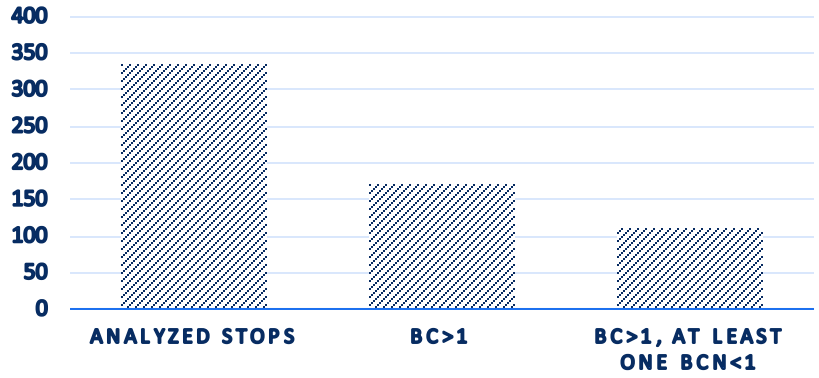


Figure 17.1 Analyzed stops.

The results of the amount of analyzed stops are given in figure 17.1. In annex 7, the expected amount of passenger loss per stop is given (confidential data). This passenger loss is based on additional walking distance to an adjacent stop and the willingness to bridge the distance. The parameters of willingness to bridge this distance were given in section 12.3

When the BC_n-ratios are analyzed, there are quite different results on stop elimination. If the stop elimination is approached per passenger group, the amount of stops that theoretically could be eliminated is divergent. The results per passenger group are discussed below.

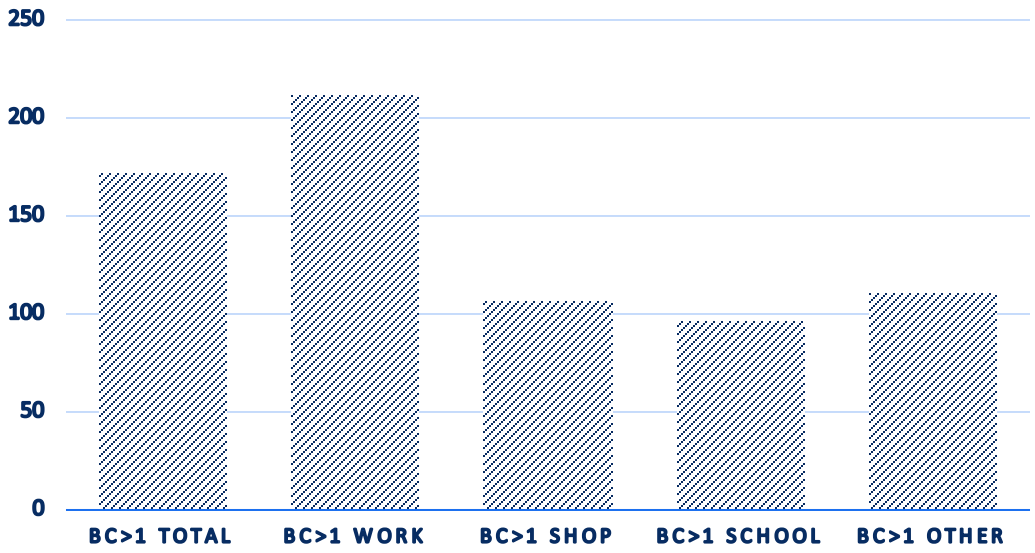


Figure 17.2 Differentiated BC-ratios.

The difference in BC-ratios implies that the stop distance for each differentiated passenger group is unique. On average, 50% of all analyzed stops have a BC-ratio that is bigger than one. This implies that 172 stop locations should be evaluated to verify their existence. These figures differ strongly per trip purpose, which makes it interesting to evaluate.

According to the high level of BC-ratios of the working group, many stops for this group could be closed. In other words, the stopping distance for this group of passengers is too low on average. These values are much lower of the other groups (shop, school and other). This implies that stopping distances for these groups are fairly more in accordance with the preferences of these passenger groups. When the BC_n-ratios are solely approached per passenger group, it appears that almost two third (63%) of the stops for passengers with work-purpose is too close. The same ratio is much smaller for shoppers, students and others (respectively 30%, 28% and 32%).

Therefore, stops that are mostly used by working-passengers have a much higher potential to eliminate than stops that host the other three passenger groups.

Another part of the stop level method is the passenger loss. According to the K-factor that was introduced in section 13.3.2, a certain passenger loss is calculated per stop. The calculated passenger loss is too high to be realistic. Therefore, no further conclusions are drawn on passenger loss on stop level. The applied method (K-factor) is found to be too inaccurate to apply.

17.2.2 LINE LEVEL: GREEDY ALGORITHM

A total amount of 38 strings of subsequent stops was found with a BC-ratio>1. The amount of stops involved in those strings is 139 in total. Since stops only qualify for removal if the BC-ratio is bigger than one in both directions (as described in 7.6), 60 remain on which the BC-ratio is applied. The list with stop results on greedy algorithm is recorded in annex 8.

If the greedy algorithm is executed without any constraint, 40 stops should be removed and 20 stops are 'saved' by the algorithm. If applicable in both directions, 9 stops could be removed.

If a maximum distance constraints the stop removal (as discussed in the case analysis in chapter 16), 6 stops could be removed and 54 stops are saved by a maximum stopping distance of 600 meters. For 800 meters stopping distances, these levels are respectively 18 and 42. The total amount of stops is visualized in the figure below.

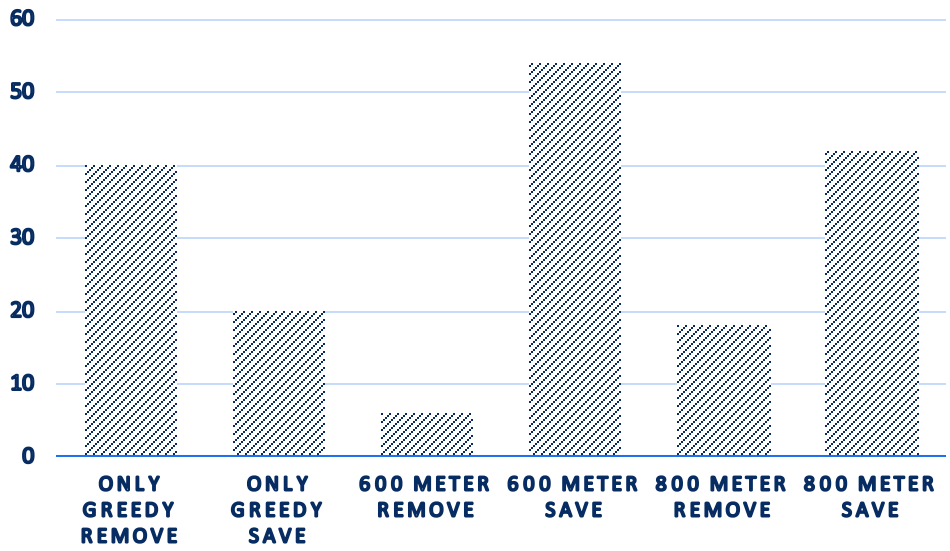


Figure 17.3 Results of line-level assessment.

17.2.3 NETWORK LEVEL: OMNITRANS

A selection of stops that is proposed to close (see table 17.1 below) was put in omniTRANS. Only stops without network function and by the line-level method saved stops were used. By doing so, both the methods on stop level (BC-ratio) and the method on line level (greedy algorithm) were tested. The results of omniTRANS were not specified towards trip purpose.

The results are remarkable. Most passengers redistribute over the adjacent stops. Loss of passengers is limited to several percent of the total amount of passengers that used the stop for their trip, without regarding trip purpose. The losses of passengers are not as high as originally calculated in the stop level-method. The table below shows some examples:

	Observed loss (Network level-method)	Theoretical loss from stop level-method
Mathenesserlaan	8% loss	D_{aw} = 120 m, K-factor gives 20%
Montignyplein	12% loss	D_{aw} = 160 m, K-factor gives 30%
Burg. Van Walsumweg	6% loss	D_{aw} = 190 m, K-factor gives 30%

Table 17.1 Passenger loss on network level method

There is even a small growth noticeable at certain stops on the whole line, which implies that skipping stops and thus saving travel time indeed increases the use of public transport, according to the model. This implies that removing some stops leads to passenger losses in the specific service area as table XX confirms, while the travel time gain on the whole line causes growth of passengers due to shorter travel times. The table below illustrates the gain over the whole line for a few examples.

	Growth over whole line
Line 4	4 % growth
Line 21	7% growth
Line 23	4% growth

Table 17.2 Passenger loss on network level method

These results confirm the usability of the BC-ratio as a proper way of rationalizing stopping distances in a public transport network. However, this method also shows that the parameters used to calculate passenger loss are overestimated in this particular case, since the network level method shows lower rates of passenger loss.

However, it must be said that the results could imply that the valuation for travel time in the omniTRANS-model is such high that passenger growth is the result of shorter travel times. Nonetheless, this has not been studied.

In the passenger assessment, the loss of passengers due to stop closure is measured again in a survey. In the result analysis (chapter 19), the results of the initial passenger loss, the results of this network level check and the results of the passenger assessment are compared.

17.2.4 SENSITIVITY ANALYSIS

Varying the stopping times results in different BC-ratios. The BC-ratio analysis produces different results depending on the chosen values for the factors. For this sensitivity analysis, stopping times for tramline 25 between Leuvehaven and Wilgenplaslaan are changed. This line was chosen, because the original BC-ratios lie close to 1 and are therefore quite 'vulnerable' when factors are changed.

The vehicle stopping time is varied between the 30 and 50 seconds (40 seconds was used in the overall analysis). By reducing the stopping times, not one stop has a significant changed BC-ratio (from 1> to >1 and vice versa). By increasing the stopping times to maximum 50 seconds, only one stop gets a BC-ratio >1. This implies that a wide range of stopping times produces similar results in terms of suggesting stop closure.

17.3 RESULT EVALUATION

The results for all stops are given in annex 7. It contains an overview of stops that have BC-ratios bigger than one, BC_n-ratios smaller than one and the selection of stops in two directions.

The following stops are proposed to close based on the BC-ratio. Green stops should be saved based on the greedy algorithm (both direction elimination). Orange stops should be saved based on the network function. Stops are only mentioned if the criteria for elimination are applicable in both directions.

Table 17.3 Stops that should be closed based on the network assessment.

Line	Stop	Line	Stop	Line	Stop
4	Mathenesserlaan	7	Westerstraat	8	P.C. Hooftplein
	s-Gravendijkwal		Essenlaan		Zeilmakersstraat
	Bloemkwekersstraat		Groene Wetering		Delfshaven
	Kruisplein		Eendrachtsplein		Kievitslaan
	Van den Hoonaardstraat				Vasteland
	Soetendaalseweg				Weena
	Station Noord				Noorderbrug
	Kootsekade				Zaagmolenbrug
	Lommerrijk				Kootsekade
	Bergse Plaslaan				
	CNA Looslaan				
	Burg. Le F. de Montplein				
Line	Stop	Line	Stop	Line	Stop
21	Parkweg	23	Schubertplein	25	Melanchtonweg
	s-Gravelandseweg		Bachplein		Schiekade
	Hogenbanweg		Hof van Spaland		Churchillplein
	Het Witte Dorp		Piersonstraat		
	Tiendplein		Parkweg		
	Kruisplein		s-Gravelandseweg		
	Stadhuis		Hogenbanweg		
	Burg. Van Walsumweg		Het Witte Dorp		
	Woudestein		Kruisplein		
	Oude Plantage		Weena		
			Stadhuis		
			Churchillplein		
	Red: stop closure suggested		Orange: network function		Green: saved by greedy

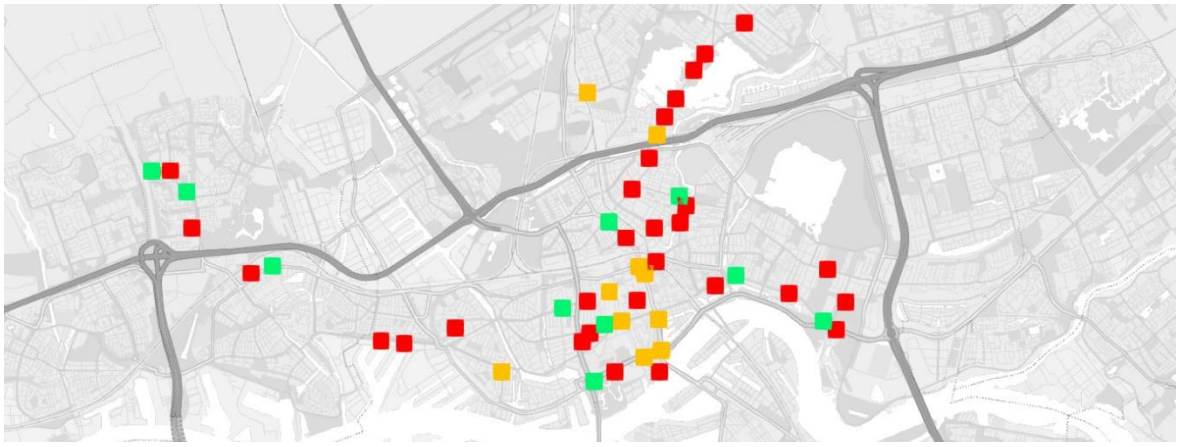


Figure 17.4 Stops displayed on map. Red means closure, orange stops are saved by the line level-method and green stops have a network function.

The amount of stops that is considered to be too close to the adjacent stop is significantly higher for working passengers than for passengers with other trip purposes. Stops that should be closed because of the overall BC-ratio bigger than one but with a BC_n-ratio smaller than one are listed in the following table. Green stops should be saved based on the greedy algorithm (both direction elimination). Orange stops should be saved based on the network function. Stops are only mentioned if the criteria for elimination are applicable in both directions.

Table 17.4 Stops that should be eliminated, but that are still useful for passenger groups based on the network assessment.

Line	Stop	Line	Stop	Line	Stop
4	Eendrachtsplein	7	Kruisplein	8	Euromast
	Heer Bokelweg		Mecklenburglaan		Pompenburg
	Noordsingel		Essenlaan		Noorderbrug
			s-Gravenwetering		Zwaanshals
					Soetendaalseweg
Line	**Stop**	**Line**	**Stop**	**Line**	**Stop**
21	Piersonstraat	23	Leuvehaven	25	Walenburgerweg
	1e Middellandstraat		Prinses Beatrixlaan		Schiekade
	Oostplein				Kruisplein
	Avenue Concordia				Lijnbaan
					Leuvehaven
	Red: stop closure suggested		Orange: network function		Green: saved by greedy

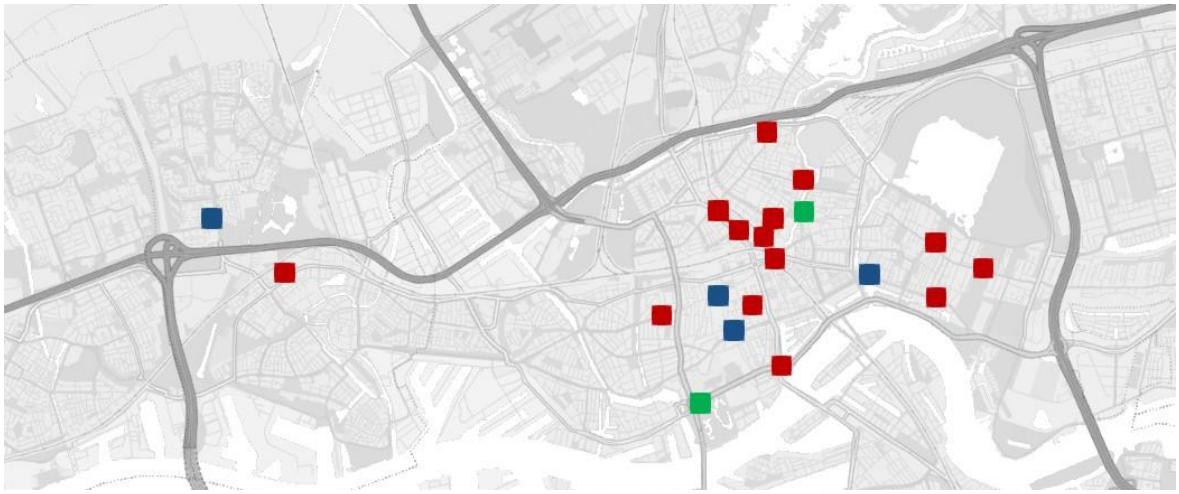


Figure 17.5 Stops useful for at least one passenger group. Red: stop closure suggested. Orange: saved by line level-method. Green: network function.

The amount of stops that should be closed according to the BC_n-ratio is thus lower, since only a selection of the BC-ratio > 1 stops has a BC_n-ratio < 1. Stops with this condition are proposed for eliminated, but have at least one group that uses the stop frequently what would make it suitable to keep the stop. Therefore, per passenger group, conclusions can be drawn on keeping the stop, eliminating the stop and apply compensation facultative.

The check on urban functions gave the following results. The stop Hof van Spaland is near a local shopping center and therefore frequently used by shoppers. There aren't much other alternatives around, furthermore, there is no other stop within a distance range. Stadhuis is near the central business district, but there are numerous other tram stops nearby. Mathenesserlaan is not serving a special activity nearby. 's-Gravenwetering is neither doing so. Groene Wetering is near one of the entrances of the Erasmus University, but so are two other tram stops as well. The urban selection has only be made for the stops that are also treated in the passenger assessment (next chapter). Annex 4 contains a list of important urban functions that are related to the trip purpose around the specific stop.

17.4 CONCLUDING REMARKS

The results of the case application are lists of stops that could be closed. Furthermore, the application of the three methodological levels proved that the BC-ratio on stop level is workable.

The three steps performed in the network assessment had two purposes. The stop-level method (BC-ratio) was used to find results on which stops should be closed. The line-level and the network-level aimed to check the consequences on those levels. The line-level method (greedy algorithm) showed that applying the greedy algorithm is one way to solve the problem of rows of stops that should be closed. The network-level method (omniTRANS) showed that the whole network was not corrupted by stop closure. This step was applied to prove that the method on stop level (BC-ratio) works in a proper way. This step is not required any more if the network assessment is applied on other cases.

Unfortunately, the proposed passenger loss calculation method (as described in annex 10) did not produced any realistic results, since passenger loss calculation was largely overestimated, especially compared to the outcome of the network level-methodology. Therefore, this step is not part of the final method.

One of the most important conclusions for the adapted network methodology is that the stop-level method was verified due to application of the network level methodology. Furthermore, a line level method remains necessary to assure an accurate stop closing pattern and to prevent strings of stops that should be closed. This methodology is based on a greedy algorithm.

A small recap on the expectations learns that all expectations are confirmed. BC-ratios for stops near very busy stops are quite high. Furthermore, stops near offices and schools are frequently used by related passenger groups.

The next section aims to find compensating measures to prevent passenger loss. Furthermore, it aims to find figures that are more realistic on passenger behavior when stops are eliminated.

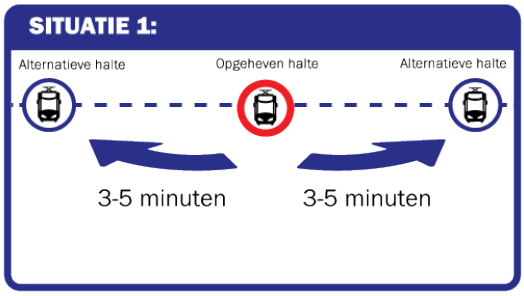
18 CASE PASSENGER ASSESSMENT

The network assessment showed that there is a significant difference in stopping distances for each differentiated passenger group. The network assessment also resulted in a list with stops that could be eliminated based on their usage.

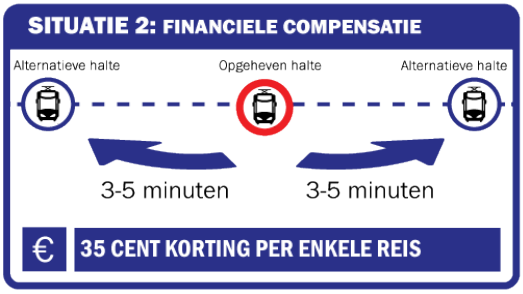
The purpose of this thesis was to find compensating measures for differentiated passenger groups. This part of the thesis aims to find those compensating attributes.

18.1 COMPENSATION ATTRIBUTES OF ENGAGEMENT PLAN

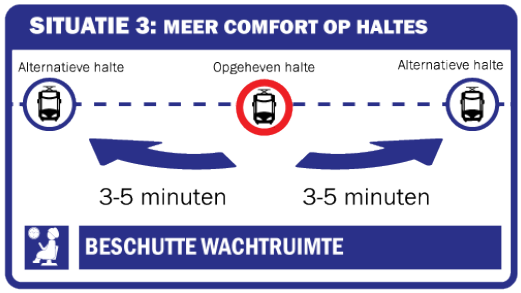
The generic attributes of the SP-survey were discussed in the previous part. The following compensation measures were developed for the case application (in Dutch):



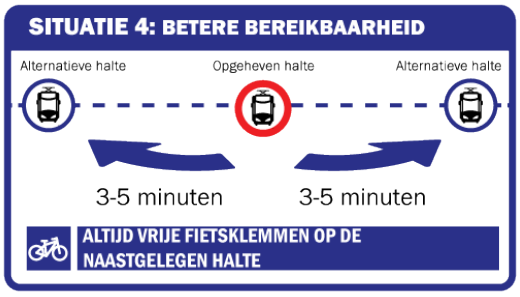
1: average walking distance is 3 to 5 minutes to adjacent stops. This walking distance is based on the average distance to all adjacent stops for all stops involved in the SP-survey.



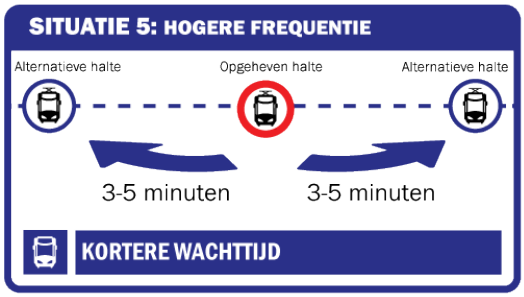
2: is as 1 and with a financial compensation. This compensation is based on the value of time of passengers. The average value of time is €6.75 per hour for passengers that use public transport (AVV, 1997; KiM, 2013). A walking distance of 3 to 5 minutes is in accordance with the applied financial compensation.



