EFFECTS OF CHANGING A PART OF A BUSROUTE TO AN LRT

A case study on the Binnenstadsas, Utrecht

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Executive summary

The city of Utrecht is growing enormously fast in terms of inhabitants, with the municipality expecting an increase of almost 30% in 2040. This requires improvements to be made in many aspects to keep the city liveable. Also, the transport possibilities of the city must adapt to this increase. The municipality of Utrecht prioritizes sustainable modes of transportation, such as walking, cycling or public transportation.

One area in the city centre is already reaching its capacity in terms of transportation capacity. With 74 buses per hour per direction, 34 thousand cyclists per day and five thousand motorized vehicles per day, the Binnenstadsas can be seen as a busy area. Thus, plans are being made to change this area.

There are plans for creating an improved Binnenstadsas, however the decision which plan to choose has not been taken yet. The plans include a cycling street, spatial optimalization, smaller buses, a city tram, or an LRT. The LRT seems a solution for the optimizing space, as at the Binnenstadsas it will go underground, creating a liveable and safe surface area. However, little is known about the total outcomes of this intervention. As it is an expensive intervention, knowledge should be gained on the effects.

This research focuses on the effects of implementing an LRT in this area, especially on the effects on travel time. This will be done in actual travel time analyses and perceived travel time analyses. Also, this research will investigate what is the best location for the transfer hub, where buses and the LRT will have their transfers. This creates the research question: How does changing part of a current bus route to an LRT affect the absolute and perceived travel time on the Binnenstadsas in Utrecht?

The three scenarios analysed are the current scenario, and the possible future scenarios with Oorsprongpark or Rijnsweerd-Noord as transfer station. In the new scenarios, the total trip will consist of a bus trip, a transfer, an LRT trip and an egress trip, while in the current scenario it will only consist of a bus trip and an egress trip. For the perceived travel time perception factors and penalties are used to provide an accurate estimation.

In the results it was visible that the new situation had higher travel times than the current situation. While for the perceived travel time results, the new situations were better for areas. As for the comparison between the scenarios using either Oorsprongpark or Rijnsweerd-Noord as transfer station, no significant better station was found based on actual or perceived travel times. Oorsprongpark looks better in both comparisons, however in absolute numbers it does not differ to much between both locations.

To conclude, in this research it does not look like the LRT has a positive effect on either the perceived or actual travel time. However, only the most negative trips are considered in this research. Trips that only use the LRT and do not have to transfer, are better of than currently as the LRT is faster than the buses. Also, there is no significant better transfer station based on the results and many other variables will have a larger influence on that decision than the few minutes difference on travel times.

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1. Introduction

The city of Utrecht is growingly rapidly in terms of inhabitants, with an expected increase of 100.000 inhabitants to a total of 450.000 inhabitants in 2040. This requires a change in transport possibilities in the city, for which Utrecht aims to prioritise sustainable modes of transportations such as walking, cycling and public transport. One area within the city centre is already reaching its capacity with 74 buses per hour per direction: the Binnenstadsas. This can be seen as an excessive amount of bus traffic, which can be seen as a barrier for people who want to cross the bus lane, for example cyclists or pedestrians. There are five proposed changes to the transport network in this area. As the Binnenstadsas is a bus lane within the historic centre of Utrecht, changes will have a large impact on the liveability, travel capacity, accessibility and urban environment.

In 2040, the Binnenstadsas should be a liveable area and an attractive part of the city centre (Studio Bereikbaar, 2021). Hence, studies are ongoing on one of the proposed changes that analyse a potential underground and/or overground Light Rail Transit (LRT) line to replace the existing bus lane. Buses that currently end at the Utrecht Centraal train station will need to be rerouted to create transport hubs on the city edges, after which the city centre can be reached by tram. As the bus routes are no longer serving Utrecht Centraal directly when realising an LRT line on the Binnenstadsas, the general view of the municipality and province of Utrecht as key stakeholders is that extra transfers will cause increased travel times and thus a reduction in public transport usage.

1.1 Context on the Binnenstadsas

The study area of this study consists of multiple areas, which connect to each other through the main area; the Binnenstadsas. This is a busy connection area between the city centre of Utrecht and the eastern part of Utrecht. In figure 1, the bus lines of the city centre of Utrecht are shown, where it is visible that the Binnenstadsas, that is encircled, is the place where many bus routes pass through.