3: is as 1 and with comfortable waiting facilities at adjacent stop. The case analysis learned that most stops in the case have limited shelter facilities. A more comfortable and sheltered waiting room is proposed as compensation in this scenario.



4: is as 1 and with better bicycle parking at adjacent stops. This improves the accessibility to adjacent stops. This scenario is also in accordance with policy of the authority to improve accessibility to public transport stops.



5: is as 1 and with higher line frequency. This scenario was not found in the general analysis, but specifically requested by the operator. Originally, compensating measures solely focused on stop attributes and compensation measures focused on adjacent stops. This scenario therefore was not selected in the generic passenger assessment.

18.2 STOP SELECTION

In the generic section, a certain approach for stop selection was proposed. This selection was based on the overall BC-ratio (bigger than one) and a BC_n-ratio (smaller than 1 or with the biggest difference). During the SP-survey, the case forced that the stop selection was adapted, so that the volume of passengers using the stop would be high enough to assure enough respondents. The following stops were selected for the SP-survey.

- Work: 's-Gravendijkwal (September 24, 7.00 hrs-10.00 hrs.);
  Although the 's-Gravendijkwal would be the best stop for the working-group, the survey took place at the adjacent stop Mathenesserlaan. This stop has similar characteristics, but the amount of passengers is higher and so is the level of response.
- Other: 's-Gravenwetering (September 25, 7.00 hrs-12.00 hrs.)
  This stop did not have sufficient amount of passengers. Therefore, the sessions was shifted to the adjacent stop Groene Wetering with the same passenger-group characteristics.
- Shop: Hof van Spaland (September 26, 11.30 hrs-14.30 hrs.). Although this stop would be saved by the greedy algorithm, the level of usage made the stop suitable for the survey.
- School: Heer Bokelweg (September 27, 14.30 hrs-17.30 hrs.). The stop was not in use at the moment of the survey and therefore the survey took place at the Piersonstraat.

- Extra stop: Stadhuis (September 30, 14.00-17.30 hrs.). The level of initial response was not high enough at the first four stops. Therefore, the stop Stadhuis was added to the survey. All passenger groups are present at the stop.

The time of research was determined in accordance with the operator. The chosen time was selected to find the target group the most present.

18.3 EXPERIMENT SET UP

The experiment layout was already introduced in the generic passenger assessment. The structure of the case-related SP-survey is depictured in annex 2.

The desired total sample size is 200 to 250 respondents. As discussed in chapter 13, the share per passenger differentiation group is based on quota sampling:

- N = all tram passengers;
- n = sample size = 200-250;
- n_n = sample size per passenger group;
- Hx_n = strata (amount of groups) = 4;
- X_n = percentage passengers present in the network (RET, 2014):
  - Work: 43%.
  - School 34%.
  - Shop 7%.
  - Others 16%.

Sample size

- $n_1 = X_1 * n = 85$;
- $n_2 = X_2 * n = 68$;
- $n_3 = X_3 * n = 14$;
- $n_4 = X_4 * n = 33$.

It is expected that the share of interviewed passengers at the stop is not influenced by that fact that some passenger groups may optimize their travel time by arriving just in time at the stop, which would make it impossible to interview them. This could lead to a distorted result. White et al. (1992) and Nielsen & Lange (2007) state that a frequency higher than 6 vehicles per hour causes passengers to not check the schedule before departure. This assures that all groups are equally present at the stop.

18.4 SP-SURVEY RESULTS

A total amount of 228 passengers has been questioned during the SP-surveys. The results of the SP-survey were processed with a software tool for statistics (SPSS) to obtain results and to link variables. This chapter discusses the results of the SP-survey. The pictures below illustrate the process of the survey.



Figure 18.1 Performing the SP-survey at the tram stops in Rotterdam.

18.4.1 SAMPLE CHARACTERISTICS

As introduced in chapter 13, different characteristics of the passengers were part of the SP-survey. This section contains an overview of the profile data that was found in the SP-survey.

The minimum amount of respondents was given in 18.3. The actual sample size is:

- n_1 (work) = 52
- n_2 (school) = 55
- n_3 (shop) = 45
- n_4 (other) = 76

The groups with the purpose work and school are underrepresented, while the groups with the purpose shop and other are overrepresented. This implies that the average passenger representation was not found during the survey. This has no further consequences for the results, since they are normalized. The population has furthermore the following characteristics:

Table 18.1 Differentiation of profile data observed in the SP-survey.

Under 15	15yrs-25yrs	26yrs-45yrs	46yrs-65yrs	Over 65
14	72	48	52	42
Student	**Work fulltime**	**Work parttime**	**Retired**	**Other**
77	52	31	44	24

Purpose work	Purpose school	Purpose shop	Other purposes
52	55	45	76
Daily PT use	**3 or more per week**	**less than 3 per week**	**less usage of PT**
68	62	48	50

Month/year card	Student card	Saldo	Other
51	52	111	14

Totally dependent on PT	Partially	Hardly
96	80	52

Man	Woman
82	146

18.4.2 VALUATION OF COMPENSATION MEASURES

As logically expected, the first compensation (walking to adjacent stop) was valued quite low. More than half of the passengers would not adapt their travel behavior. About 25 percent of the passengers would reduce their amount of trips and over 20 percent of the passengers admitted not to travel any more if their stop was cancelled.

The second measure (financial compensation) was appreciated by a larger group of passengers. Slightly less than 20 percent would not travel anymore and less than 20 percent would reduce their travel frequency. Moreover, slightly more than 10 percent of the passengers would travel more in case of a financial compensation.

The sheltered waiting room –measure 3- was also well appreciated, according to the survey. The loss of passengers is comparable to the second measure, but only less than 15% reduces the travel frequency and slightly over 20 percent increases the transport usage.

Measure 4 (bicycle parking) was somewhat better valuated than doing nothing besides stop closure, but the reactions did not differ that much from measure 1. A slightly increase in usage was observed and passenger loss lingers around 20%.

The fifth measure (higher frequency) was by far the favorite as one of the best appreciated measures. Enlarging stopping distances and increasing the frequency does not only compensate for the loss of extra travel time, but also increases (more than 30%) the use for certain passengers, as observed clear by analyzing the results. Less than 10% loss of passengers was observed and slightly more than 10% would reduce the trip frequency.

It is remarkable that the fifth measure was mostly chosen. Although this measure was originally not part of the methodology, it was the best valued compensation. The consequences for this choice are explained in the following sections.

The figure below summarizes the total results of the compensation measure valuation.

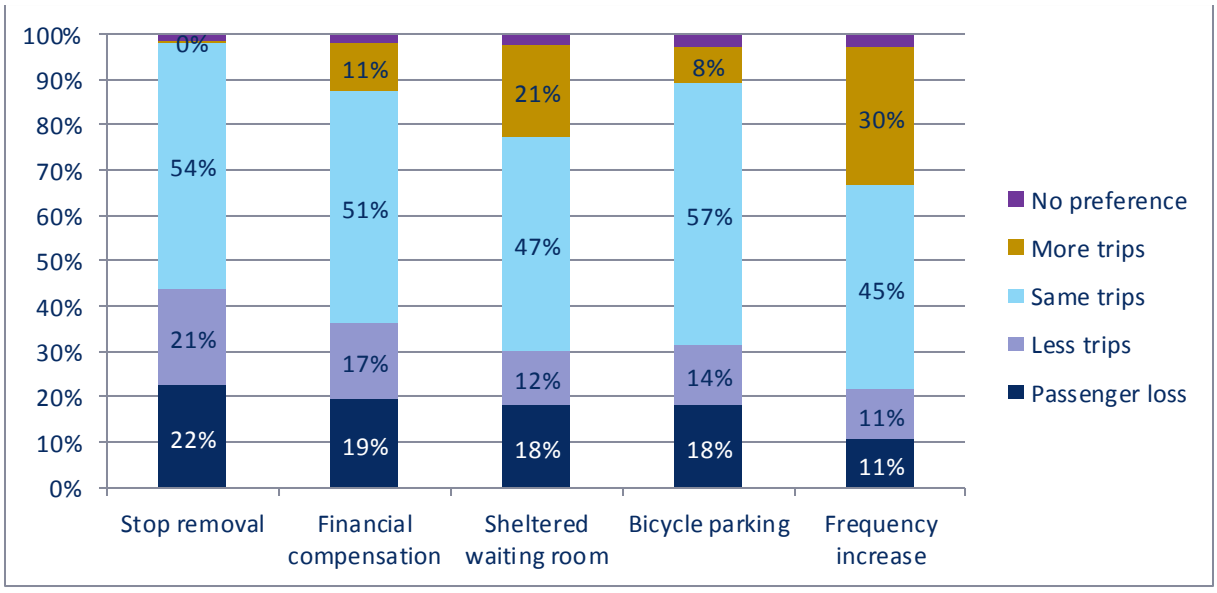


Figure 18.2 Results of sample data on compensation valuation for all passenger groups.

The next section differentiates the results of the survey towards trip purpose. By doing so, the results per group are obtained and conclusion can be drawn on the characteristics per passenger group.

18.4.3 DIFFERENTIATION TOWARDS TRIP PURPOSE

There is a clear connection visible between the type of proposed attributes and the appreciation for the compensating measures. Some measures were valued high by and some were hardly chosen at all. Remarkable is that some measures are only valuated high by a selected group of passengers with a given trip purpose. This proves the existence of the relationship between differentiation towards trip purpose and the valuation of results.

The first measure suggests stop removal without any compensating measures on adjacent stops. The trip-purpose work is hardly affected by stop removal. The results for school-passengers are quite similar. This is surprising, since previous theory stated that access-time for school-passenger was valuated four times as high as in-vehicle time. This would imply that a big loss of passengers could be expected. Nonetheless, the majority of this group would travel in a similar way if their stop was closed. The willingness to travel for shop-passengers changes strongly from the above mentioned groups. Most respondents would stop travelling by public transport if their stop was closed

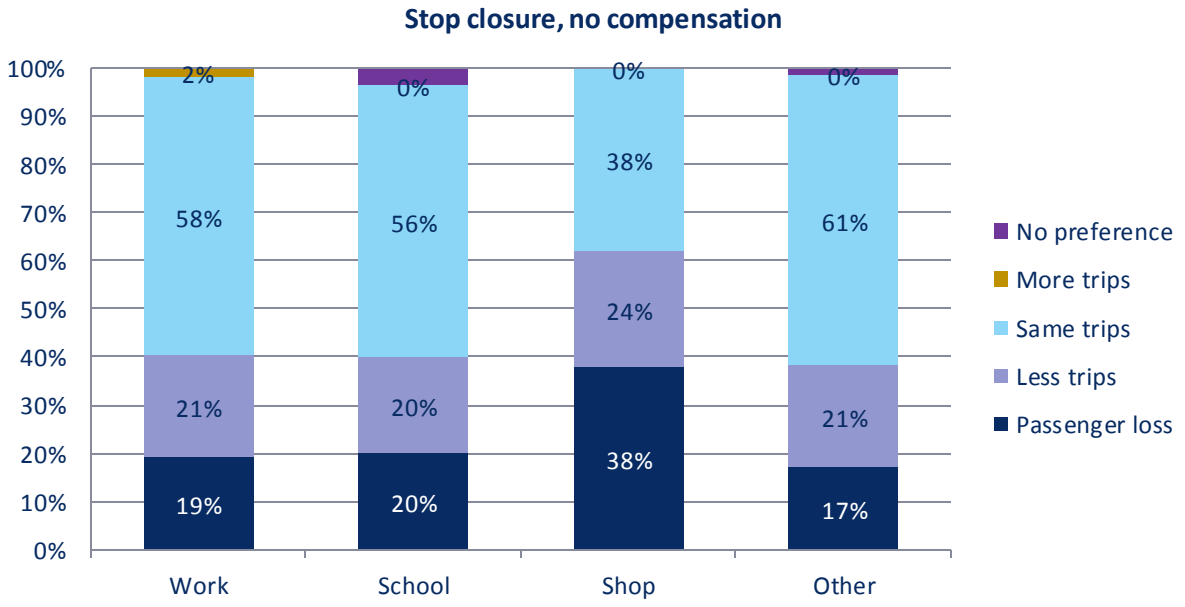


Figure 18.3 Appreciation of the first measure: stop closure without compensation.

The second measure, financial compensation is quite similar in results as the first compensation, although the level of decreasing use and loss are slightly lower for all passenger groups. The difference between the shopping group and the other groups is still strongly visible. Remarkable is the fairly large increase of transport usage among students. Moreover, the big appreciation for this alternative by the other-group comes mainly from people without work. This was observed when both trip purpose (other) and daily activity (other) were compared.

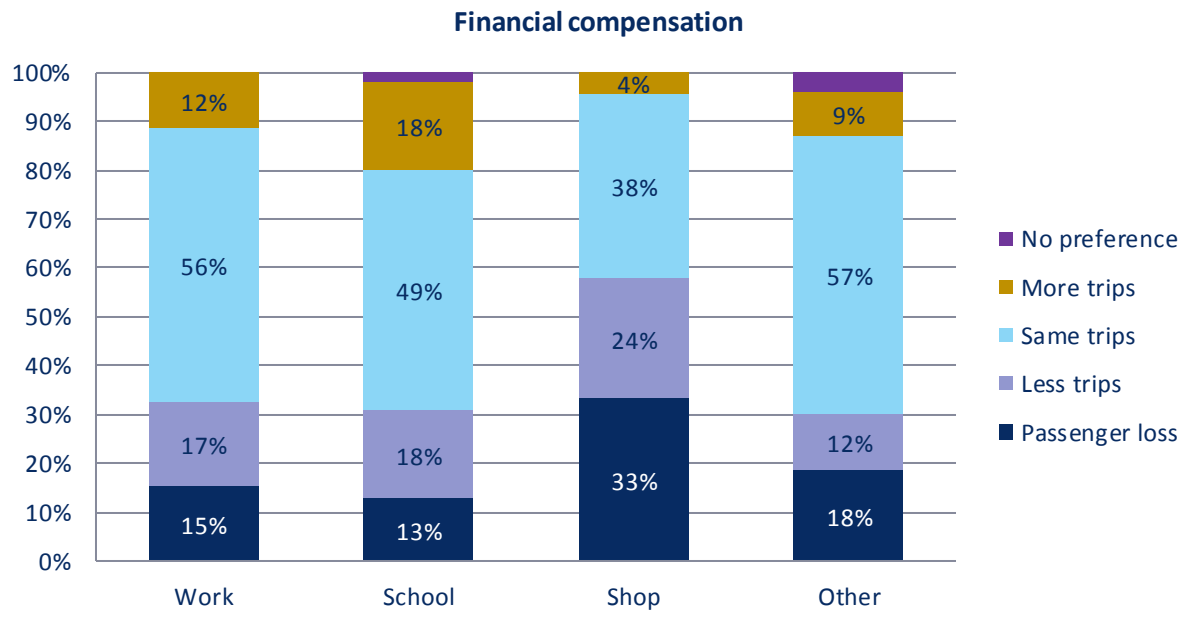


Figure 18.4 Appreciation for the second measure: financial compensation.

Regarding the third alternative (sheltered waiting room), the increases in public transport use is quite striking. Passengers with the purpose work and moreover with the purpose school appreciate the sheltered waiting room. Besides a high level of constant transport use, the increase of transport use is also noticeable.

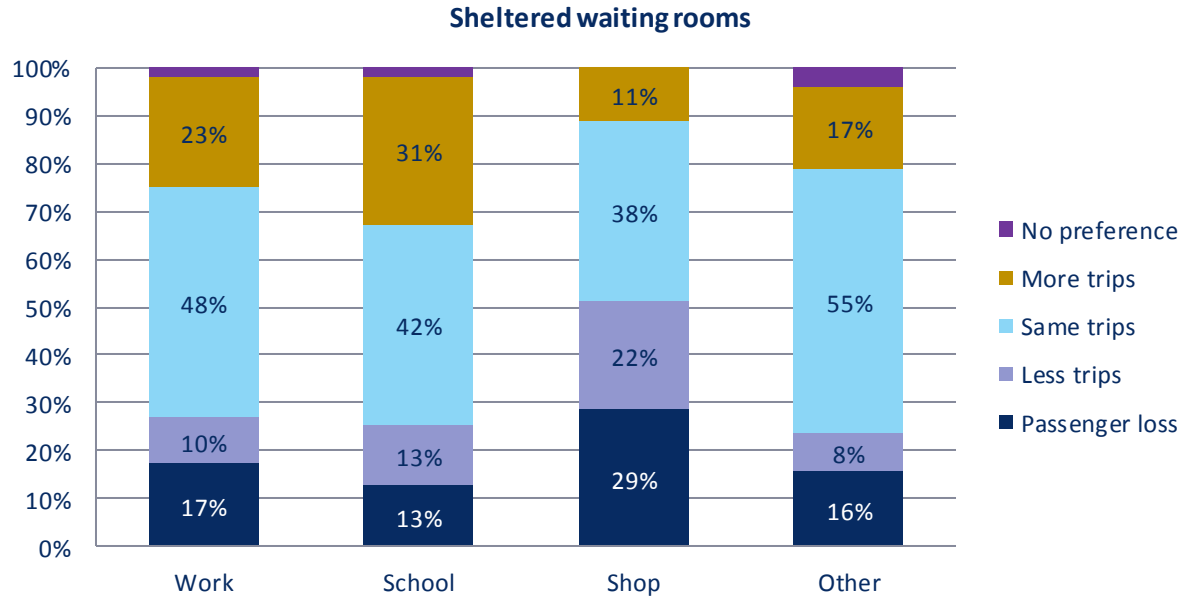


Figure 18.5 Appreciation for the third measure: sheltered waiting rooms at adjacent stops.

Bicycle parking and thus better accessibility is not one of the favorite compensating measures. The level of transport use remains constant for most passenger groups, but there is hardly any growth noticeable. Remarkable is the difference appreciation for this compensation measure for the purposes work, school and other in terms of decreased usage or loss. Students and shoppers have slightly lower results on transport reduction, while this amount is almost halved by the workers.

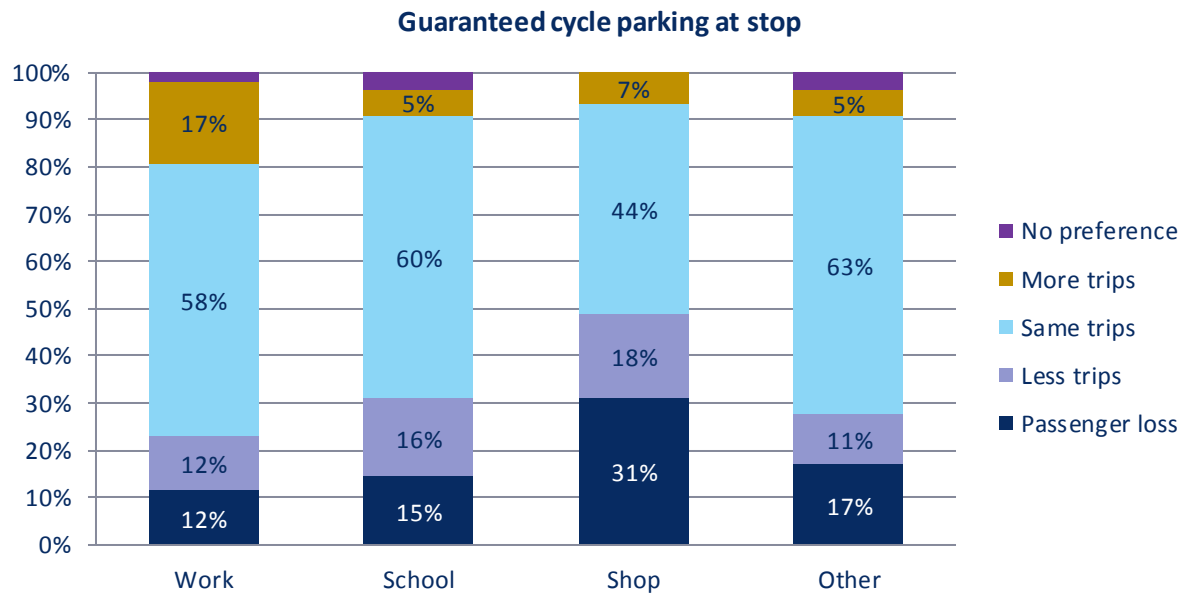


Figure 18.6 Appreciation for the fourth compensation: guaranteed free cycle parking space at the tram stop.

The most remarkable compensation is the fifth measure. Loss of passenger is almost negligible for the purposes school and work. The increase of transport usage is substantial with almost 50% for the students and somewhat less impressive for the workers with 33%. Even the increase for shoppers is quite high with 22% increase.

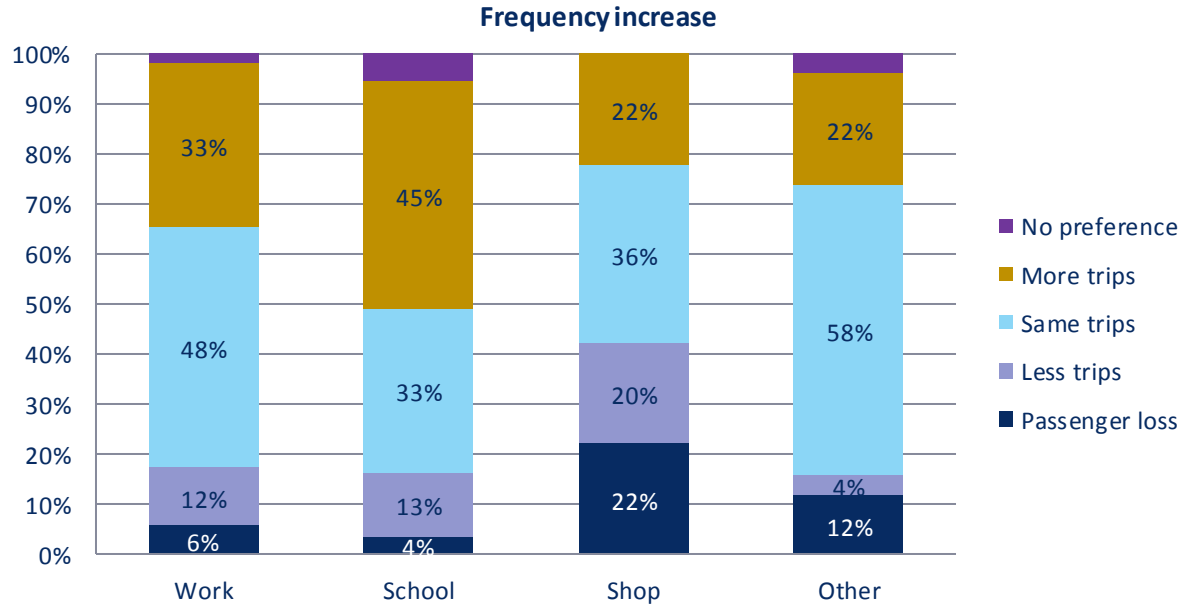


Figure 18.7 Appreciation for the fifth measure: increased frequency.

The figures above illustrate the existence in the different preferences per passenger group per compensation method. Furthermore, they illustrate the expected loss of passengers and increase of transport use per method per passenger group. The next chapter elaborates a bit more on passenger loss.

18.4.4 FIRST AND SECOND CHOICES PER PASSENGER GROUP

Each respondent in the survey was also asked to give a first choice and a second choice for each compensation. In this part, the results are exemplified. For the convenience, in each graph the total choices are given as well.

Working passengers had a diverse preference on their first choice. Most passengers picked the frequency increase, but the extra comfort, financial compensation and better accessibility are responsible for almost 50% of the first choices as well. The second choice is mostly equal spread over frequency increase, better comfort and a financial compensation. Compared to the total average, these passengers have a diverse preference for compensation measures.

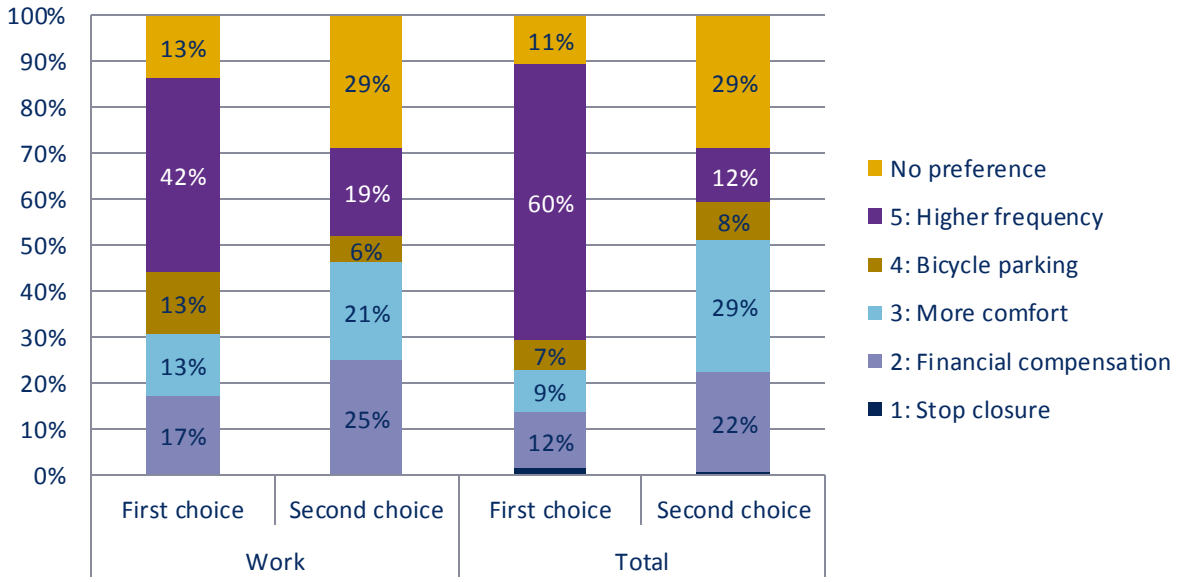


Figure 18.8 First and second choices of working passengers.

Passengers with the purpose school almost choose unanimously for the frequency increase as their first choice. The second choice is mainly focused on more comfort at tram stops. The choices do match quite well with the average results, although the second choice is somewhat more focused on more comfort.

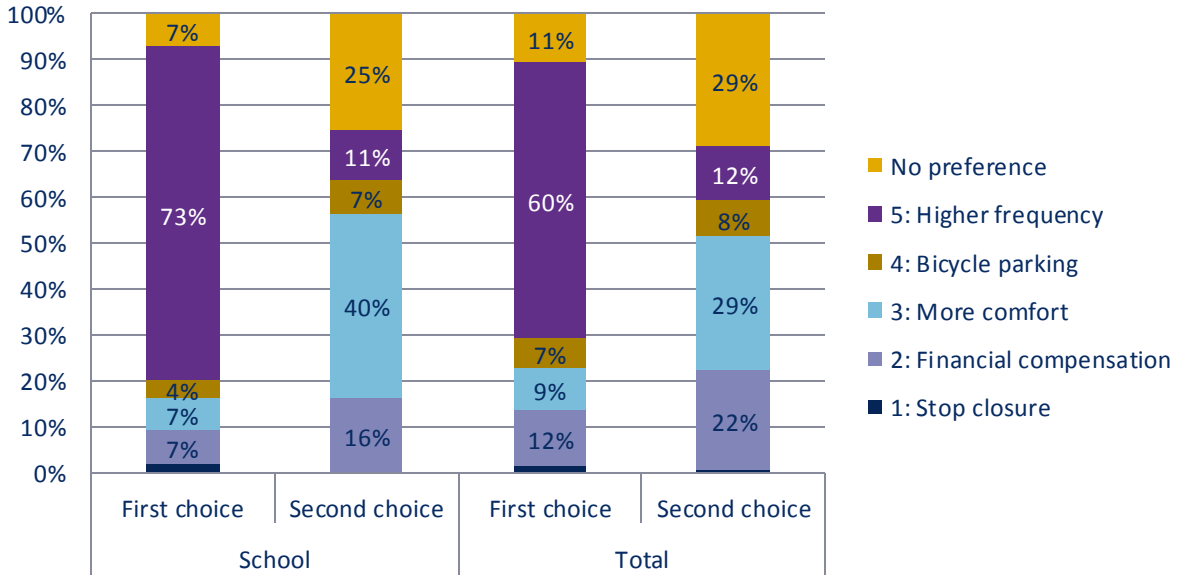


Figure 18.9 First and second choices for school-going passengers

The shoppers also do have a high preference on frequency increase for their first choice. Remarkable is the high amount of respondents not having a second preference, especially compared to the total amount of respondents. This could be explained by the high passenger loss that appears in case of stop closure. Although more comfort at the stop is a second-best for their second choice.

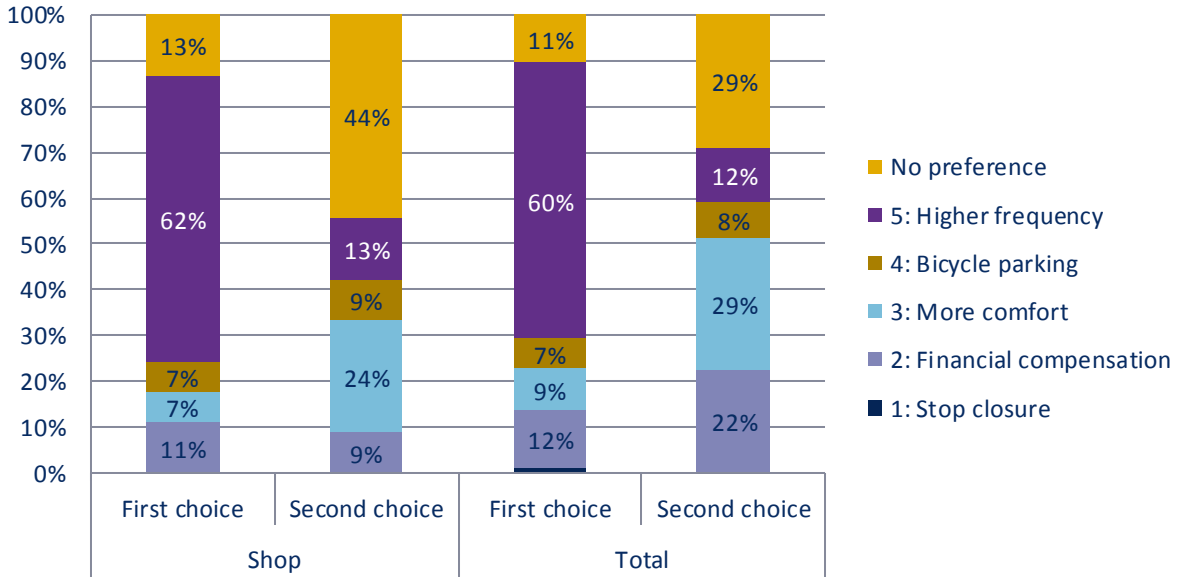


Figure 18.10 First and second choice for shoppers

The other-group has a strong preference on frequency increase as well for their first choice. Their second choice is mainly focused on financial compensation and more comfort. This could be explained by the high amount of non-working passengers in this group (almost 50% of the second choice for compensation was made by non-working respondents).

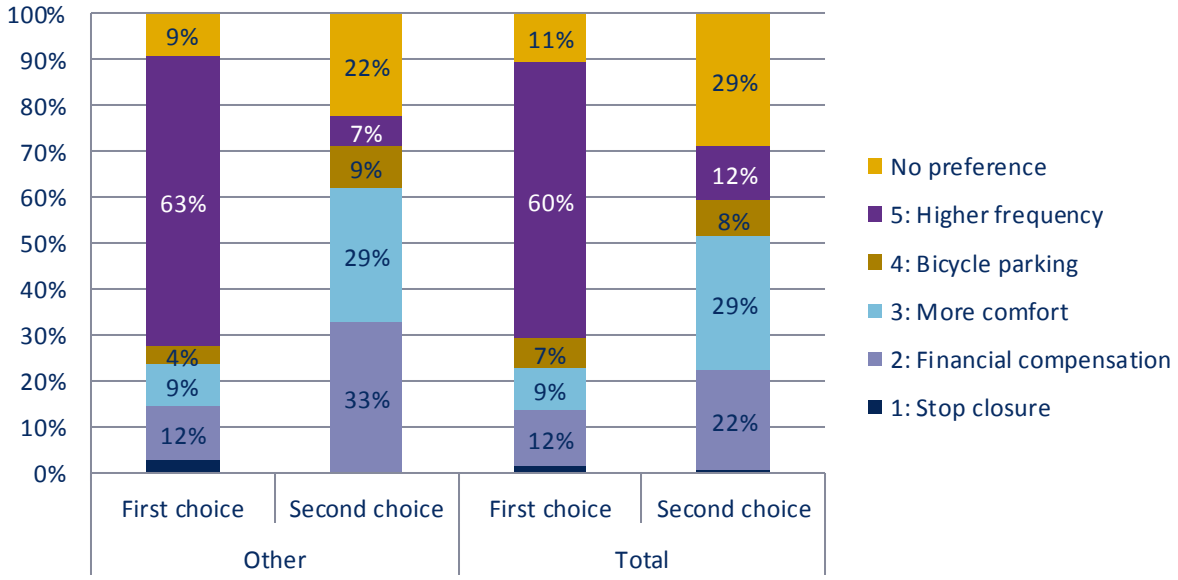


Figure 18.11 First and second choice for others

Comparing the preferences per compensation and the choices for compensations, one can conclude that better accessibility is hardly chosen. It does not reduce neither increase transport usage and only a few respondents have chosen this compensating attribute as mostly or secondly preferable.

18.4.5 PASSENGER LOSS

The passenger loss that was found during the SP-survey is generally much lower than originally calculated in the network assessment. The values of observed loss are the average values of all compensating measures. When these figures are compared with the theoretical loss, the differences are substantial. Depending on the figures found in theory, passenger loss varies between the 10 and 50 percent, depending on the stopping distances.

Table 18.6 summarizes the expected losses of amounts of passengers (the amount of times that respondents chose to stop travel is divided over the total amount of respondents multiplied by the range of choices) and gives the observed losses as well. Only for the stop Mathenesserlaan, the observed losses of passengers are higher than the earlier calculated losses. For all other stops, the losses are less.

Table 18.2 Observed amounts of passenger loss on stop level-method compared with the results of the SP-survey

	Observed loss (SP-survey)	Theoretical loss from stop level-method
Mathenesserlaan	36 times passenger loss / 29*5 observations = 25%	202/807 = 20%
Groene Wetering	18 times passenger loss / 5*26 observations = 14%	115-268 = 30%
Hof van Spaland	91 times passenger loss / 5*65 observations = 28%	1251/2733 = 45%
Piersonstraat	34 times passenger loss / 5*26 observations = 25%	376/1251 = 30%
Stadhuis	22 times passenger loss / 5*82 observations = 5%	269 / 2686 = 10%

The network level-method already showed that passenger loss was lower than estimated according to the passenger loss at stop-level. In chapter 19, the three approaches of passenger loss are evaluated.

18.4.6 NON QUANTIFIABLE RESULTS

During the SP-survey, the respondents often reacted on the proposed and suggested stop closure. The reactions, which could not be caught in the SP-survey, are nonetheless worthy to mention. Most passengers indicated that stop closure would not be a big problem for them, since often another transport mode was available for those passengers. Those passengers were mostly workers and students, who see the advantages of stop closure.

However, those who opposed again stop closure, did so in a verbally strong way. Some passengers admitted that this stop meant so much to them. The stop offered the possibility to stay mobile.

The most remarkable reactions were found at the stop Stadhuis. Although the adjacent stops are the closest nearby (only 190 meters), some passengers reacted harshly. Closing the stop was out of question, according to their opinion. Even compensating measures did not made any difference.

18.5 OTHER DIFFERENTIATIONS

When regarding other possible differentiations of passenger groups (towards age, travel frequency and transport dependency), some other conclusions can also be drawn. The conclusions are given below. These conclusions are based on the observation of the choice of the two best compensating measures that were asked for during the SP-survey. The associated figures can be found in annex 9.

Age: the younger the group of respondents, the more the cycle parking is appreciated. The financial compensation is the most appreciated by young people and elderly people. The more respondents are older, the more comfort is appreciated. Shorter waiting times due to higher frequencies are highly appreciated by all groups.

Travel frequency: the differentiation on travel frequency is less clear. For all groups count that increasing frequency is highly appreciated. The most frequent passengers and elderly people hardly care on financial compensation (since they often have a monthly or yearly subscription or free public transport).

Travel dependency: differentiation towards travel dependencies hardly gives any different results. That implies that the availability of other transport modes does not influence the decision making on different compensations.

Differentiations towards age, daily activity and ticket use are comparable to the analyses on trip purpose. This suggests that the use of the ticket is in line with the trip purpose. Obviously, the same applies for the daily activity. This suggests that trip purpose is one of the purest ways of differentiating passenger groups, as was stated in the problem introduction. This also implies that based on the age, the travel frequency, the ticket type and the daily activity, one could make a rough guess on the trip purpose.

18.6 CONCLUDING REMARKS

In chapter 13, expectations were drawn on the results of the passenger assessment. The passenger assessment showed that some compensating attributes are more appreciated than others. And that reaction on stop closure strongly differs per group. This confirms the first assumption, stating that stop removal would be more tangible for shoppers than for other groups.

The second assumption is obviously not true. A better accessibility to adjacent stops is hardly appreciated as compensating measure. Only a few passengers are willing to cycle to the tram stop, even if good cycle facilities are present.

The third assumption is true. Almost two third of the passengers that have alternative possibilities would travel less or no more by at least one of the suggested measures (including stop removal without compensation). Only one fifth of the passengers without alternative would travel less or no more under the same circumstances.

One of the most remarkable findings is that the frequency increase is a highly appreciated compensation measure. Although this measure was originally not part of the SP-survey, the preference for this compensation is substantial for all passenger groups. This measure has different consequences for implementation than the other compensations. Implementation of original compensations means mostly out-of-pocket costs (a budget could be reserved for financial compensation), while adjusting the frequency comes with a whole range of costs and implementation challenges, as extra vehicles, new schedules or more staff. Remarkable is also the growth in transport if frequency increase is applied.

Overall, the loss of passengers is not as high as originally expected. Although the passenger loss that was preliminary used in the network assessment was not correct, the losses by stop closure are not as high as expected. Compensation measures do have a certain influence on preventing passenger loss, but solely stop closure does not cause severe fallbacks of transport usage.

The passenger assessment found furthermore that most passengers will shift to adjacent stops. The groups with the purpose school and work are hardly bothered by stop removal and even experience a shorter travel time. However, shoppers are more difficult to keep in the system and no matter what compensation is applied, losses remain high among this group. Nonetheless, shoppers are often a small passenger group in the network (in this case only 7%) and therefore, the absolute losses are limited.

19 RESULT ANALYSIS

In this part, the case analysis was introduced and results were generated for the case, based on the methodology that was discussed in the previous part. The goal of this case study was to test the functionality of the proposed –and adapted- methodologies and to generate results for the particular case. This part aims to analyze the results of both the network assessment and the passenger assessment and to find correlations between the mutual results and to generalize the results that were found in the case study.

The most important result of the network assessment is an overview of stops and performance per stop in combination with the knowledge which passenger group does use those stops. The network assessment lists stops that function well (BC smaller than one), stops that do not function well (BC bigger than one) and stops that perform overall bad, but are nonetheless important for a given passenger group.

The passenger assessment found compensating measures per passenger group. It furthermore concluded that passenger loss is quite different per passenger group, regardless any applied compensation. Based on trip purposes, different compensation attributes can be suggested per type of stop (depending on the group of passengers) to prevent passenger loss.

19.1 COMPENSATION FOR CLOSED STOPS

The working group and school-going group consider their travel time as important and value it high. Therefore, compensation on reducing waiting time is valued the best, which is translated to higher frequencies in this case. So, if a stop needs to be removed which is mainly serving these groups of passengers, frequency increase is the best step. Better comfort is a good second option.

The shoppers are more difficult to compensate. The best decision could be to not eliminate the stop, since the loss of passengers is high in any other case. Compensation for the others-group translates also in frequency-increase. Furthermore, both the financial compensation and the better comfort at the stop are highly appreciated second-choice compensations.

19.2 KEEP OR ELIMINATE A STOP

Now that both the network assessment and the passenger assessment have been applied, decisions could be made on stop removal. As mentioned in the network assessment, there are two other constraints that could save a stop. The first one is the network function of a stop and the second is the urban environment.

Network functions are not per definition an excuse to keep a stop. Some stops have a very low achievement (a high BC-ratio), although the interchange possibilities would suggest otherwise. The application of the passenger assessment on the case study showed that closing some of the network stops would not harm the level of usage. This was the case at Stadhuis, which provides an interchange function between some tram lines and two metro lines. The same interchange possibilities are also provided at both adjacent tram stops. This should however be determined per stop.

The urban environment is also constraining stop removal. It is advisable to check each stop on nearby important locations. The check in the case study showed that some functions are served by nearby stops (on the same line) as well, while other stops do not serve a particular special function.

19.3 EVALUATING LOSS OF PASSENGERS

One of the most important pillars of this method is the loss of passengers. The original used stop elimination method did not cope with passenger loss. This research aimed to find a new approach on stop elimination. Therefore, a new approach of passenger loss was suggested as well. The loss of passengers has been calculated in three ways in this thesis.

- The passenger loss was initially part of the stop level method. The goal was to find a proper and accurate way of calculating passenger loss rates when stops are closed. This method was not considered to be accurate enough. The originally applied method was extended so that passenger usage could be

calculated in both horizontal and vertical direction towards the stop, but the loss figures were too high to be realistic. An example of passenger loss calculation is given in annex 10;

- The network level-method indicated passenger loss as well top verify the loss on stop level. The results of this method showed that the major part of the passengers spreads over adjacent stops and only a few percent of the passengers is lost at the particular location;
- During the passenger assessment, respondents were asked about their travel behavior in case of stop closure. Based on those results, figures were obtained that suggested a certain passenger loss.

Due to the fact that no accurate passenger loss methodology was found on stop level, only the results on network level and from the passenger assessment are evaluated.

One of the most remarkable results of the network assessment is the growth of passenger usage on network level. A growth of 2% to 5% on the whole line was observed by closing certain stops. This proves that closing stops and thus shorter travel times lead to more appreciated transport.

Regarding the trip purpose separately, the loss per group differs as well. The passenger assessment found that, while working and school-going passengers mainly remain traveling if their stop is closed, the shoppers are less willing to bridge longer distances to adjacent stops. They do not have the high need to perform the trip, in contrast to the above-mentioned groups. Therefore, this group is less willing to put extra effort in performing their trip.

These results correspondent to the analysis of different passengers groups that was performed in chapter 8. This analysis stated that the students and workers have a high reliability on transport. Therefore, changes in supply of transport are easier accepted. After all, they have little choice, because they have to go to their destination.

These results imply that compensation measures at adjacent stops are not per se necessary to prevent fallbacks in transport usage. The fear that passengers are lost when a stop is closed is therefore ungrounded. However, if one decides that compensation is necessary, a certain range of measures is available (as concluded in chapter 18).

The figure below visualizes the way passenger loss was calculated in both the network assessment and the passenger assessment.