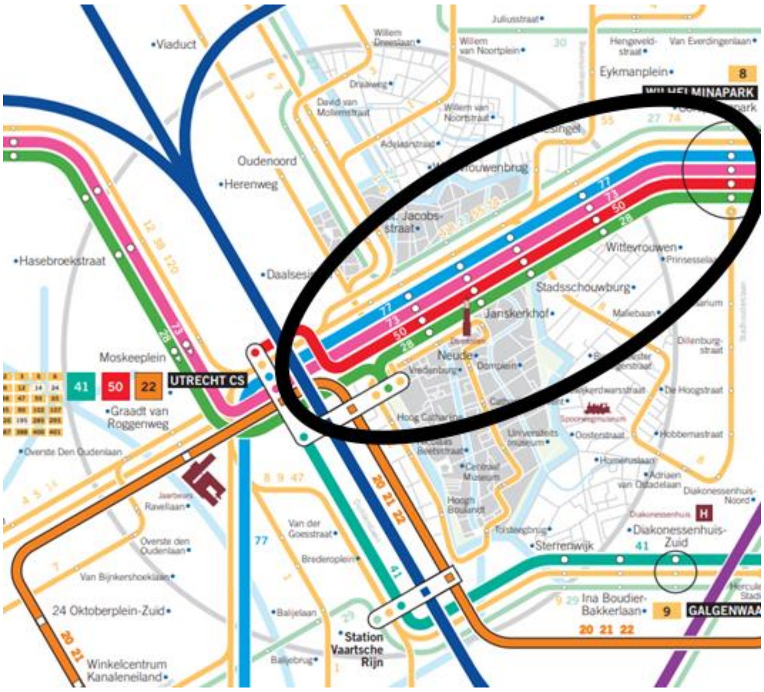

Figure 26 - Busnetwork Utrecht city centre (source: U ov (2024))

The Binnenstadsas is a city section where many commuters pass through. In absolute numbers this gives that there are 34 thousand cyclists and more than five thousand motorized vehicles on an average workday. In addition, 74 buses per hour per direction on peak hours (Studio Bereikbaar, 2021). The high number of buses is caused by the bus lines coming from the east that can only use the Binnenstadsas to reach the city center. The bus lines that pass through the area are shown in the table below.

Table 1, bus lines in area

Regional bus line				Local bus line to the central station			
Line	**Peak flow per hour per dir.**	**Off-peak flow per hour per dir.**	**Destinations**	**Line**	**Peak flow per hour per dir.**	**Off-peak flow per hour per dir.**	**Destinations**
77	6	4	Nieuwegein - Utrecht CS - Bilthoven	**4**	4	2	Terwijde - Utrecht CS - Voordorp
73	6	4	Maarssen - Utrecht CS - Zeist	**8**	6	4	Wilhelminapark - Utrecht CS - Lunetten
50	6	2	Utrecht CS - Zeist - Wageningen/Veenendaal	**27**	6	4	Zuilen - Utrecht-Centrum - Science Park
28	6	6	Vleuterweide - Utrecht CS - Science Park	**55**	2	2	Utrecht CS - Groenekan – Maartensdijk
				74	4	4	Vianen - Utrecht CS - Zeist

Table 1 also indicates that neighbouring cities of Utrecht are also part of the study area as the buses that use the Binnenstadsas go to these cities. The important neighbouring cities are shown in figure 2. It is clear that the Binnenstadsas is a connection to the eastern part of the municipality of Utrecht.

Figure 27 – Connecting cities using bus lines using the Binnenstadsas

The importance of the Binnenstadsas can also be seen in figure 3, where the public transport network is shown for the province of Utrecht. The purple lines are the bus routes, and the purple line indicated by the red arrow is the Binnenstadsas. This clearly shows the dependency for bus routes to the eastern part from Utrecht City centre on the Binnenstadsas as it is the only link available.