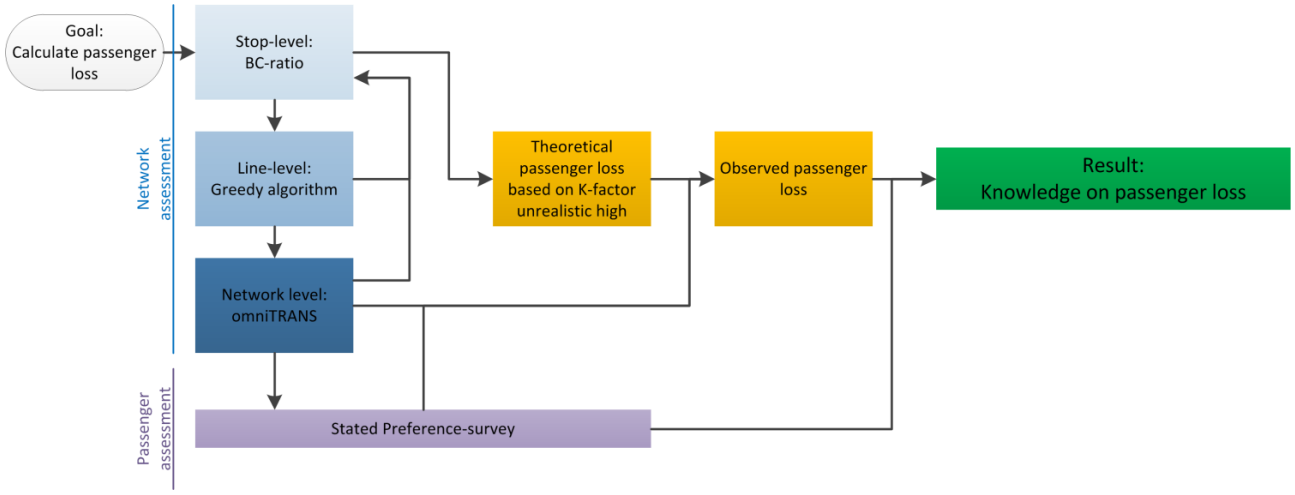
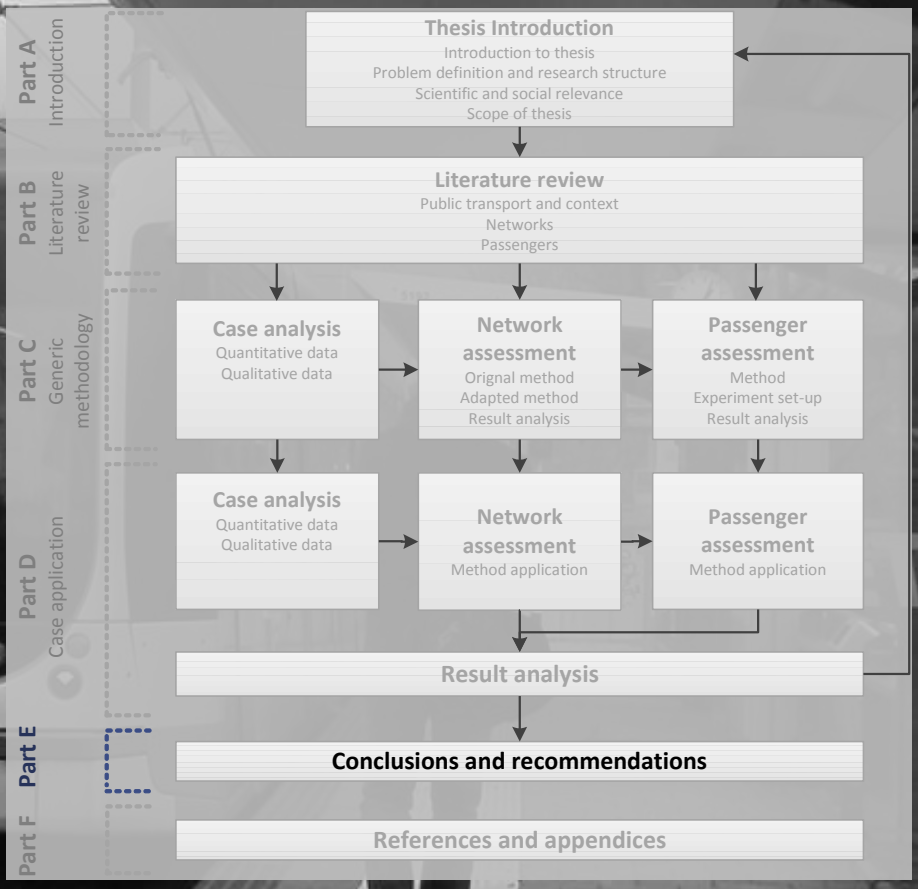


Figure 19.1 Influences of different methods on other methods applied in this thesis.

PART E – GENERAL CONCLUSIONS AND RECOMMENDATIONS



20 GENERAL CONCLUSIONS

This thesis aims to find a more accurate approach of optimizing public transport systems. There is a particular interesting field in the public transport network that is suitable for network optimization. There is a gain in enlarging and optimizing stopping distances, since larger stopping distances result in faster operation in the network.

As stated in the introduction, there is little scientific knowledge about passenger differentiation towards trip purpose and the relation towards public transport optimization. Both topics were extensively addressed. This thesis aimed to find a better way of optimizing stopping distances with the use of a new method and the application of towards trip purpose differentiated passenger groups.

Those topics were addressed in two main sections, the *network assessment* and the *passenger assessment*. The network assessment focused on the scientific network optimization. An existing stop level optimization method was adjusted, so that it could deal with differentiated passenger groups based on trip purpose. With the addition of two other methods in line level (greedy algorithm) and network level (omniTRANS), the functionality of this method was proven.

By applying a passenger assessment, a social study was conducted towards characteristics and preferences per trip purpose. Knowledge is obtained on social behavior of those different passenger groups in relation to the optimization of the network. This step was performed with a stated preference survey.

The next sections subsequently answer the sub questions, the main question and formulate the general conclusion. Finally, the developed methodology is discussed.

20.1 ANSWERS TO THE SUB QUESTIONS

Sub questions were formulated to answer the main question. The section below answers the sub questions step by step and eventually the main question is answered.

1. **What is the current challenge in urban public transport related to network optimization?**

Public transport systems (and the society as a whole as well) face a rationalization challenge in which the existing system must be adjusted so that it saves costs. Reduction of transport supply is inherent attached to this challenge. It is the task for the researcher to find a solution that aims to answer the rationalization challenge in such a way that the welfare –which is related to transport supply- is diverted over the passengers in such a way that supply of transport comes to those who would like to use it.

On operational level, there is a financial gain to make for the operator in rationalizing stopping distances. Performing this rationalization leads to longer stopping distances and thus a travel time reduction for passengers. Shorter travel times may lead to an increase in transport usage. On the other hand, longer stopping distances cause longer access or egress distances for the passenger as well and thus a fallback in supply. This contradiction is the current challenge in urban public transport networks. This thesis aims to find a more accurate approach of optimizing public transport systems

2. **Does differentiation of passengers contribute to network optimization?**

If the travel demand from passengers is known, the supply of public transport can be adjusted to the demand. A better adjustment of supply and demand could lead to more consumption of public transport. The differentiation of passengers leads to a more detailed view on the demand of public transport. These different preferences translate themselves in behavioral characteristics. When these characteristics are observed in literature for the motive trip purpose, one finds quite different preferences per passenger group regarding public transport.

This research found out that differentiating passenger groups is to a certain extend useful for network optimization, since demands and preferences on public transport for differentiated passenger groups are more specified per passenger group. The biggest gain for the operator, based on this research, is that per stop and per passenger group, a decision can be made on either keeping or removing the stop.

However it must be reckoned that the outcomes of the stated preference did not result into proves that differentiating passengers according to trip purpose leads to a better way of optimizing stopping distances according to passenger groups. Besides the observation that there exists a difference in passenger loss and compensation appreciation between workers and school-going passengers on one hand and shopper on the other hand, no results were found that prove that trip purpose differentiation leads to different results on optimization than when passengers are approached as one solely group.

3. How do passenger groups react to optimized stopping distances?

The network assessment showed that some stops should be closed. Closing these stops would lead to more benefits than costs for all passengers. However, some stops that perform badly overall, might be useful for a certain passenger group. The reaction towards stop closure is quite diverse. The passenger assessment showed that some passengers did not see problems in stop closure, while stop closing was very sensitive to others.

Stop closure mainly affects shopping passengers. Those passengers are less willing to access the transport system via adjacent stops, in contrast to passengers that go to work, school or have another purpose. The overall reactions of all groups was somewhat more diverse. Stop closure was mainly accepted if alternatives were present (a nearby stop or another transport mode). Due to the fact that most of the stops that are proposed for closure had nearby stops, the overall reaction was not very negative.

The proposed method to calculate passenger loss on stop level was considered to be too inaccurate. Figures of passenger loss were subsequently overestimated by the applied method. Therefore, only a method to calculate passenger loss is proposed for stop level, while no results have been generated by this method. In the recommendations, a suggestion is done to develop a tool for passenger loss on stop level.

4. Do compensating attributes cost efficiently contribute to public transport use?

When the different characteristics of passengers are applied to network optimization, it will lead to a demand that is specified to those characteristics. Regarding trip purpose, it means that passengers with the purpose work and school are willing to accept longer stop distances.

Moreover, the results of the SP-survey showed even a willingness to travel more with public transport, if some compensation measures were applied (frequency increase for example). However, the SP-survey did not gave insight in this growth. This growth could come from a changed distribution of mode choice for the same trip purpose, which means that passengers would travel more by the particular mode to their destination. Another possibility is that these passengers would use public transport for other purposes as well.

This differs for shoppers. They are less willing to bridge longer distances, disregarding compensation measures. This is in line with the theory that was treated in this thesis. The profiles that were sketched by literature per passenger group are in line with the findings on preferences in the passenger assessment. In which way compensation influences the travel behavior is answered in the next sub question.

However, the costs of passenger loss are not very high, since the losses linger at 8% to 12% according to the network level-methodology and around the 20% to 30% according to the passenger assessment. On the other hand, the network level-methodology shows an increase of usage on network level, which results in more transport use. Therefore, it seems that costly compensation measures are not necessary to implement

5. Is compensation necessary to prevent fallback of transport usage in case of stop closure and what compensation can be applied?

Rationalizing public transport goes hand in hand with loss of supply, no matter how small. Therefore, compensation to prevent the fallback in public transport was originally suggested. Compensation in general is useful, because passengers are willing to bridge a longer distance to adjacent stops, if they are 'rewarded' in some way for doing so.

One of the most important outcomes of the network assessment and the passenger assessment is that stops that are mostly being used by work-passengers are the most suitable to close from cost-efficiency point of view, since those passengers are willing to bridge a bigger distance, even without compensation. Besides, only a very small amount of passengers (20% workers, 19% students) would not travel any more if their stop was closed. These results are in contrast to shoppers for example. Those passengers would use other transport modes if the stop was closed (up to 38% is lost and another 24% travels less). Compensation measures only partially intercept this loss as will be explained in the next section.

The stated preference-survey found that the highest appreciated compensation is increase in frequency. This leads to the least decrease (6% loss of workers, 4% loss of students and still 22% loss of shoppers) of usage and the biggest growth (up to 33% for workers and even 45% of students), according to the observations and results found among the respondents. Other compensating measures are a better waiting room. This type of compensation is mainly appreciated by shoppers and school-going passengers. Passengers with trip purpose 'other' also value this attribute high. Financial compensation is mainly appreciated by *others*.

A better accessibility is partially appreciated but does not score significantly better than the zero-alternative (doing nothing besides stop closure). Therefore, improving bicycle parking at tram stops is not a suitable compensation measure, since the results do not differ from the scenario in which the stop is closed and no compensation is proposed.

20.2 ANSWERS TO THE MAIN QUESTION

Now that the questions on network optimization and passenger differentiation have been answered, the next section aims to answer the main question. A repetition on the main question:

To what extend does the use of passengers groups differentiated towards trip purpose contribute to public transport network optimization, with respect to the travel demand of differentiated passenger groups?

At first, this research found out that differentiating passenger groups is useful for network optimization, since demands and preferences on public transport for differentiated passenger groups are more specified per passenger group. The consideration to eliminate a stop is namely more balanced if the trip purpose is incorporated in the BC-ratio.

Furthermore, by applying those characteristics on network optimization, decisions on stop removal, which this thesis addresses-, could be made more accurate. If per stop the amount of passengers and their trip purpose is known, the existence of the stop can better be justified. Moreover, the loss of passengers could be estimated more accurate. The passenger assessment found that stop closure has more impact on shoppers than other passengers.

If it is decided that a stop will be closed, a certain loss of passengers takes place. This loss depends on the type of passenger group that is involved. The loss of passengers is high if shoppers are involved and low when workers and students are involved.

The passenger assessment found a range of compensating measures that can be implemented, based on the concerning passenger groups (frequency is overall useful, while compensations as sheltered waiting room and more convenient access hardly influence shoppers). However, no found compensation measure prevents the fallback of shoppers. Moreover, costs involved by implementing the compensation do not seem to offset the gains in reduced losses. Therefore, compensation is possible but not necessary.

The second part of the answer is that this research found that public transport usage and the willingness to accept changes in the system, is quite diverse per passenger group. The groups work and school are much more willing to accept changes than passengers with the purpose shopping, expressed in transport usage rates. Therefore, the travel demand for the latter group differs with the first two mentioned groups. One should be aware of this difference when stop closure is executed, since the loss of passengers in this group will be much

higher than in the other groups. However, in the case, the group of shoppers was only 7% of the total amount of passengers. Therefore, the absolute losses are not so bad.

The stop and its function are highly linked to the urban environment. Closing stops near shopping centers for example, will lead to loss of passengers, since those shoppers will chose other transport modes. Meanwhile, this has effect on the urban environment as well, since the use of other transport modes have other consequences in terms of usage. Moreover, closing stops in areas where workers and students dominantly use public transport, has less effects on other mode usages. Those passengers are more willing to bridge those longer access distances.

Furthermore, by applying those passenger groups on network optimization, decisions on stop removal, which this thesis addresses-, could be made more accurate. If per stop the amount of passengers and their trip purpose is known, the existence of the stop can be justified better.

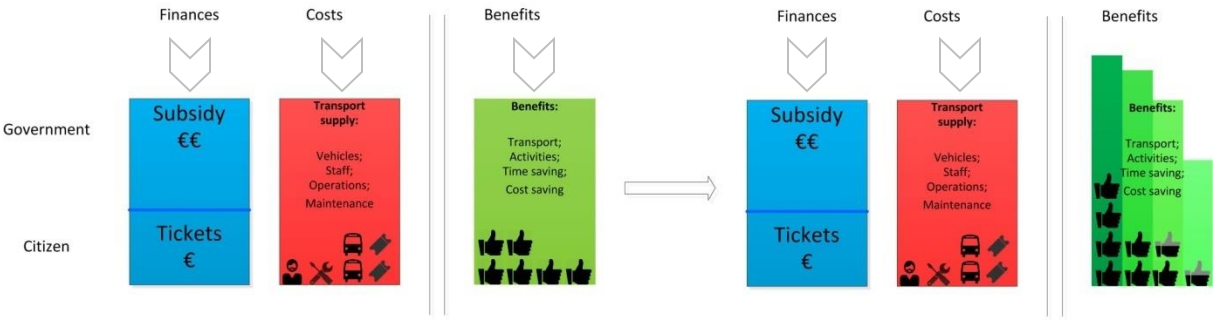


Figure 20.1 Rationalizing public transport does not lead to overall lower transport benefits for all passenger groups.

So, concluding on the redistribution of transport benefits over public transport passengers, the network assessment and the passenger assessment showed that rationalizing (increasing) stopping distances does not lead to overall lower benefits for passengers. Instead, it can lead to more benefits for certain passenger groups and less benefits for other groups. The profiting groups seem to be the workers and the students, since their travel times decrease. The shoppers lose to a greater extent their transport benefits.

So to answer the main question: there exist a possibility in rationalizing a public transport network, based on trip purpose, since there exists a difference in willingness to bridge a certain distance to a stop based on a specific passenger group. However, the differences between those passenger groups are only strongly visible when the group of shoppers is involved. Furthermore, the observed passenger loss suggests that –expect among shoppers- the loss of passengers is limited among all passenger groups. Furthermore, even an increase of usage was observed over the whole network, due to reduced travel times.

20.3 GENERAL RESULTS

If the results of the research are summed up, the following conclusions can be drawn:

- There is a need to optimize stopping distances according to the amount of stops that is proposed to close;
- Optimizing stopping distances leads to redistribution of transport benefits, since benefits belong mainly to the working and school classes, since they will profit from benefits of shorter travel times. Shoppers fall out of network and thus have less benefits;
- Stop closure leads to lower overall costs for system operations lower due to faster operations within the same circumstances (amount of vehicles and staff).
- Closing stops does cost passengers (loss), but leads to an overall increase of passengers on the whole line, which is bigger than the loss at the stop;
- Passenger groups with the purpose school and work are willing to bridge longer distances to adjacent stops than shoppers;
- Compensation measures are useful, but not necessary. Frequency increase leads to big increases of transport usage;

- There is only a limited amount of shoppers in the network, thus overall passenger loss among this group is low;
- **Differentiating towards trip purpose leads to suggestions on how to approach stop distance optimization, but does not lead to a whole new unique approach of stopping distance optimization.**

20.4 DEVELOPED METHODOLOGY AND ADVICE ON STOP ELIMINATION

Among the results of this thesis is a methodology that helps to optimize stopping distances on stop level. This thesis developed the methodology out of an existing methodology that was considered to be incomplete. The methodology exists of three layers, i.e. stop level, line level and network level. The network level was solely applied to verify the stop level methodology. The steps below must be conducted to obtain similar results.

STOP LEVEL

The methodology on stop level calculates costs and benefits in terms of time for respectively accessing and egressing passengers and for in-vehicle passengers. The methodology takes different value-of-time ratios in account, so that results are obtained per passenger group differentiated towards trip purpose. The result of the method on stop level is a ratio that helps to judge if the stop should be closed or kept. The stop level -method is based on the BC-ratio which is calculated according to the following formulas.

Benefit-Cost Ratio = B/C (BC-ratio) [1]

Where
B= Total Benefit
C= Total cost

$Benefit_n$-$Cost_n$ Ratio = B_n/C_n (BC_nratio) [2]

Where
B_n = Benefit for passenger group n
C_n = Cost for passenger group n

The stop is evaluated as follows:

If B/C> 1, the stop removal should be approved
If B/C< 1, the stop removal should be rejected

The BC_n-ratios are based on the Benefits and Costs per passenger group. In the following formulas, passenger groups are specified towards trip purpose.

$B = P_r * T_r$ [3]

Where
B = generalized benefit
P_r = passengers riding trough (number)
T_r = additional travel time due to stop (constant)

The cost for removing a stop is a function of the number of passengers that is using the stop. These passengers experience an increased travel time, because they have to access the network via another stop.

$C = P_a * T_a * W_a$ [4]

Where
C = generalized costs
P_a = passengers accessing or egressing at stop
T_a = net increase in travel time per person to use adjacent stop
W_a = weight for access time

T_a is the average additional travel time experienced by passengers whose stop is removed and have to access via another stop.

$T_a = D_{aw}/V_w$ [5]

Where

D_{aw} = average additional walking distance to remaining stops
V_w = average walking speed

The stop's service area is assumed half the distance to the nearest stop in each direction. The method assumes passengers to migrate to the nearest remaining stop after elimination.

$$D_{aw} = (D_n * D_f)/(D_n + D_f) \quad [6]$$

Where
D_n = Distance to near stop
D_f = Distance to far stop

The result is a list of stops that has a BC-ratio higher than one and is thus candidate for elimination. Only stops ready for elimination in two directions are actual candidate for close. The next step explains the line level method.

Annex 10 consists a suggestion to recalculate passenger loss. However, the used parameters in this thesis showed that the loss was calculated in an unrealistic way. Therefore, the method could be applied according to the explanation in annex 10, but the parameters need to be revised.

LINE LEVEL

The methodology on line level helps to decide which stops should be kept and which not if multiple stops in a row have a BC-ratio that nominate them for closure. This methodology should be applied together with the stop level methodology.

This step does not distinguishes stops with BC > 1 and stops with BC > 1, $BC_n < 1$, since both types of stops are candidate for elimination. Therefore, the greedy algorithm does not make distinction between stops that perform overall badly and stops that perform badly, but have at least one group of passengers that do has stake in keeping the stop. Stops that are eliminated by the greedy algorithm are also candidate for compensation measures (discussed in the passenger assessment). The following steps must be conducted to perform the line level-methodology if a row of stops has been discovered:

1. Select the stop with the highest BC-ratio;
2. Change the stopping distances between the selected stop and the adjacent stops in such a way that they become new consecutive stops;
3. Calculate passenger distribution over adjacent stops;
4. Eliminate original stop and check the new BC-ratios of the former adjacent stops;
5. The process stops when all stops with BC-ratio > 1 are gone either through removal or due to passenger increase.

By incrementally removing the stops with the highest BC-ratio, other stops get the 'opportunity' to reduce their BC-ratio, because passengers redistribute over the adjacent stops. The calculation of passenger redistribution is done via a ratio based on the stopping distances between the near stop and the far stop. This ratio is calculated as follows:

- Near stop ratio: (additional walking distance / near stop distance) * 100%
- Far stop: (additional walking distance / far stop distance) * 100%

The final result is a list of stops that could be eliminated. However, as concluded above, the consequences of stop closure depend on the involved passenger group and therefore the decision of closing a stop should be carefully considered, since the consequences of passenger loss differ per passenger group.

Furthermore, this thesis contains an advice on compensation measures to prevent passenger fallback. Besides, an advice on stop closure is given for the case study that was applied in this thesis.

It is recommended that the user of this method has good knowledge of the particular public transport system.

21 RECOMMENDATIONS

Although this research aimed to close the earlier mentioned gap as good as possible, there remains always an unanswered part. And each solution raises new questions. Therefore, the following recommendations are made for this research.

21.1 MODEL EXTENSION

The purpose methodological roadmap as discussed in this thesis was twofold. Besides creating results, the BC-ratio method was also tested as a proper method to apply for stopping distance rationalization. The loss of passengers was not realistic calculated according to the results of the passenger assessment and the network level check. Therefore, it is suggested that based on these findings, further research focuses on optimizing calculations for passenger loss. This research should focus on creating new parameters based on compensating attributes. It would be useful to find out what increase of passengers would be generated by what sort of compensation measure, instead of just knowing that a certain increase takes place.

21.2 FOCUS ON MORE INFRASTRUCTURAL COMPONENTS

Although network rationalization could lead to big benefits for passengers, the operator and the authority, it is not realistic to assume that the process of stop elimination is a stand-alone process to improve the quality of public transport. Rationalization is only one way of optimizing and solely applying this method is not good enough. This was recently proved by an example of stop removal in Amsterdam. The removed stop leads to a theoretical improve of travel time. Unfortunately, a traffic light near the removed stop was not adjusted to the new infrastructural situation. The result was that trams still had to stop and stood still for about the same time as it would have done at the stop (OVPro [2], 2014). This small example illustrates the relation between different infrastructural aspects. Therefore, stop removal should be done in direct relation with other infrastructural elements like traffic signs, traffic lights and other transportation policies. It is recommended that a new research combines all elements to observe the mutual effects.

21.3 INCORPORATE PASSENGER REPRESENTATION GROUPS

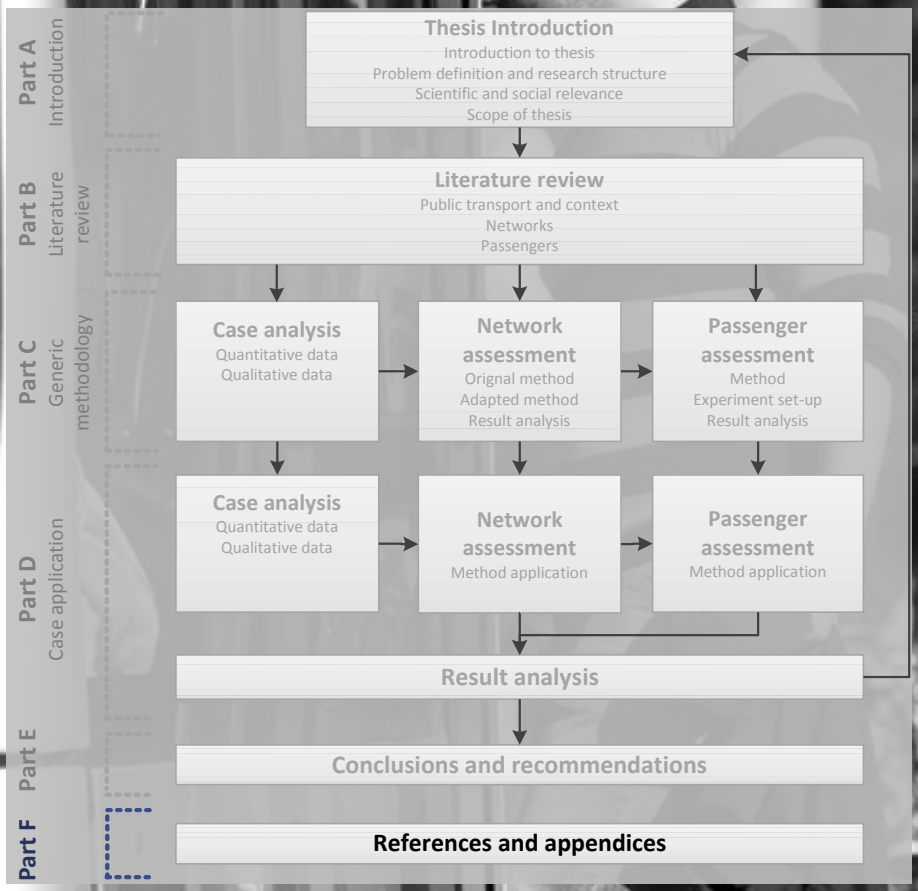
Although this thesis mainly focused on the playing field of the authority, the operator and the passenger (groups), it would be useful to incorporate other interest groups as well. One of the most important groups is the range of passenger representation groups. They are groups that defend the interests of passengers in general or dedicated passenger groups (like the visually impaired). The goal of these groups is to improve the supply of public transport. The interests of these groups are high, since their reason of existence is based on public transport. Passenger representation groups gained more importance in transport planning during the last decades. Nowadays, they are involved in the whole process from initial planning to operation of transport systems (Bickerstaff et al., 2002 Schiefelbusch & Dienel, 2009)

One can expect resistance from those groups when the public transport system is rationalized, since it will affect the accessibility in a certain way. This thesis did not focused on the specific relation. Nonetheless, there is not much known about the relation and the power of those groups versus the operator and the authority. It would therefore be useful to do more research in the institutional playing field between the passenger representation groups and the authority and operator. This research should have the purpose to map the stakes and power of the groups and should therefore help to smoothen the process of changing the public transport system and would therefore lead to quicker effectuation of stop removal.

21.4 NEW APPROACH OF PASSENGER LOSS ON STOP LEVEL

The proposed calculations for passenger loss on stop level were too stringent. The results calculated too big losses of passengers. The proposed method as explained in annex 10 could help to calculate a new approach of passenger loss on stop level. However, the used parameters are overestimated according to the observed losses in the case application. Therefore, new parameters should be calculated, so that this method could be applied on stop level as well.

PART F – REFERENCES AND APPENDICES



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ANNEX 1 – WALKING DISTANCE TO ADJACENT STOP

Assuming that the influence areas around stops is a rectangle (as explained in the case analysis, 5.2) and passengers walk along the line to the adjacent stop, the additional walking distance is calculated according to the method described below. The method assumes that the density of passengers using the public transport is equally distributed over the rectangles. For the sake of simplicity, additional walking distance is only calculated parallel to the line (distance along the PT-line) and not in perpendicular or diagonal direction.

The method calculates for each stop the original walking distance to the stop and the new walking distance to adjacent stops if the particular stop is eliminated. The difference between the original walking distance and the new walking distance is the additional walking distance. Stop B is the stop that is to be eliminated. All distances are in meters.

Original walking distance to B:

A, B and C are stops

D_{ab} = distance between A and B
D_{bc} = distance between B and C
Where
$D_{ab} = (K+L)$, $K=L$
$D_{bc} = (M+N)$, $M=L$

$D_{ow} = (L/(M+L)*0,5L) + (M/(M+L)*0,5M)$
Where
D_{ow} = original walking distance

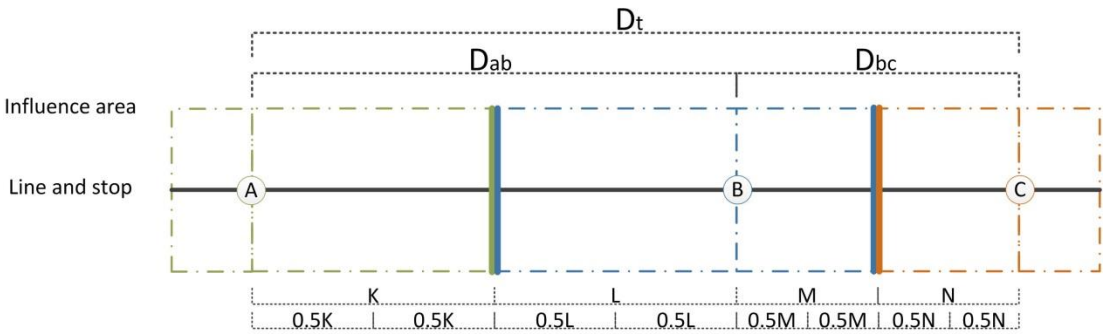


Figure A 1 Original situation.

New walking distance

A and C are stops, B is eliminated

D_t = distance between A and C
D_{ba} = distance between edge of influence area A and the middle of AC
D_{bc} = distance between edge of influence area C and the middle of AC
Where
$D_t = (K+L+M+N)$
$D_{ba} = 0,5D_t-K$
$D_{cb} = 0,5D_t-N$

$D_{nw} = (D_{ba}/(D_{ba}+D_{cb})*(0,5D_{ba}+K)) + (D_{cb}/(D_{ba}+D_{cb})*(0,5D_{cb}+N))$
Where
D_{nw} = new average walking distance

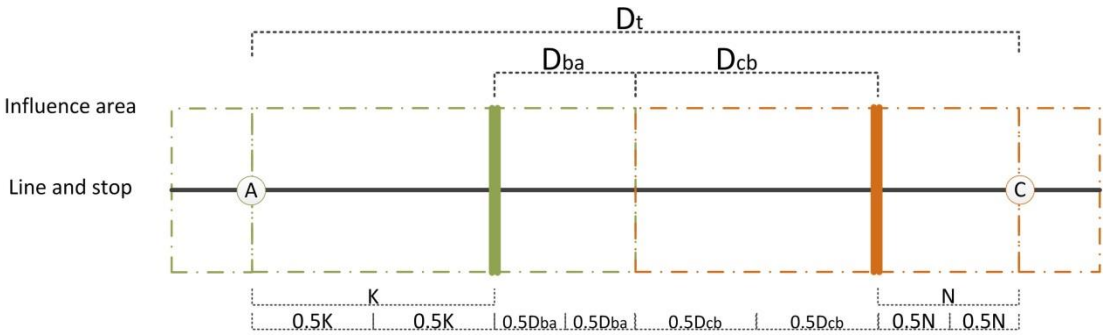


Figure A 2 New situation with removed stop.

Additional walking distance

The additional walking distance is the difference between the original average walking distance and the new walking distance:

$D_{aw} = D_{nw} - D_{ow}$

Where

D_{aw} = additional walking distance

The results of the formulas of D_{aw} and D_w are the same. However, the D_{aw} formula contains more steps, but this method is more logic to understand.

ANNEX 2 – SP-EXAMPLE

An example of the general SP-survey is visualized below.

1 Introduce purpose of this survey

		Work	School	Shop	Other,
2	Trip purpose (from/to)				

		Daily.	3>wk	3<wk	Less
3	Frequency				

		Yes	No	Other:	
4	Alternative modes?				(car, bike, etc.)

5	Destination (tram stop):	
6	Average trip time	

7 Introduce scenarios, let respondent imagine that stop is eliminated

		No	Less	Same	More
A	To other stop Still make trip?				
B	To other stop and: financial compensation Still make trip?				
C	To other stop and: more comfort on adj. stop Still make trip?				
D	To other stop and: better accessibility Still make trip?				

		A	B	C	D
	Which alternative is preferred?				

6 Bio-data

		<15	15-25	26-45	46-65	65>
a	Age					

		Man	Woman
b	Gender		

		Student	Work full.	Work part.	Ret.	Other
c	Daily activity					

		Total	Partially	Hardly
d	Dependency on PT			

		Abon.	Stud-OV	Saldo	Other
e	Ticket type				

Figure A 3 Example of general SP-survey.

An example of the case-related SP-survey (in Dutch).

1	Introduceer doel					
		Werk	School	Winkelen	Anders, namelijk	
2	Reisdoel (van/naar)					
		dag.	3>wk	3<wk	minder	
3	Frequentie van reis					
		Ja	Nee	Anders:		
4	Alternatieve vervoer?					(auto, fiets, enz.)
	(voor deze reis)					
5	Bestemming: (overstaphalte of eindhalte)					
6	Gemiddelde reistijd					
7	Introduceer scenario's: stel dat halte opgeheven wordt, dan:					
A	1: Naar andere halte	Nee	Minder	Gelijk	Meer	
	Blijft u deze reis maken?					
B	2: Naar andere halte en: financiële compensatie	Nee	Minder	Gelijk	Meer	
	Blijft u deze reis maken?					
C	3: Naar andere halte en: betere wachtruimtes	Nee	Minder	Gelijk	Meer	
	Blijft u deze reis maken?					
D	4: Naar andere halte en: betere bereikbaarheid	Nee	Minder	Gelijk	Meer	
	Blijft u deze reis maken?					
E	5: Naar andere halte en: hogere frequentie	Nee	Minder	Gelijk	Meer	
	Blijft u deze reis maken?					
		A	B	C	D	E
	Welk alternatief heeft uw voorkeur?					
6	Bio-data	<15	15-25	26-45	46-65	65>
a	Leeftijd					
		man	Vrouw			
b	Geslacht					
		Student	Werk full.	Werk part.	Gepens.	Anders
c	Dagelijkse activiteit					
		Totaal	Deels	Nauwelijks		
d	Afhankelijk van OV?					
	(algemeen)	Abon.	Stud-OV	Saldo	Anders	
e	Type vervoersbewijs					

Figure A 4 Example of SP-survey as applied in case.

ANNEX 3 – NETWORK FUNCTION

Table A 1 Network function

Stop	Interchange				Other tram lines using stop						
	TRAM	BUS	METRO	RAIL							
	T	B	M	R							
Harreweg		B			21						
Boeier					21						
Bachplein	T				21	24					
Hof van Spaland					21	24					
Prinses Beatrixlaan					21	24					
Station Schiedam Nieuwland		B		R	21	24					
Piersonstraat					21	24					
Parkweg					21	24					
s-Gravenlandseweg					21	24					
Station Schiedam Centrum		B	M	R	21	24					
Broersvest					21	24					
Koemarkt		B			21	24					
Rotterdamsedijk					21	24					
Hogenbanweg					21	24					
Het Witte Dorp					21	24					
Holy		B			24						
De Loper					24						
Over de dammen					24						
Parijslaan		B			24						
Schubertplein					24						
Marconiplein	T	B	M		4	8	21	23	24		
P.C. Hooftplein	T				8	21	23	24			
Mathenesserbrug					21	23	24				
Mathenesserplein					21	23	24				
Vierambachtstraat					21	23	24				
1e Middelandstraat					21	23	24				
Tiendplein					21	23	24				
Kruisplein	T				8	4	7	21	23	24	25
Marconiplein	T	B	M		4	8	21	23	24		
Zeilmakerstraat					4	8					
Van Duylstraat					4	8					
Delfshaven	T	B			4	8					
Ruilstraat					4						
Heemraadsplein					4						
Claes de Vrieselaan					4						

s-Gravendijkwal					4						
Mahtenesserlaan		B			4						
Bloemkwekersstraat					4						
Eendrachtsplein	T	B	M		4						
Spangen					8						
Huygenslaan					8						
Spanjaardstraat					8						
Schiemond					8						
Oostkousdijk					8						
Pieter de Hoochweg					8						
Euromast					8						
Kievitslaan					8						
Vasteland	T				8	20					
Leuvehaven	T		M		8	23	25				
Beurs	T	B	M		8	21	23	24	25		
Lijnbaan					8	25					
Willemsplein					7						
Westplein					7						
Museumpark					7						
Rotterdam Centraal	T	B	M	R	4	7	8	21	23	24	25
Weena/Hofplein	T	B			8	4	7	21	23	24	25
Pompenburg					7	8					
Goudsesingel					7	8					
Noorderbrug					7	8					
Zaagmolenbrug	T	B			7	8					
Crooswijksestraat		B			7						
Boezemstraat					7						
Boezemsingel					7						
Vlietlaan					7						
Jericholaan					7						
Mecklenburglaan					7						
Voorschoterlaan			M		7						
Essenlaan					7						
s-Gravenwetering					7						
Groene wetering					7						
Woudestein	T				7	21	24				
Heer Bokelweg					4						
Noordsingel					4						
Eudokiaplein					4						
Van den Hoonaardstraat					4						

Stoendaalseweg	T				4	8					
Station Noord		B		R	4	8					
Kootsekade					4	8					
Lommerrijk					4						
Bergse Plaslaan					4						
CNA Looslaan					4						
Bergse Dorpsstraat		B			4						
Liduinaplein					4						
Burg. Le Fevre de Montignyplein					4						
Molenlaan		B			4						
Zaagmolenbrug					8						
Zwaanshals					8						
Benthuizerstraat					8						
Bergpolderplein		B			8						
Kleiweg					8						
Stadhuis			M		21	23	24				
Keizerstraat					21	24					
Blaak		B	M	R	21	24					
Burgemeester van Walsumweg					21	24					
Oostplein			M		21	24					
Willem Ruyslaan					21	24					
Avenue Concordia					21	24					
Woudestein	T				7	21	24				
Oude Plantage					21	24					
Lage Filterweg					21	24					
Schiekade					25						
Walenburgerweg					25						
Schieweg					25						
Sint Fransiscusziekenhuis					25						
Melanchthonweg			M		25						
Donkersingel					25						
Meidoornsingel		B			25						
Wilgenlei					25						
Meidoornweide					25						
Larikslaan		B			25						
Peppelweg					25						
Kastanjeplein					25						
Total	16	23	12	5							

ANNEX 4 – STOP FUNCTION

Table A 2 Urban environment stop function

Stop	Function			
	SCHOOL	HOSPITAL	SHOPPING	WORK HUBS
Harreweg				
Boeier				
Bachplein				
Hof van Spaland			Yes	
Prinses Beatrixlaan	Yes			
Station Schiedam Nieuwland	Yes	Yes		
Piersonstraat				
Parkweg	Yes			
s-Gravenlandseweg				
Station Schiedam Centrum	Yes			Yes
Broersvest			Yes	Yes
Koemarkt			Yes	
Rotterdamsedijk				
Hogenbanweg				
Het Witte Dorp				
Holy		Yes		
De Loper			Yes	
Over de dammen				
Parijslaan				
Schubertplein				
Marconiplein	Yes			Yes
P.C. Hooftplein				
Mathenesserbrug				
Mathenesserplein			Yes	
Vierambachtstraat				
1e Middelandstraat				
Tiendplein			Yes	
Kruisplein	Yes			Yes
Marconiplein	Yes			
Zeilmakerstraat				
Van Duylstraat			Yes	
Delfshaven				
Ruilstraat				
Heemraadsplein	Yes		Yes	
Claes de Vrieselaan			Yes	

s-Gravendijkwal				
Mahtenesserlaan				
Bloemkwekersstraat				
Eendrachtsplein	Yes		Yes	Yes
Spangen				
Huygenslaan				
Spanjaardstraat			Yes	
Schiemond				
Oostkousdijk	Yes			
Pieter de Hoochweg				
Euromast	Yes			
Kievitslaan	Yes	Yes		
Vasteland				
Leuvehaven		Yes		Yes
Beurs			Yes	Yes
Lijnbaan			Yes	Yes
Willemsplein				
Westplein				
Museumpark				
Rotterdam Centraal	Yes		Yes	Yes
Weena/Hofplein			Yes	Yes
Pompenburg				Yes
Goudsesingel				
Noorderbrug			Yes	
Zaagmolenbrug				
Crooswijksestraat				
Boezemstraat				
Boezemsingel				
Vlietlaan			Yes	
Jericholaan				
Mecklenburglaan				
Voorschoterlaan			Yes	
Essenlaan				
s-Gravenwetering				
Groene wetering				
Woudestein	Yes			Yes
Heer Bokelweg	Yes			Yes
Noordsingel				
Eudokiaplein			Yes	
Van den Hoonaardstraat				

Stoendaalseweg				
Station Noord				
Kootsekade			Yes	
Lommerrijk				
Bergse Plaslaan				
CNA Looslaan				
Bergse Dorpsstraat	Yes		Yes	
Liduinaplein				
Burg. Le Fevre de Montignyplein				
Molenlaan				
Zaagmolenbrug				
Zwaanshals				
Benthuizerstraat			Yes	
Bergpolderplein			Yes	
Kleiweg	Yes	Yes		
Stadhuis			Yes	Yes
Keizerstraat				Yes
Blaak	Yes		Yes	Yes
Burgemeester van Walsumweg				
Oostplein		Yes		
Willem Ruyslaan				
Avenue Concordia				
Woudestein	Yes			
Oude Plantage				
Lage Filterweg			Yes	
Schiekade	Yes			Yes
Walenburgerweg				
Schieweg				
Sint Fransiscusziekenhuis		Yes		
Melanchthonweg	Yes			
Donkersingel				
Meidoornsingel				
Wilgenlei				
Meidoornweide				
Larikslaan				
Peppelweg	Yes		Yes	
Kastanjeplein				
Total	SCHOOL	HOSPITAL	SHOPPING	WORK
	22	7	27	17

ANNEX 5 – STOPPING DISTANCE AND AVERAGE SPEED

Table A 3 Stopping distances and average speed – line 4

Line 4 - Stop name		Distance (m)	Speed (km/h)
Marconiplein	Zeilmakerstraat	480	28,8
Zeilmakerstraat	Van Duylstraat	320	19,2
Van Duylstraat	Delfshaven	240	14,4
Delfshaven	Ruilstraat	460	13,8
Ruilstraat	Heemraadsplein	330	19,8
Heemraadsplein	Claes de Vrieselaan	290	8,7
Claes de Vrieselaan	s-Gravendijkwal	270	16,2
s-Gravendijkwal	Mahtenesserlaan	210	12,6
Mahtenesserlaan	Bloemkwekersstraat	290	17,4
Bloemkwekersstraat	Eendrachtsplein	310	9,3
Eendrachtsplein	Kruisplein	370	11,1
Kruisplein	Rotterdam Centraal	380	11,4
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Heer Bokelweg	530	10,6
Heer Bokelweg	Noordsingel	530	15,9
Noordsingel	Eudokiaplein	600	36
Eudokiaplein	Van den Hoonaardstraat	330	19,8
Van den Hoonaardstraat	Stoendaalseweg	550	16,5
Stoendaalseweg	Station Noord	420	12,6
Station Noord	Kootsekade	230	13,8
Kootsekade	Lommerrijk	360	21,6
Lommerrijk	Bergse Plaslaan	500	15
Bergse Plaslaan	CNA Looslaan	320	19,2
CNA Looslaan	Bergse Dorpsstraat	490	14,7
Bergse Dorpsstraat	Liduinaplein	300	18
Liduinaplein	Burg. Le Fevre de Montignyplein	330	19,8
Burg. Le Fevre de Montignyplein	Molenlaan	300	9
Average		380	16

Table A 4 Stopping distances and average speed – line 7

Line 7 - Stop name		Distance (m)	Speed (km/h)
Willemsplein	Westplein	270	16,2
Westplein	Museumpark	770	11,55
Museumpark	Eendrachtsplein	260	15,6
Eendrachtsplein	Kruisplein	370	11,1
Kruisplein	Rotterdam Centraal	380	11,4
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Pompenburg	240	14,4
Pompenburg	Goudsesingel	510	15,3
Goudsesingel	Noorderbrug	570	17,1
Noorderbrug	Zaagmolenbrug	380	7,6
Zaagmolenbrug	Crooswijksestraat	460	27,6
Crooswijksestraat	Boezemstraat	210	12,6
Boezemstraat	Boezemsingel	310	18,6
Boezemsingel	Vlietlaan	530	31,8
Vlietlaan	Jericholaan	360	10,8
Jericholaan	Mecklenburglaan	420	25,2
Mecklenburglaan	Voorschoterlaan	260	15,6
Voorschoterlaan	Essenlaan	480	14,4
Essenlaan	s-Gravenwetering	490	14,7
s-Gravenwetering	Groene wetering	350	21
Groene wetering	Woudestein	440	13,2
Average		409	16

Table A 5 Stopping distances and average speed – line 8

Line 8 - Stop name		Distance (m)	Speed (km/h)
Spangen	Huygensstraat	160	9,6
Huygensstraat	P.C. Hooftplein	270	16,2
Marconiplein	Zeilmakerstraat	480	28,8
Zeilmakerstraat	Van Duylstraat	320	19,2
Van Duylstraat	Delfshaven	240	14,4
Delfshaven	Spanjaardstraat	330	19,8
Spanjaardstraat	Schiemond	390	23,4
Schiemond	Oostkousdijk	500	30
Oostkousdijk	Pieter de Hoochweg	490	14,7
Pieter de Hoochweg	Euromast	630	37,8
Euromast	Kievitslaan	350	10,5
Kievitslaan	Vasteland	520	15,6
Vasteland	Leuvehaven	340	20,4
Leuvehaven	Churchillplein	460	9,2
Churchillplein	Beurs	200	(no data)
Beurs	Lijnbaan	440	26,4
Lijnbaan	Kruisplein	480	14,4
Kruisplein	Rotterdam Centraal	380	11,4
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Pompenburg	240	14,4
Pompenburg	Goudsesingel	510	15,3
Goudsesingel	Noorderbrug	570	17,1
Noorderbrug	Zaagmolenbrug	380	7,6
Zaagmolenbrug	Zwaanshals	280	16,8
Zwaanshals	Benthuizerstraat	520	15,6
Benthuizerstraat	Soetendaalseweg	470	14,1
Stoendaalseweg	Station Noord	420	12,6
Station Noord	Kootsekade	230	13,8
Kootsekade	Bergpolderplein	470	14,1
Bergpolderplein	Kleiweg	500	10
Average		403	17

Table A 6 Stopping distances and average speed – line 21

Line 21 - Stop name		Distance (m)	Speed (km/h)
Harreweg	Boeier	540	16,2
Boeier	Bachplein	645	19,35
Bachplein	Hof van Spaland	500	30
Hof van Spaland	Prinses Beatrixlaan	510	30,6
Prinses Beatrixlaan	Station Schiedam Nieuwland	790	15,8
Station Schiedam Nieuwland	Piersonstraat	730	21,9
Piersonstraat	Parkweg	340	20,4
Parkweg	s-Gravenlandseweg	530	31,8
s-Gravenlandseweg	Station Schiedam Centrum	450	13,5
Station Schiedam Centrum	Broersvest	510	30,6
Broersvest	Koemarkt	330	19,8
Koemarkt	Rotterdamsedijk	520	15,6
Rotterdamsedijk	Hogenbanweg	660	39,6
Hogenbanweg	Het Witte Dorp	340	20,4
Het Witte Dorp	Marconiplein	560	11,2
Marconiplein	P.C. Hooftplein	300	18
P.C. Hooftplein	Mathenesserbrug	500	15
Mathenesserbrug	Mathenesserplein	370	22,2
Mathenesserplein	Vierambachtstraat	490	14,7
Vierambachtstraat	1e Middelandstraat	460	13,8
1e Middelandstraat	Tiendplein	340	20,4
Tiendplein	Kruisplein	420	12,6
Kruisplein	Rotterdam Centraal	410	12,3
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Stadhuis	170	5,1
Stadhuis	Beurs	580	17,4
Beurs	Keizerstraat	300	18
Keizerstraat	Blaak	400	12
Blaak	B. Van Walsumweg	430	25,8
B. van Walsumweg	Oostplein	360	21,6
Oostplein	Willem Ruyslaan	540	32,4
Willem Ruyslaan	Avenue Concordia	390	23,4
Avenue Concordia	Woudestein	670	20,1
Woudestein	Oude Plantage	250	15
Oude Plantage	Lage Filterweg	330	19,8
Lage Filterweg	De Esch	490	14,7
Average		463	20

Table A 7 Stopping distances and average speed – line 23

Line 23 - Stop name		Distance (m)	Speed (km/h)
Holy	De Loper	340	10,2
De Loper	Over de dammen	530	10,6
Over de dammen	Parijslaan	400	12
Parijslaan	Schubertplein	670	13,4
Schubertplein	Bachplein	320	19,2
Bachplein	Hof van Spaland	500	30
Hof van Spaland	Prinses Beatrixlaan	510	30,6
Prinses Beatrixlaan	Station Schiedam Nieuwland	790	15,8
Station Schiedam Nieuwland	Piersonstraat	730	21,9
Piersonstraat	Parkweg	340	20,4
Parkweg	s-Gravenlandseweg	530	31,8
s-Gravenlandseweg	Station Schiedam Centrum	450	13,5
Station Schiedam Centrum	Broersvest	510	30,6
Broersvest	Koemarkt	330	19,8
Koemarkt	Rotterdamsedijk	520	15,6
Rotterdamsedijk	Hogenbanweg	660	39,6
Hogenbanweg	Het Witte Dorp	340	20,4
Het Witte Dorp	Marconiplein	560	11,2
Marconiplein	P.C. Hooftplein	300	18
P.C. Hooftplein	Mathenesserbrug	500	15
Mathenesserbrug	Mathenesserplein	370	22,2
Mathenesserplein	Vierambachtstraat	490	14,7
Vierambachtstraat	1e Middelandstraat	460	13,8
1e Middelandstraat	Tiendplein	340	20,4
Tiendplein	Kruisplein	420	12,6
Kruisplein	Rotterdam Centraal	410	12,3
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Stadhuis	170	5,1
Stadhuis	Beurs	580	17,4
Beurs	Leuvehaven	660	13,2
Average		436	15

Table A 8 Stopping distances and average speed – line 25

Line 25 - Stop name		Distance (m)	Speed (km/h)
Leuvehaven	Beurs	660	13,2
Beurs	Lijnbaan	440	26,4
Lijnbaan	Kruisplein	480	14,4
Kruisplein	Rotterdam Centraal	380	11,4
Rotterdam Centraal	Weena/Hofplein	530	15,9
Weena/Hofplein	Schiekade	540	16,2
Schiekade	Walenburgerweg	410	24,6
Walenburgerweg	Schieweg	560	16,8
Schieweg	Sint Fransiscusziekenhuis	980	19,6
Sint Fransiscusziekenhuis	Melanchthonweg	940	18,8
Melanchthonweg	Donkersingel	540	16,2
Donkersingel	Meidoornsingel	320	9,6
Meidoornsingel	Wilgenlei	400	24
Wilgenlei	Meidoornweide	450	13,5
Meidoornweide	Larikslaan	360	21,6
Larikslaan	Peppelweg	230	13,8
Peppelweg	Kastanjeplein	310	18,6
Kastanjeplein	Wilgenplaslaan	310	9,3
Average		491	17

ANNEX 6 – OMNITRANS SCRIPTS

The assessment-scripts in this section are made for the used omniTRANS model to derive the data about passenger usage of PT-systems for activity-end based trips (in Dutch).

1) Work

```
# OmniTRANS Job for '20140324_ot60_rvmk31'
# Created 23-06-2014 13:45:52

# ================================================================================================
  writeln "Inlezen parameter bestanden..."
# ================================================================================================
  load $Ot.dirJob+'Simjobs\parameters_rvmk3_rtd2010.rb'
  include Parameters_rtd
# ================================================================================================

aantalThreads   = 4     # voorkeur Rotterdam is 4 (ivm rekenen op rekenserver met meerdere gebruikers tegelijk)

writeln "========================================================="
varname = $Ot.currentVariant
writeln "The current variant is [",varname[1], "]"
vardir = $Ot.variantDirectory
writeln "in ", vardir
writeln "========================================================="

for t in [1,2,3]
                writeln "   * Openbaar vervoer ", t
                transit=OtTransit.new
                transit.network                                 = [Ov,t]
                transit.logitParameters                 = [0.5,0.1,0.1]
                transit.load                                    = [Werk,Ov,t,Usercat,Aon,1]
                transit.routeFactors                    = [[0,1,60,60,60,1]]
                transit.minProbability                  = [0.02,0.02]
                transit.minFind                                 = [[Lopen,1]]
                transit.searchRadius                    = [[Lopen,2.00]]
                transit.maxInterchanges                 = 5
                transit.numberOfThreads                 = aantalThreads
                transit.execute
end

writeln "Einde toedelingen"
```

Figure A 5 omniTRANS script to distribute trip purpose *work*.

2) Shop

```
# OmniTRANS Job for '20140324_ot60_rvmk31'
# Created 23-06-2014 13:45:52

# ================================================================================================
  writeln "Inlezen parameter bestanden..."
# ================================================================================================
  load $Ot.dirJob+'Simjobs\parameters_rvmk3_rtd2010.rb'
  include Parameters_rtd
# ================================================================================================

aantalThreads   = 4     # voorkeur Rotterdam is 4 (ivm rekenen op rekenserver met meerdere gebruikers tegelijk)

writeln "========================================================="
varname = $Ot.currentVariant
writeln "The current variant is [",varname[1], "]"
vardir = $Ot.variantDirectory
writeln "in ", vardir
writeln "========================================================="

for t in [1,2,3]
                writeln "   * Openbaar vervoer ", t
                transit=OtTransit.new
                transit.network                                 = [Ov,t]
                transit.logitParameters                 = [0.5,0.1,0.1]
                transit.load                                    = [Winkel,Ov,t,Usercat,Aon,1]
                transit.routeFactors                    = [[0,1,60,60,60,1]]
                transit.minProbability                  = [0.02,0.02]
                transit.minFind                                 = [[Lopen,1]]
                transit.searchRadius                    = [[Lopen,2.00]]
                transit.maxInterchanges                 = 5
                transit.numberOfThreads                 = aantalThreads
                transit.execute
end

writeln "Einde toedelingen"
```

Figure A 6 omniTRANS script to distribute trip purpose *shop*

3) School

```
# OmniTRANS Job for '20140324_ot60_rvmk31'
# Created 23-06-2014 13:45:52

# ================================================================================================
  writeln "Inlezen parameter bestanden..."
# ================================================================================================
  load $Ot.dirJob+'Simjobs\parameters_rvmk3_rtd2010.rb'
  include Parameters_rtd
# ================================================================================================

aantalThreads   = 4     # voorkeur Rotterdam is 4 (ivm rekenen op rekenserver met meerdere gebruikers tegelijk)

writeln "========================================================="
varname = $Ot.currentVariant
writeln "The current variant is [",varname[1], "]"
vardir = $Ot.variantDirectory
writeln "in ", vardir
writeln "========================================================="

for t in [1,2,3]
                writeln "   * Openbaar vervoer ", t
                transit=OtTransit.new
                transit.network                                 = [Ov,t]
                transit.logitParameters                 = [0.5,0.1,0.1]
                transit.load                                    = [onderwijs,Ov,t,Usercat,Aon,1]
                transit.routeFactors                    = [[0,1,60,60,60,1]]
                transit.minProbability                  = [0.02,0.02]
                transit.minFind                                 = [[Lopen,1]]
                transit.searchRadius                    = [[Lopen,2.00]]
                transit.maxInterchanges                 = 5
                transit.numberOfThreads                 = aantalThreads
                transit.execute
end

writeln "Einde toedelingen"
```

Figure A 7 omniTRANS script to distribute trip purpose *school*

4) Other

```
# OmniTRANS Job for '20140324_ot60_rvmk31'
# Created 23-06-2014 13:45:52

# ================================================================================================
  writeln "Inlezen parameter bestanden..."
# ================================================================================================
  load $Ot.dirJob+'Simjobs\parameters_rvmk3_rtd2010.rb'
  include Parameters_rtd
# ================================================================================================

aantalThreads   = 4     # voorkeur Rotterdam is 4 (ivm rekenen op rekenserver met meerdere gebruikers tegelijk)

writeln "========================================================="
varname = $Ot.currentVariant
writeln "The current variant is [",varname[1], "]"
vardir = $Ot.variantDirectory
writeln "in ", vardir
writeln "========================================================="

for t in [1,2,3]
                writeln "   * Openbaar vervoer ", t
                transit=OtTransit.new
                transit.network                                 = [Ov,t]
                transit.logitParameters                 = [0.5,0.1,0.1]
                transit.load                                    = [Overig,Ov,t,Usercat,Aon,1]
                transit.routeFactors                    = [[0,1,60,60,60,1]]
                transit.minProbability                  = [0.02,0.02]
                transit.minFind                                 = [[Lopen,1]]
                transit.searchRadius                    = [[Lopen,2.00]]
                transit.maxInterchanges                 = 5
                transit.numberOfThreads                 = aantalThreads
                transit.execute
end

writeln "Einde toedelingen"
```

Figure A 8 omniTRANS script to distribute trip purpose *other*

ANNEX 7 – STOP LEVEL

ALL STOPS

Table A 9 BC-ratio and passenger loss – line 4

Stop line 4	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction Molenlaan					
Marconiplein	0,0	0,00	0,00	0,00	0,00
Zeilmakerstraat	2,1	3,50	1,01	1,45	0,86
Van Duylstraat	0,8	1,71	0,36	0,51	0,34
Delfshaven	0,5	0,81	0,31	0,37	0,21
Ruilstraat	0,5	0,66	0,34	0,26	0,21
Heemraadsplein	0,9	1,53	0,73	0,23	0,55
Claes de Vrieselaan	0,9	1,77	0,73	0,17	0,71
s-Gravendijkwal	1,7	1,47	1,88	1,01	1,25
Mathenesserlaan	2,2	2,03	2,24	1,34	1,70
Bloemkwekersstraat	5,8	6,42	3,20	4,07	3,43
Eendrachtsplein	2,4	2,97	0,72	1,21	1,95
Kruisplein	5,2	5,90	1,31	3,69	3,53
Rotterdam Centraal	0,2	0,18	0,16	0,09	0,08
Weena/Hofplein	1,5	1,59	0,59	0,88	1,01
Heer Bokelweg	1,6	2,19	1,08	0,36	1,04
Noordsingel	2,3	3,28	1,03	0,77	1,14
Eudokiaplein	1,6	2,01	0,69	0,59	0,77
V.D. Hoonaardstr.	2,4	3,15	1,00	0,93	1,16
Soetendaalseweg	3,2	4,11	1,40	1,17	1,44
Station Noord	2,6	2,21	2,26	1,06	1,22
Kootsekade	5,0	6,05	3,77	2,67	3,06
Lommerrijk	26,0	30,71	17,89	12,58	15,84
Bergse Plaslaan	15,6	11,68	23,07	14,57	11,96
CNA Looslaan	2,2	2,61	1,59	0,87	1,48
Bergse Dorpsstraat	0,8	0,96	0,33	0,42	0,55
Liduinaplein	1,3	1,77	1,02	0,37	0,83
Burg. Le Fevre de Montignyplein	1,4	2,40	0,94	0,51	0,73
Molenlaan	0,0	0,00	0,00	0,00	0,00
Direction Marconiplein					
Molenlaan	0,0	0,00	0,00	0,00	0,00
Burg. Le Fevre de Montignyplein	1,3	2,17	0,67	0,52	0,65
Liduinaplein	1,0	1,54	0,69	0,24	0,62
Bergse Dorpsstraat	1,1	1,43	0,49	0,46	0,77
CNA Looslaan	0,3	4,28	1,64	1,13	1,96
Bergse Plaslaan	7,3	7,54	5,74	4,26	4,99
Lommerrijk	17,1	17,41	17,12	9,53	11,21
Kootsekade	7,5	8,63	4,67	3,75	5,24
Station Noord	2,7	3,37	2,84	1,40	1,47
Soetendaalseweg	2,1	3,74	0,85	1,17	1,14
V.D. Hoonaardstr.	2,5	3,83	1,22	1,11	1,43
Eudokiaplein	1,5	2,38	0,83	0,69	0,87
Noordsingel	1,6	2,44	0,96	0,61	0,85
Heer Bokelweg	1,2	2,10	1,46	0,17	1,16
Weena/Hofplein	0,9	1,03	0,48	0,72	0,54
Rotterdam Centraal	0,3	0,47	0,36	0,20	0,14
Kruisplein	4,9	6,78	0,79	5,37	4,77
Eendrachtsplein	1,6	1,98	0,61	0,63	1,58
Bloemkwekersstraat	6,6	8,94	2,62	4,93	3,94
Mathenesserlaan	1,6	1,14	1,90	1,44	1,44

s-Gravendijkwal	2,1	3,13	2,55	2,06	1,81
Claes de Vrieselaan	0,6	2,22	0,91	0,21	0,98
Heemraadsplein	0,4	1,39	0,94	0,24	0,62
Ruilstraat	0,3	1,17	0,49	0,35	0,40
Delfshaven	0,2	0,77	0,44	0,27	0,26
Van Duylstraat	0,1	0,77	0,09	0,12	0,12
Zeilmakerstraat	0,3	2,23	0,31	0,83	0,32
Marconiplein	0,0	0,00	0,00	0,00	0,00

Table A 10 BC-ratio and passenger loss – line 7

Stops line 7	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction Woudestein					
Willemsplein	0,0	0,00	0,00	0,00	0,00
Westerstraat	1,3	1,76	1,07	0,80	0,85
Westplein	0,2	0,33	0,17	0,08	0,16
Museumpark	0,9	2,16	0,55	0,03	0,97
Eendrachtsplein	2,0	3,58	0,77	0,48	1,71
Kruisplein	2,7	4,67	0,45	1,50	1,77
Rotterdam Centraal	0,1	0,07	0,05	0,03	0,03
Weena	1,1	1,31	0,67	0,71	0,75
Pompenburg	0,6	0,84	0,22	0,29	0,49
Meent	0,0	0,00	0,00	0,00	0,00
MISSING DATA					
Vlietlaan	0,0	0,00	0,00	0,00	0,00
Jericholaan	0,9	1,10	0,34	0,73	0,36
Mecklenburglaan	2,2	3,62	0,56	1,43	0,97
Voorschoterlaan	0,8	0,72	0,15	0,86	0,15
Essenlaan	4,2	5,01	0,76	3,37	0,81
s-Gravenwetering	2,3	1,24	0,10	4,10	0,13
Groene Wetering	0,2	0,18	1,08	0,09	0,21
Erasmus Universiteit	0,0	0,00	0,00	0,00	0,00
Direction Willemsplein					
Erasmus Universiteit	0,0	0,00	0,00	0,00	0,00
Groene Wetering	1,0	0,98	0,67	0,51	0,50
s-Gravenwetering	2,4	1,44	0,25	2,08	0,35
Essenlaan	5,7	3,61	0,81	7,32	0,74
Voorschoterlaan	0,5	0,68	0,18	0,25	0,26
Mecklenburglaan	1,7	2,16	0,28	1,51	0,55
Jericholaan	0,7	0,67	0,23	0,63	0,23
Vlietlaan	0,0	0,00	0,00	0,00	0,00
MISSING DATA					
Meent	0,0	0,00	0,00	0,00	0,00
Pompenburg	0,4	0,71	0,28	0,13	0,33
Weena	1,5	1,48	0,94	1,17	0,20
Rotterdam Centraal	0,1	0,12	0,08	0,04	0,08
Kruisplein	1,1	1,93	0,21	0,74	0,34
Eendrachtsplein	0,3	0,77	0,09	0,04	0,19
Museumpark	0,5	1,00	0,14	0,07	0,00
Westplein	0,0	0,00	0,00	0,00	0,00
Westerstraat	0,0	0,00	0,00	0,00	0,00
Willemsplein	0,0	0,00	0,00	0,00	0,00

Table A 11 BC-ratio and passenger loss – line 8

Stops line 8	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction Kleiweg					
Spartastraat	0,0	0,00	0,00	0,00	0,00
Huygensstraat	0,3	0,41	0,18	0,14	0,14
P.C. Hooftplein	1,5	1,86	1,31	0,75	0,84
Marconiplein	0,5	0,50	0,42	0,22	0,32
Zeilmakersstraat	3,0	5,51	1,07	2,36	1,21
Van Duylstraat	1,3	2,39	0,52	0,84	0,60
Delfshaven	1,2	2,16	0,47	0,85	0,44
Spanjaardstraat	1,1	1,60	0,68	0,75	0,45
Schiemond	0,5	0,78	0,26	0,44	0,18
Oostkousdijk	0,8	0,95	0,50	0,67	0,33
Pieter de Hoochweg	0,2	0,30	0,19	0,02	0,16
Euromast / Erasmus MC	1,3	2,35	1,79	0,37	1,20
Kievitslaan	3,3	3,48	6,03	1,53	2,99
Vasteland	2,2	2,21	1,29	1,84	1,39
Leuvehaven	0,7	0,93	0,78	0,33	0,38
Churchillplein	2,3	2,87	2,04	1,06	1,62
Beurs	2,7	3,46	0,54	2,72	1,96
Lijnbaan	0,9	1,05	0,09	2,49	0,82
Kruisplein	2,4	3,10	1,20	1,59	1,58
Rotterdam Centraal	0,1	0,07	0,07	0,03	0,03
Weena	1,5	1,82	0,82	0,76	1,02
Pompenburg	1,7	2,14	0,77	0,65	1,70
Meent	0,4	0,65	0,16	0,19	0,25
Noorderbrug	1,2	1,98	0,57	0,57	0,64
Zaagmolenbrug	2,8	4,02	2,92	1,10	1,47
Zwaanshals	1,1	1,87	0,80	0,40	0,52
Benthuizerstraat	0,7	1,32	0,30	0,33	0,38
Soetendaalseweg	1,3	2,35	0,52	0,53	0,68
Station Noord	0,5	0,78	0,43	0,23	0,25
Kootsekade	5,2	8,92	1,67	2,27	3,08
Bergpolderplein	0,4	1,00	0,14	0,05	0,15
Kleiweg RET	0,0	0,00	0,00	0,00	0,00
Kleiweg RET	0,0	0,00	0,00	0,00	0,00
Direction Spangen					
Kleiweg RET	0,0	0,00	0,00	0,00	0,00
Bergpolderplein	0,9	1,81	0,30	0,09	0,43
Kootsekade	3,2	5,37	1,20	1,35	1,87
Station Noord	0,7	0,91	0,78	0,25	0,37
Soetendaalseweg	1,1	1,89	0,45	0,37	0,57
Benthuizerstraat	0,8	1,53	0,31	0,32	0,47
Zwaanshals	1,4	2,20	0,76	0,57	0,70
Zaagmolenbrug	1,7	2,82	1,30	0,77	0,78
Noorderbrug	1,1	1,91	0,75	0,38	0,59
Meent	0,5	0,80	0,21	0,23	0,33
Pompenburg	0,8	1,21	0,53	0,26	0,57
Weena	3,6	4,12	2,28	1,62	3,01
Rotterdam Centraal	0,2	0,30	0,26	0,11	0,09
Kruisplein	0,8	1,28	0,51	0,38	0,39
Lijnbaan	1,0	1,68	0,11	2,02	0,82
Beurs	1,8	2,98	0,49	1,32	1,14
Churchillplein	1,2	1,94	0,36	0,77	0,70
Leuvehaven	0,2	0,37	0,41	0,07	0,18
Vasteland	1,4	1,36	0,59	1,54	0,66
Kievitslaan	3,1	3,59	2,05	2,09	1,64

Euromast / Erasmus MC	1,0	1,95	1,65	0,27	0,87
Pieter de Hoochweg	0,2	0,31	0,25	0,04	0,20
Oostkousdijk	0,6	0,72	0,27	0,47	0,23
Schiemond	0,9	1,36	0,53	0,78	0,31
Spanjaardstraat	1,6	2,43	0,91	1,15	0,62
Delfshaven	0,6	0,81	0,47	0,29	0,30
Van Duylstraat	0,8	1,59	0,29	0,43	0,38
Zeilmakersstraat	2,8	5,51	0,88	2,46	1,11
Marconiplein	0,2	0,18	0,14	0,12	0,14
P.C. Hooftplein	2,7	3,10	1,64	1,80	1,50
Huygensstraat	0,0	0,05	0,00	0,00	0,00
Spartastraat	0,0	0,00	0,00	0,00	0,00

Table A 12 BC-ratio and passenger loss – line 21

Stops line 21	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction De Esch					
Harreweg	0,0	0,00	0,00	0,00	0,00
Boeier	0,2	0,20	0,11	0,14	0,09
Bachplein	0,9	1,18	0,64	0,66	0,43
Hof van Spaland	0,9	1,33	0,42	0,65	0,48
Prinses Beatrixlaan	0,9	1,32	0,66	0,20	0,57
Station Nieuwland	0,2	0,29	0,29	0,12	0,13
Piersonstraat	2,1	4,07	1,99	0,29	1,80
Parkweg	1,4	2,06	1,27	0,70	0,70
s-Gravelandseweg	2,0	1,87	0,98	2,52	1,53
Station Schiedam C.	0,2	0,17	0,33	0,06	0,09
Broersvest	1,5	2,10	0,81	1,06	0,94
Koemarkt	0,2	0,31	0,12	0,17	0,14
Rotterdamsedijk	0,7	0,72	0,51	0,57	0,45
Hogenbanweg	9,6	9,34	7,19	9,17	6,92
Het Witte Dorp	3,7	3,40	6,86	0,70	5,99
Marconiplein	0,7	0,86	0,63	0,34	0,47
P.C. Hooftplein	1,0	1,54	0,76	0,47	0,58
Mathenesserbrug	0,8	1,32	0,47	0,44	0,42
Mathenesserplein	1,1	1,72	0,61	0,83	0,54
Vierambachtsstraat	0,6	0,98	0,51	0,15	0,38
1e Middellandstraat	1,4	2,24	0,97	0,42	0,95
Tiendplein	2,8	4,00	1,65	1,34	1,76
Kruisplein	3,0	3,74	1,02	2,06	2,26
Rotterdam Centraal	0,1	0,11	0,20	0,05	0,04
Weena	1,0	1,78	1,00	0,37	0,43
Stadhuis	1,6	1,79	0,31	1,72	1,55
Beurs	1,3	1,42	0,40	1,15	1,03
Keizerstraat	1,1	1,36	1,09	0,34	1,06
Blaak	0,2	0,31	0,34	0,09	0,13
Burg. Van Walsumweg	3,5	5,23	1,62	2,76	1,90
Oostplein	1,3	1,64	1,04	0,66	0,73
Willem Ruyslaan	0,8	1,29	0,54	0,16	0,48
Avenue Concordia	2,5	4,48	1,48	0,65	1,46
Woudestein	1,8	1,88	1,85	1,34	1,15
Oude Plantage	3,1	5,22	2,63	0,78	1,68
Lage Filterweg	0,2	0,39	0,16	0,05	0,08
Nesserdijk	0,0	0,00	0,00	0,00	0,00
Opstelspoor De Esch	0,0	0,00	0,00	0,00	0,00
Direction Woudhoek					
Opstelspoor De Esch	0,0	0,00	0,00	0,00	0,00
Nesserdijk	0,2	0,36	0,17	0,05	0,16

Lage Filterweg	0,8	1,30	0,79	0,23	0,39
Oude Plantage	3,0	4,28	3,23	1,12	1,58
Woudestein	3,4	2,76	7,76	2,45	3,09
Avenue Concordia	1,5	2,51	1,16	0,23	0,88
Willem Ruyslaan	1,0	1,57	0,74	0,25	0,59
Oostplein	1,6	2,34	1,04	0,82	0,92
Burg. Van Walsumweg	3,4	4,63	1,72	1,91	2,14
Blaak	0,3	0,37	0,49	0,14	0,15
Keizerstraat	0,7	0,90	0,90	0,15	0,65
Beurs	1,6	1,64	0,36	2,13	1,61
Stadhuis	0,4	0,60	0,26	0,26	0,23
Weena	1,7	2,16	1,34	1,25	0,88
Rotterdam Centraal	0,3	0,29	0,46	0,15	0,20
Kruisplein	0,6	0,84	0,30	0,31	0,42
Tiendplein	3,5	5,57	1,79	1,72	2,08
1e Middellandstraat	1,1	1,73	0,80	0,23	0,87
Vierambachtsstraat	0,4	0,70	0,33	0,17	0,24
Mathenesserplein	0,5	0,71	0,26	0,29	0,23
Mathenesserbrug	0,8	1,46	0,48	0,43	0,37
P.C. Hooftplein	3,0	4,68	1,75	2,00	1,42
Marconiplein	0,6	0,66	0,69	0,23	0,42
Het Witte Dorp	5,2	5,38	5,93	1,15	6,97
Hogenbanweg	15,7	13,49	9,78	8,25	23,57
Rotterdamsedijk	0,6	0,57	0,50	0,45	0,35
Koemarkt	0,3	0,37	0,11	0,22	0,17
Broersvest	1,4	2,07	0,75	1,08	0,85
Station Schiedam C.	0,1	0,07	0,12	0,03	0,03
s-Gravelandseweg	3,4	3,11	1,20	5,70	2,68
Parkweg	2,2	2,97	1,46	1,35	1,11
Piersonstraat	2,4	4,41	1,77	0,44	2,02
Station Nieuwland	0,6	0,71	0,63	0,26	0,45
Prinses Beatrixlaan	1,0	1,51	0,94	0,32	0,63
Hof van Spaland	0,6	0,91	0,29	0,39	0,35
Bachplein	0,4	0,44	0,35	0,25	0,22
Boeier	0,2	0,20	0,09	0,13	0,09
Harreweg	0,0	0,00	0,00	0,00	0,00

Table A 13 BC-ratio and passenger loss – line 23

Stops lijn 23	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction Beverwaard					
Holysingel	0,0	0,00	0,00	0,00	0,00
De Loper	0,4	0,51	0,16	0,20	0,22
Over de Dammen	0,9	1,26	0,98	0,37	0,49
Parijslaan	0,4	0,53	0,45	0,23	0,26
Schubertplein	1,5	2,25	1,10	0,69	0,78
Bachplein	2,6	4,00	1,70	1,37	1,30
Hof van Spaland	1,5	2,46	0,54	0,79	0,79
Prinses Beatrixlaan	1,5	2,32	0,98	0,33	0,94
Station Nieuwland	0,3	0,33	0,32	0,15	0,14
Piersonstraat	3,1	6,46	2,58	0,42	2,41
Parkweg	2,4	3,77	1,89	0,94	1,21
s-Gravelandseweg	2,1	2,01	1,07	2,71	1,78
Station Schiedam C.	0,2	0,16	0,33	0,07	0,08
Broersvest	1,8	2,49	0,93	1,26	1,07
Koemarkt	0,3	0,42	0,13	0,21	0,18
Rotterdamsedijk	0,8	0,81	0,54	0,64	0,50

Hogenbanweg	10,6	10,38	7,54	10,13	7,71
Het Witte Dorp	3,5	3,17	6,55	0,70	6,22
Marconiplein	0,8	0,90	0,64	0,35	0,50
P.C. Hooftplein	1,1	1,56	0,79	0,48	0,59
Mathenesserbrug	0,8	1,36	0,48	0,45	0,44
Mathenesserplein	1,1	1,73	0,62	0,83	0,54
Vierambachtsstraat	0,6	0,98	0,52	0,15	0,38
1e Middellandstraat	1,4	2,24	0,97	0,43	0,95
Tiendplein	2,9	4,03	1,66	1,35	1,76
Kruisplein	3,4	4,09	1,13	2,26	2,69
Rotterdam Centraal	0,1	0,10	0,18	0,05	0,04
Weena	2,0	3,31	1,25	1,01	0,94
Stadhuis	4,4	5,11	0,73	4,69	4,24
Beurs	3,5	5,22	1,01	1,46	2,95
Churchillplein	4,3	5,57	1,35	2,87	3,18
Leuvehaven	1,2	1,37	1,01	0,62	0,98
Wilhelminaplein	0,0	0,00	0,00	0,00	0,00
Direction Holy					
Wilhelminaplein	0,0	0,00	0,00	0,00	0,00
Leuvehaven	1,2	1,23	1,91	0,70	0,86
Churchillplein	1,2	1,49	0,89	0,45	0,96
Beurs	3,0	3,93	0,39	3,85	3,46
Stadhuis	0,5	0,76	0,30	0,27	0,33
Weena	2,6	2,98	1,56	1,77	1,64
Rotterdam Centraal	0,3	0,26	0,39	0,15	0,15
Kruisplein	0,7	0,93	0,31	0,33	0,46
Tiendplein	3,7	5,95	1,84	1,81	2,21
1e Middellandstraat	1,0	1,65	0,76	0,21	0,82
Vierambachtsstraat	0,6	0,94	0,44	0,21	0,32
Mathenesserplein	0,4	0,64	0,23	0,26	0,20
Mathenesserbrug	0,9	1,56	0,51	0,46	0,41
P.C. Hooftplein	3,1	4,85	1,81	2,07	1,48
Marconiplein	0,7	0,74	0,74	0,25	0,47
Het Witte Dorp	5,2	5,43	5,91	1,17	7,14
Hogenbanweg	17,4	14,95	10,53	8,81	27,20
Schiedam	0,6	0,61	0,52	0,48	0,38
Koemarkt	0,3	0,38	0,11	0,23	0,18
Broersvest	1,0	1,42	0,50	0,75	0,60
Station Schiedam C.	0,1	0,07	0,11	0,03	0,03
s-Gravelandseweg	3,9	3,65	1,33	6,39	3,12
Parkweg	3,0	4,18	1,81	1,63	1,58
Piersonstraat	3,1	6,00	2,08	0,54	2,62
Station Nieuwland	0,7	0,79	0,69	0,27	0,50
Prinses Beatrixlaan	1,6	2,48	1,29	0,47	1,04
Hof van Spaland	1,0	1,56	0,41	0,55	0,55
Bachplein	1,1	1,74	0,60	0,51	0,60
Schubertplein	2,2	2,89	1,35	1,50	1,19
Parijslaan	0,4	0,51	0,37	0,18	0,22
Over de Dammen	1,1	1,72	1,48	0,34	0,60
De Loper	0,5	0,52	0,15	0,35	0,33
Holysingel	0,0	0,00	0,00	0,13	0,35

Table A 14 BC-ratio and passenger loss – line 25

Stops line 25	BC TOTAL	BC WORK	BC SHOP	BC SHOOL	BC OTHER
Direction Carnisselande					
Wilgenplaslaan	0,0	0,00	0,00	0,00	0,00
Meidoornsingel	0,6	1,09	0,45	0,19	0,35
Donkersingel	0,8	1,33	0,78	0,15	0,54
Melanchthonweg	1,5	1,02	1,84	2,06	1,16
Schieweg	0,4	0,56	0,28	0,25	0,24
Walenburgerweg	1,8	2,64	1,18	0,72	1,09
Schiekade	2,1	4,73	2,30	0,28	2,17
Weena	0,9	1,06	0,37	0,81	0,54
Rotterdam Centraal	0,3	0,34	0,43	0,16	0,13
Kruisplein	2,2	3,14	1,01	0,83	1,48
Lijnbaan	2,9	4,28	0,33	4,03	3,87
Beurs	2,3	3,33	0,95	1,03	1,66
Churchillplein	1,7	2,36	1,08	0,74	1,04
Leuvehaven	1,4	1,46	1,33	0,52	1,16
Wilhelminaplein	0,0	0,00	0,00	0,00	0,00
Direction Schiebroek					
Wilhelminaplein	0,0	0,00	0,00	0,00	0,00
Leuvehaven	2,3	2,38	2,73	0,96	1,86
Churchillplein	1,3	1,74	1,90	0,38	0,84
Beurs	2,0	2,61	0,58	1,13	1,80
Lijnbaan	1,4	1,78	0,15	1,86	2,04
Kruisplein	2,3	3,26	1,19	0,80	1,80
Rottedam Centraal	0,1	0,07	0,10	0,03	0,04
Weena	0,6	0,71	0,27	0,36	0,48
Schiekade	3,4	6,85	1,95	0,72	2,91
Walenburgerweg	1,3	2,14	0,70	0,58	0,78
Schieweg	0,6	0,65	0,42	0,45	0,38
Sint Franciscus G.	24,4	30,59	32,70	9,17	16,16
Melanchthonweg	1,8	1,09	2,56	6,38	1,42
Donkersingel	0,6	1,12	0,60	0,12	0,49
Meidoornsingel	2,8	5,03	1,93	1,12	1,38
Wilgenlei	1,0	1,76	0,66	0,40	0,54
Meidoornweide	0,3	0,52	0,25	0,09	0,20
Larikslaan	0,4	0,32	0,48	0,40	0,29
Peppelweg	0,2	0,35	0,06	0,12	0,07
Kastanjeplein	1,4	3,02	0,41	0,76	0,72
Wilgenplaslaan	0,0	0,00	0,00	0,00	0,00

STOPS WITH BC>1

Table A 15 Stops with BC>1 lines 4, 7 and 8

Line	Stop
	Direction Hillegersberg
4	Zeilmakerstraat
	s-Gravendijkwal
	Mathenesserlaan
	Bloemkwekersstraat
	Eendrachtsplein
	Kruisplein
	Weena/Hofplein
	Heer Bokelweg
	Noordsingel
	Eudokiaplein
	Van den Hoonaardstraat
	Soetendaalseweg
	Station Noord
	Kootsekade
	Lommerrijk
	Bergse Plaslaan
	CNA Looslaan
	Liduinaplein
	Burg. Le Fevre de Montignyplein
	Direction Marconiplein
	Burg. Le Fevre de Montignyplein
	Bergse Dorpsstraat
	Bergse Plaslaan
	Lommerrijk
	Kootsekade
	Station Noord
	Soetendaalseweg
	Van den Hoonaardstraat
	Eudokiaplein
	Noordsingel
	Heer Bokelweg
	Kruisplein
	Eendrachtsplein
	Bloemkwekersstraat
	Mahtenesserlaan
	s-Gravendijkwal

Line	Stop
	Direction Woudestein
7	Westerstraat
	Eendrachtsplein
	Kruisplein
	Weena
	Mecklenburglaan
	Essenlaan
	s-Gravenwetering
	Direction Willemsplein
	s-Gravenwetering
	Essenlaan
	Mecklenburglaan
	Weena
	Kruisplein

Line	Stop
	Direction Kleiweg
8	P.C. Hooftplein
	Zeilmakersstraat
	Van Duylstraat
	Delfshaven
	Spanjaardstraat
	Euromast / Erasmus MC
	Kievitslaan
	Vasteland
	Churchillplein
	Beurs
	Kruisplein
	Weena
	Pompenburg
	Noorderbrug
	Zaagmolenbrug
	Zwaanshals
	Soetendaalseweg
	Kootsekade
	Direction Spangen
	Kootsekade
	Soetendaalseweg
	Zwaanshals
	Zaagmolenbrug
	Noorderbrug
	Weena
	Beurs
	Churchillplein
	Vasteland
	Kievitslaan
	Euromast / Erasmus MC
	Spanjaardstraat
	Zeilmakersstraat
	P.C. Hooftplein

Table A 16 Stops with BC>1 lines 21, 23 and 25

Line	Stop
	Direction De Esch
21	Piersonstraat
	Parkweg
	s-Gravelandseweg
	Broersvest
	Hogenbanweg
	Het Witte Dorp
	Mathenesserplein
	1e Middellandstraat
	Tiendplein
	Kruisplein
	Stadhuis
	Beurs
	Keizerstraat
	Burg. Van Walsumweg
	Oostplein
	Avenue Concordia
	Woudestein
	Oude Plantage
	Direction Woudhoek
	Oude Plantage
	Woudestein
	Avenue Concordia
	Willem Ruyslaan
	Oostplein
	Burg. Van Walsumweg
	Beurs
	Weena
	Tiendplein
	1e Middellandstraat
	P.C. Hooftplein
	Het Witte Dorp
	P.C. Hooftplein
	Hogenbanweg
	Broersvest
	s-Gravelandseweg
	Parkweg
	Piersonstraat
	Prinses Beatrixlaan

Line	Stop
	Direction Holy
23	Leuvehaven
	Churchillplein
	Beurs
	Weena
	Tiendplein
	1e Middellandstraat
	P.C. Hooftplein
	Het Witte Dorp
	Hogenbanweg
	s-Gravelandseweg
	Parkweg
	Piersonstraat
	Prinses Beatrixlaan
	Bachplein
	Schubertplein
	Over de Dammen
	Direction Beverwaard
	Schubertplein
	Bachplein
	Hof van Spaland
	Prinses Beatrixlaan
	Piersonstraat
	Parkweg
	s-Gravelandseweg
	Broersvest
	Hogenbanweg
	Het Witte Dorp
	P.C. Hooftplein
	Mathenesserplein
	1e Middellandstraat
	Tiendplein
	Kruisplein
	Weena
	Stadhuis
	Beurs
	Churchillplein
	Leuvehaven

Line	Stop
	Direction Schiebroek
25	Melanchthonweg
	Walenburgerweg
	Schiekade
	Kruisplein
	Lijnbaan
	Beurs
	Churchillplein
	Leuvehaven
	Direction Carnisselande
	Leuvehaven
	Churchillplein
	Beurs
	Lijnbaan
	Kruisplein
	Schiekade
	Walenburgerweg
	Sint Franciscus Gasthuis
	Melanchthonweg
	Meidoornsingel
	Wilgenlei
	Kastanjeplein

STOPS WITH BC>1 AND BC_N < 1

Table A 17 BC>1 and BC_n <1 lines 4, 7 and 8

Line	Stop
	Direction Hillegersberg
4	Zeilmakerstraat
	Eendrachtsplein
	Weena/Hofplein
	Heer Bokelweg
	Noordsingel
	Van den Hoonaardstraat
	Soetendaalseweg
	Station Noord
	CNA Looslaan
	Liduinaplein
	Burg. Le Fevre de Montignyplein
	Direction Marconiplein
	Burg. Le Fevre de Montignyplein
	Bergse Dorpsstraat
	Eudokiaplein
	Noordsingel
	Heer Bokelweg
	Kruisplein
	Eendrachtsplein
	Mahtenesserlaan

Line	Stop
	Direction Woudestein
7	Westerstraat
	Eendrachtsplein
	Kruisplein
	Weena
	Mecklenburglaan
	Essenlaan
	s-Gravenwetering
	Direction Willemsplein
	s-Gravenwetering
	Essenlaan
	Mecklenburglaan
	Weena
	Kruisplein

Line	Stop
	Direction Kleiweg
8	P.C. Hooftplein
	Van Duylstraat
	Delfshaven
	Spanjaardstraat
	Euromast / Erasmus MC
	Beurs
	Pompenburg
	Noorderbrug
	Zwaanshals
	Soetendaalseweg
	Direction Spangen
	Soetendaalseweg
	Zwaanshals
	Zaagmolenbrug
	Noorderbrug
	Beurs
	Churchillplein
	Vasteland
	Euromast / Erasmus MC
	Spanjaardstraat
	Zeilmakersstraat

Table A 18 BC>1 and BC_n <1 lines 21, 23 and 25

Line	Stop	Line	Stop	Line	Stop
	Direction De Esch		Direction Holy		Direction Schiebroek
21	Piersonstraat	23	Leuvehaven	25	Walenburgerweg
	Parkweg		Churchillplein		Schiekade
	s-Gravelandseweg		Prinses Beatrixlaan		Kruisplein
	Broersvest		Bachplein		Lijnbaan
	Het Witte Dorp		Over de Dammen		Beurs
	Mathenesserplein		Direction Beverwaard		Churchillplein
	1e Middellandstraat		Schubertplein		Leuvehaven
	Stadhuis		Hof van Spaland		Direction Carnisselande
	Beurs		Prinses Beatrixlaan		Leuvehaven
	Keizerstraat		Piersonstraat		Churchillplein
	Oostplein		Parkweg		Beurs
	Avenue Concordia		Broersvest		Lijnbaan
	Oude Plantage		Het Witte Dorp		Kruisplein
	Direction Woudhoek		P.C. Hooftplein		Schiekade
	Avenue Concordia		Mathenesserplein		Walenburgerweg
	Willem Ruyslaan		1e Middellandstraat		Melanchthonweg
	Oostplein		Weena		Wilgenlei
	Beurs		Stadhuis		Kastanjeplein
	Weena		Leuvehaven		
	1e Middellandstraat				
	Broersvest				
	Piersonstraat				

STOPS BIDIRECTIONAL

Table A 19 Stops with BC>1 in two directions

Line	Stop	Line	Stop	Line	Stop
4	Mathenesserlaan	7	Westerstraat	8	P.C. Hooftplein
	's-Gravendijkwal		Essenlaan		Zeilmakersstraat
	Bloemkwekersstraat		Groene Wetering		Delfshaven
	Kruisplein		Eendrachtsplein		Euromast
	Noordsingel				Kievitslaan
	Van den Hoonaardstraat				Vasteland
	Soetendaalseweg				Weena
	Station Noord				Pompenburg
	Kootsekade				Noorderbrug
	Lommerrijk				Zaagmolenbrug
	Bergse Plaslaan				Zwaanshals
	CNA Looslaan				Soetendaalseweg
	Burg. Le F. de Montplein				Kootsekade

Line	Stop	Line	Stop	Line	Stop
21	Piersonstraat	23	Schubertplein	25	Melanchtonweg
	Parkweg		Bachplein		Schiekade
	's-Gravelandseweg		Hof van Spaland		Walenburgerweg
	Hogenbanweg		Prinses Beatrixlaan		Kruisplein
	Het Witte Dorp		Piersonstraat		Lijnbaan
	Tiendplein		Parkweg		Churchillplein
	1e Middellandstraat		s-Gravelandseweg		Beurs
	Kruisplein		Hogenbanweg		Leuvehaven
	Stadfhuis		Het Witte Dorp		
	Beurrs		1e Middellandstraat		
	Burg. Van Walsumweg		Tiendplein		
	Oostplein		Kruisplein		
	Avenue Concordia		Weena		
	Woudestein		Stadhuis		
	Oude Plantage		Beurs		
			Churchillplein		

Remarks on stop closure: some stops are proposed to close for a certain line, while the stop is still useful for another line. The results above are solely the unedited results from the BC-ratio-analysis.

ANNEX 8 – LINE LEVEL

Table A 20 Applied greedy algorithm on line level

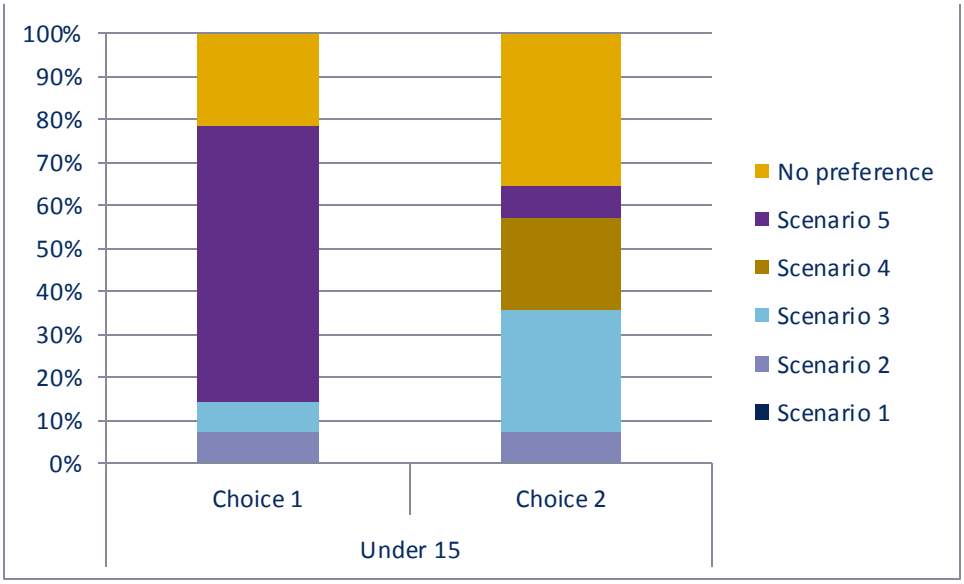
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4	s-Gravendijkwal Bloemkwekerstraat Eendrachtsplein Kruisplein	Mathenesserlaan	s-Gravendijkwal Bloemkwekerstraat	Kruisplein Eendrachtsplein	Kruisplein s-Gravendijkwal Bloemkwekerstraat	Eendrachtsplein
	Lommerijk Bergse Plaslaan CNA Looslaan Kootsekade	Liduniaplein	Lommerijk CNA Looslaan	Kootsekade CNA Looslaan Bergse Plaslaan Liduniaplein	Lommerijk CNA Looslaan	Kootsekade CNA Looslaan Bergse Plaslaan Liduniaplein
7	Eendrachtsplein Kruisplein		Kruisplein	Eendrachtsplein	Kruisplein Eendrachtsplein	
	Essenlaan Groene Wetering			Essenlaan Groene Wetering		Essenlaan Groene Wetering
8	Zeilmakersstraat	van Duylstraat		Zeilmakerstraat Van Duylstraat	Zeilmakerstraat	Van Duylstraat
	Delfshaven	Spanjaardstraat		Delfshaven Spanjaardstraat	Delfshaven	Spanjaardstraat
	Kievitslaan Vasteland	Euromast		Kievitslaan Vasteland Euromast		Kievitslaan Vasteland Euromast
	Pompenburg	Weena		Pompenburg Weena	Pompenburg	Weena
	Zaagmolenburg	Zwaanshals Noorderburg		Zaagmolenburg Zwaanshals Noorderburg	Zaagmolenburg	Zwaanshals Noorderburg
21	Piersonstraat	Parkweg		Piersonstraat Parkweg		Piersonstraat Parkweg
	Hogenbanweg Witte Dorp			Hogenbanweg Witte Dorp		Hogenbanweg Witte Dorp
	Tiendplein Kruisplein	1e Middellandstraat		Tiendplein Kruisplein 1e Middellandstraat	Tiendplein	Kruisplein 1e Middellandstraat
	Stadhuis	Beurs		Stadhuis Beurs	Stadhuis	Beurs
	Burg. Van Walsumweg	Oostplein		Burg van Walsumweg Oostplein	Burg. Van Walsumweg	Oostplein
	Oude Plantage Avenue Concordia	Woudestein	Oude Plantage	Woudestein Avenue Concordia	Oude Plantage	Woudestein Avenue Concordia

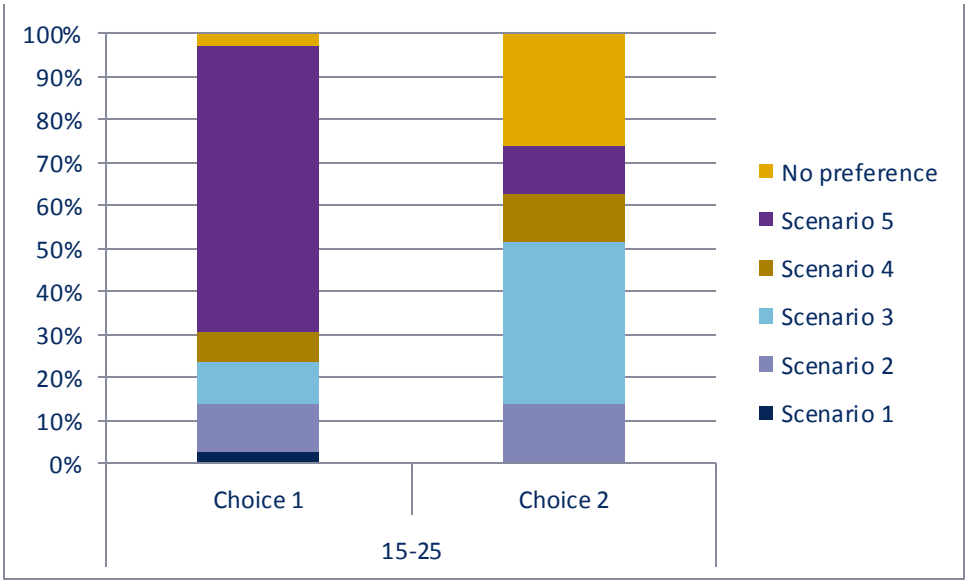
Line	Only greedy		Max Stopping distance			
			600 meter		800 meter	
	remove	Save	Remove	Save	Remove	Save
23	Bachplein Prinses Beatrixlaan Piersonstraat Witte Dorp Hogenbanweg Tiendplein Kruisplein Stadhuis Churchillplein	Schubertplein Hof van Spaland Parkweg 1e Middellandstaat Beurs		bachplein Schubertplein Prinses Beatrixlaan Hof van Spaland Piersonstraat Parkweg Witte Dorp Hogenbanweg Tiendplein Kruisplein 1e Middellandstraat Stadhuis Beurs Churchillplein	 Tiendplein Stadhuis Churchillplein	Bachplein Schubertplein Prinses Beatrixlaan Hof van Spaland Piersonstraat Parkweg Witte Dorp Hogenbanweg Kruisplein 1e Middellandstraat Beurs
25	Schiekade Kruisplein Lijnbaan Churchillplein	Walenburgerweb Beurs		Schiekade Walenburgerweg Kruisplein Lijnbaan Churchillplein Beurs		Schiekade Walenburgerweg Kruisplein Lijnbaan Churchillplein Beurs

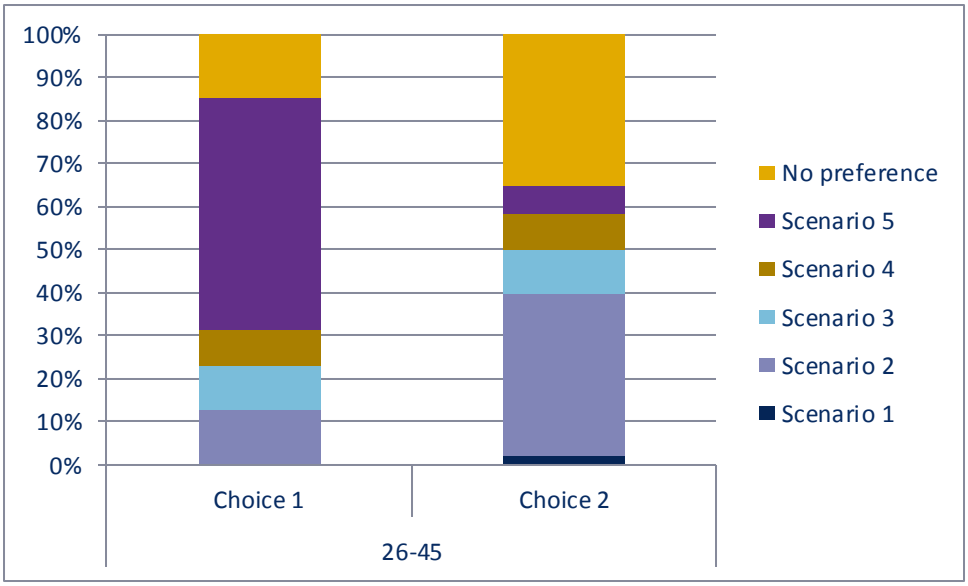
ANNEX 9 – RESULTS OF PASSENGER ASSESSMENT

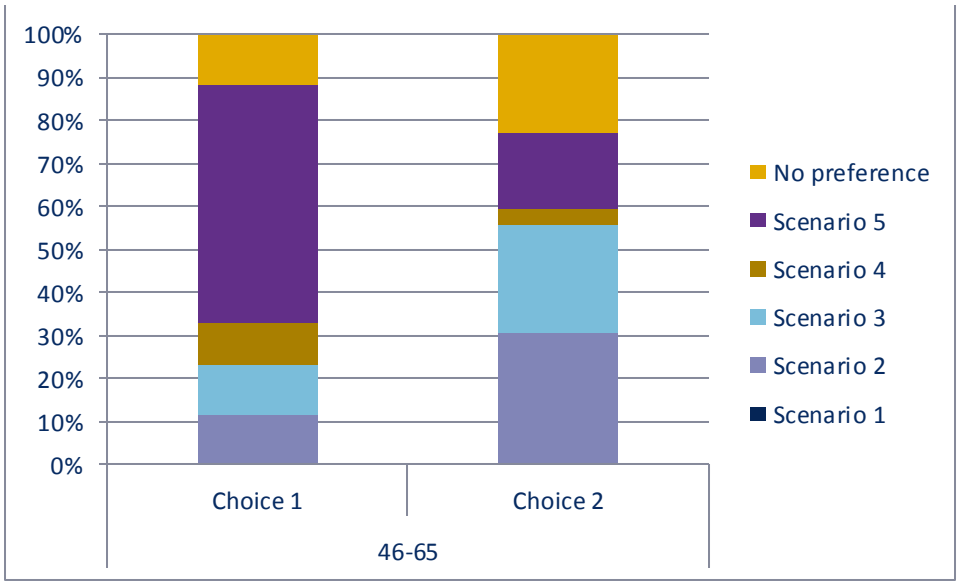
In this annex, differentiations of decision making on compensation measures are visualized.

Figure A 9 Differentiation towards age.






100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Choice 1
Choice 2
26-45
No preference
Scenario 5
Scenario 4
Scenario 3
Scenario 2
Scenario 1


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Choice 1
Choice 2
46-65
No preference
Scenario 5
Scenario 4
Scenario 3
Scenario 2
Scenario 1

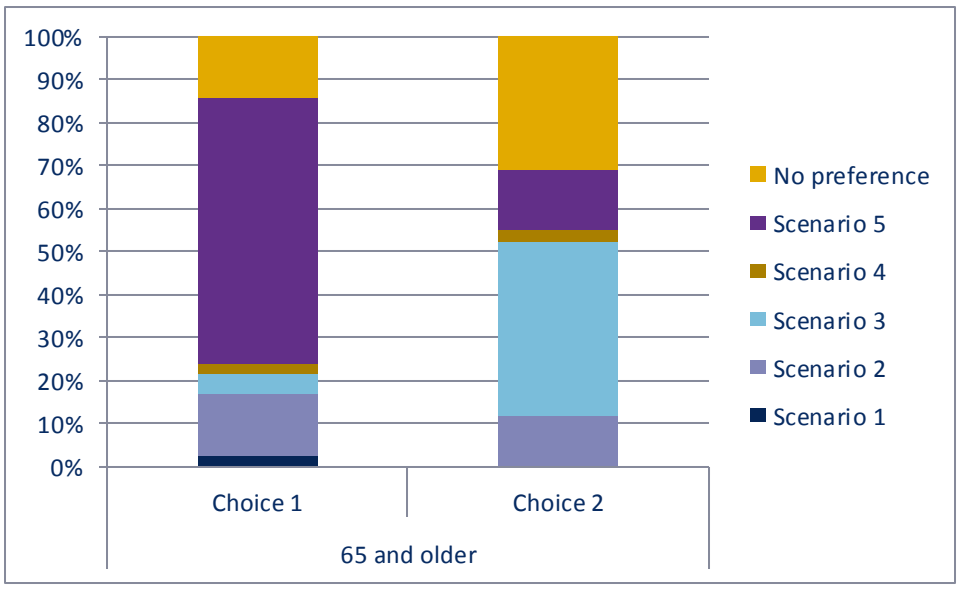
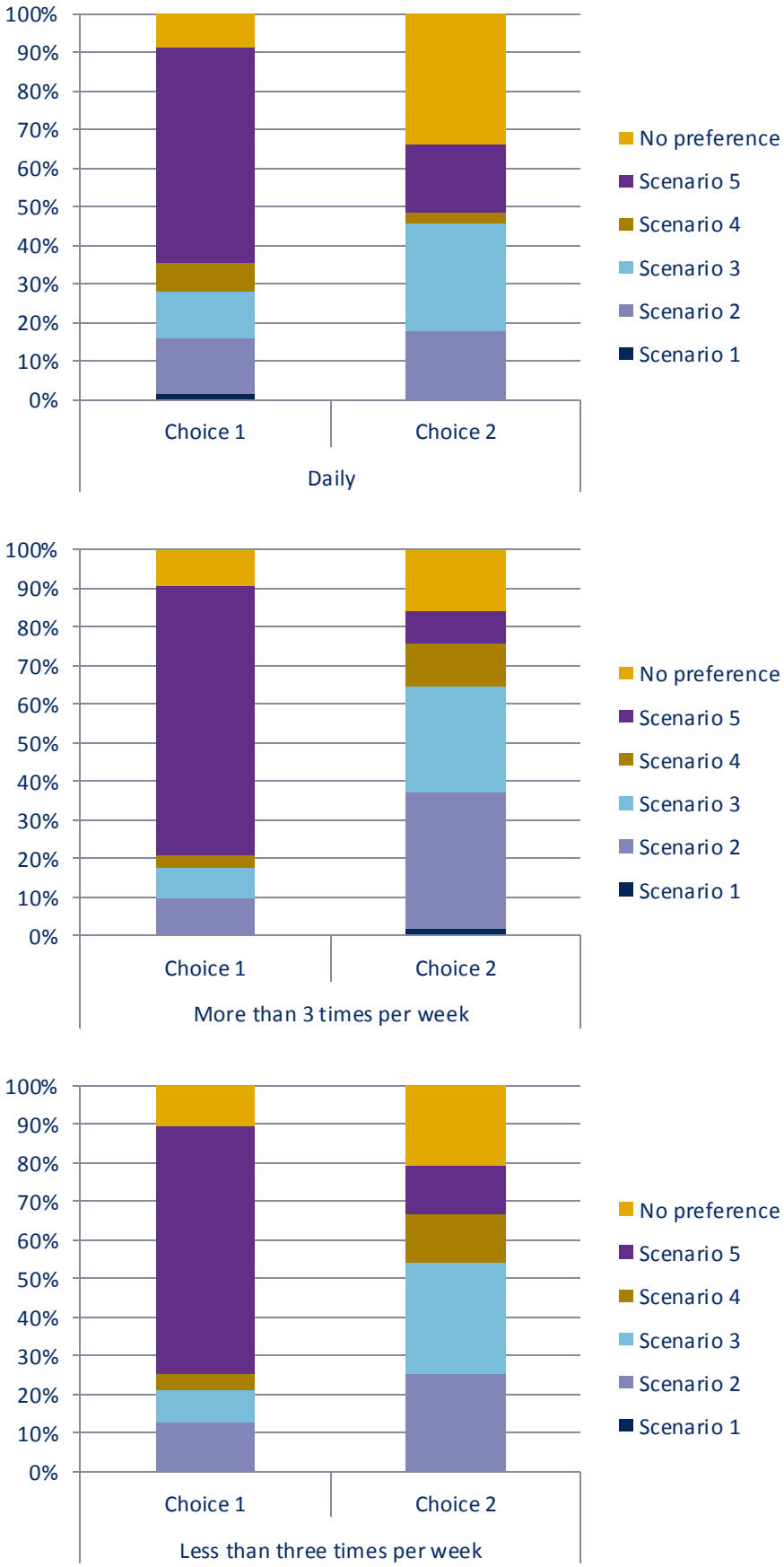

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Choice 1
Choice 2
65 and older
No preference
Scenario 5
Scenario 4
Scenario 3
Scenario 2
Scenario 1

Figure A 10 Differentiation towards travel frequency



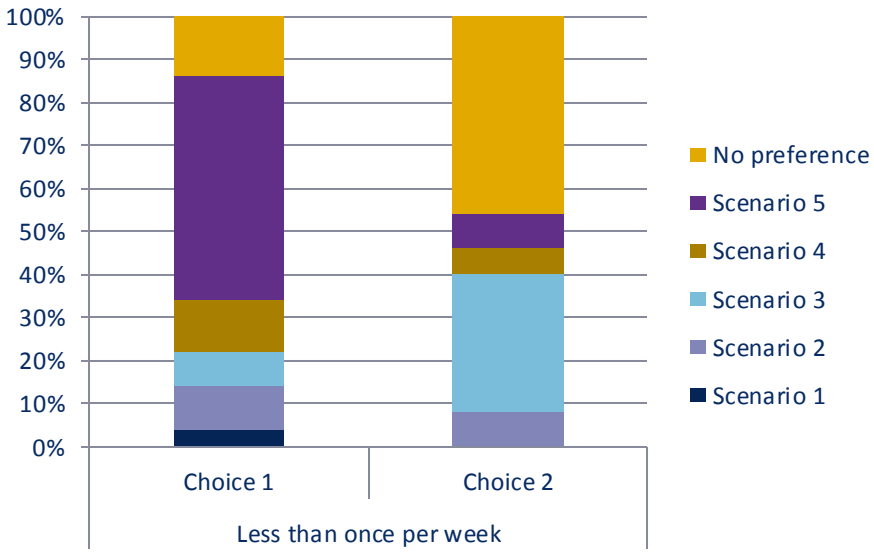
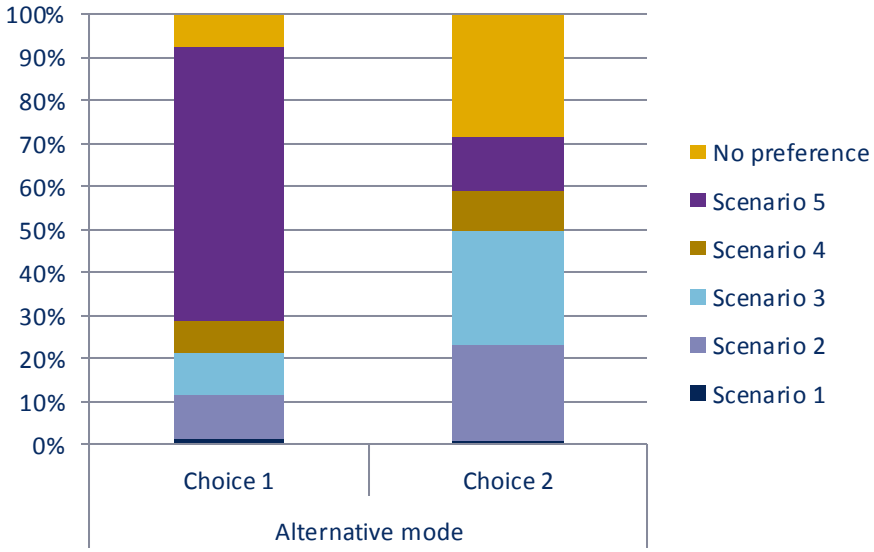
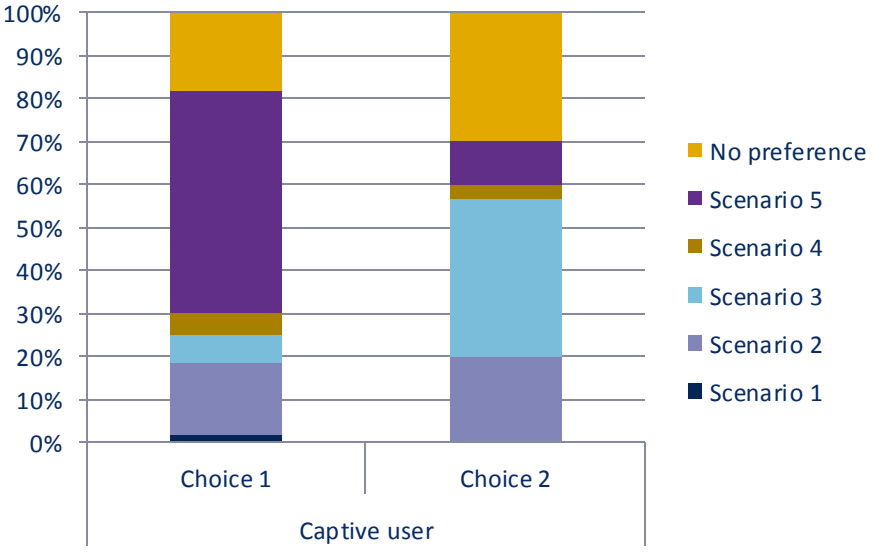


Figure A 11 Differentiation towards transport dependency





ANNEX 10 – K-FACTOR PASSENGER LOSS

The figure below indicates the passenger loss around a certain stop if the particular stop is closed. The blue squares indicate the stop. The figures below the middle line indicate the situation if the stop X is eliminated. The figures represent the percentage of passengers willing to use the public transport system.

		Influence area stop X								
distance		150-100	100-50	50-0	0-50	50-100	100-150	150-200		
	150-200	50	60	70	70	60	50	40		
	100-150	60	70	80	80	70	60	50	Total	96%
	50-100	70	80	90	90	80	70	60		
Original	0-50	80	90	100	100	90	80	70		
Stop closed	05-50	70	60	50	40	40	50	60		
	50-100	60	50	40	30	30	40	50	total	52%
	100-150	50	40	30	25	25	30	40		
	150-200	40	30	25	20	20	25	30		
distance		150-200	200-250	250-300	300-375	375-300	300-250	250-200		

Remain: **54%** **loss**

Aditional walking distance

K-factor **30%** **loss**

300*400/(300+400) = 170 meter

Figure A 12 New suggested approach for passenger loss on stop level.

The method above shows the consequence if the vertical distance is implemented in the K-factor calculation method. For this stop, the K-factors are used as they were given in section 12.3.2. The loss of passengers is so high that it can be assumed that this approach gives unrealistic losses of passengers.