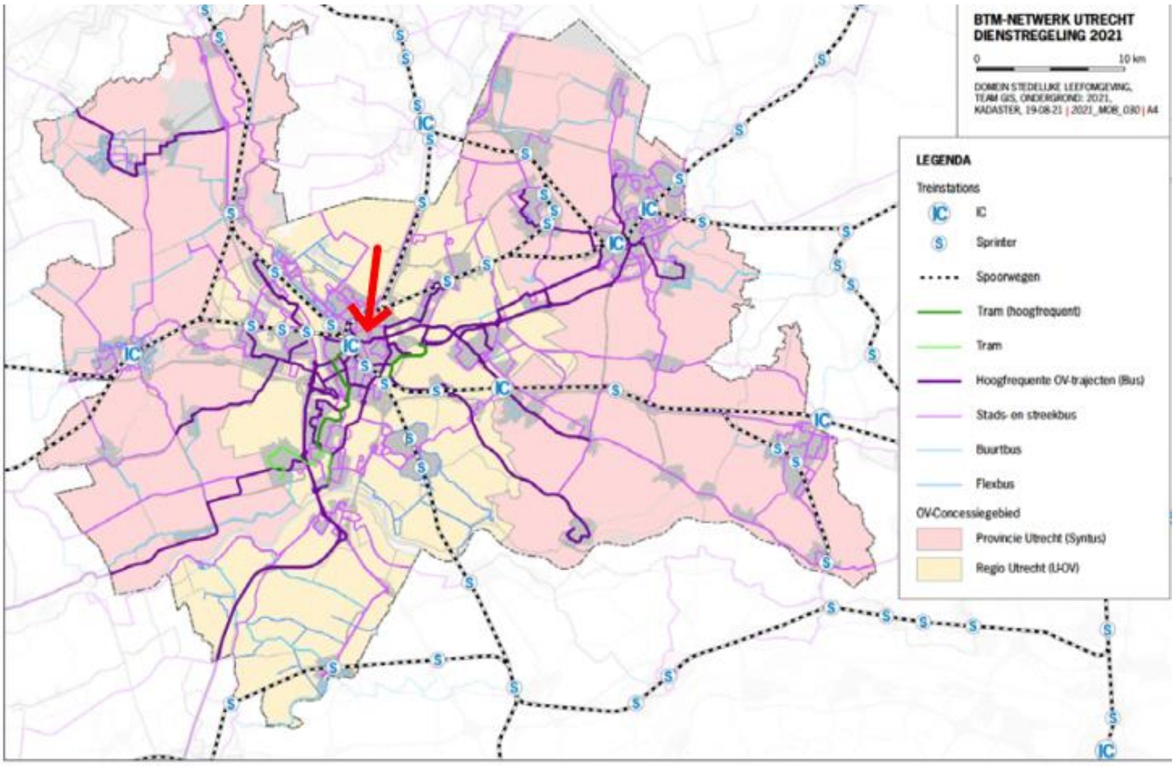

Figure 28, PT network Utrecht (Source: Provincie Utrecht, 2022)

The Binnenstadsas is an area in the city centre of Utrecht. It is approximately 2 kilometres long. The scope of the Binnenstadsas projects is shown in figure 4. From left to right it consists of the Catharijnesingel, Lange Vliestraat, Viebrug, Potterstraat, Neude, Janskerkhof, Nobelstraat and the Lucasbrug. In this area currently five bus stops are located: Sint-Jacobsstraat, Vredenburg, Neude, Janskerkhof and Stadsschouwburg. The last four mentioned bus stops are located on the route from Utrecht Centraal to the eastern part of the municipality of Utrecht.

Figure 29 - scope of Binnenstadsas (Source: Studio Bereikbaar, 2021)

1.2 Problem

The Binnenstadsas is an important link for public transport in Utrecht. The municipality tries to ensure high quality of the city centre, including safety and accessibility. The traffic demand on the Binnenstadsas is rising by large numbers; in 2019 44% more boarding people in the weekends compared to 2015 and 21% more on working days (Studio Bereikbaar, 2021). The Binnenstadsas also has a lot to win in terms of ability to cross, see figure 5, the large amount of traffic combined with the lack of visibility at some parts of the area creates a barrier for people who want to cross the street. Even the narrowness of the street creates problems. As this is a busy area for public transport, the large vehicles such as buses have to wait for each other to pass as it does not always fit. The main attention point for narrowness is at the Lucasbrug/Wittevrouwensingel, where also delays appear due to the lack of space.

Figure 30, congestion on Binnenstadsas

The Binnenstadsas is ready for improvement and multiple options are discovered by Studio Bereikbaar (2021):

1. Spatial optimisation
2. Bus in cyclingstreet (Fietsstraat)
3. City tram or TramBus
4. Smaller buses around the city centre
5. Metrotram (tunnel)

The considered options all have positive and negative effects, for example if LRT is faster but more expensive to acquire, operate and maintain, the demand must be high enough to make the rail system more cost efficient (Tirachini et al, 2010). For now, it seems that a metrotram is the best option, but there is uncertainty about absolute and perceived travel time increase caused by the transfer needed from bus to LRT.

1.3 Research objective

Little is known about the exact effect on travel time and comfort of the proposed LRT alternatives. Some of these interventions need transport hubs to accommodate the transfer from buses from outside the city center to the LRT system. This transfer seems unwanted and could lead to an increase in travel time and discomfort to users. However, it could also lead to less public transport delays and less total travel time as LRT as a single vehicle has a higher capacity and speed than the current buses. As these effects go in different directions, the aim of this research is to determine the change in travel time and perceived travel time when replacing buses for LRT. This means determining door-to-door travel times and travel time perceptions of trips using the Binnenstadsas.

1.4 Research questions

Following the objective of this research, questions have been composed to guide the research in the direction of the objective.

- How does changing part of a current bus route to an LRT affect the absolute and perceived travel time on the Binnenstadsas in Utrecht?

  The main research question will provide more information on the knowledge gaps shown in the problem. The research question will give results on what effects on travel time, perceived and actual, will occur when implementing this intervention.

  - What is the current door-to-door travel time on the bus routes that use the Binnenstadsas?

    This sub question provides an analysis of the current situation. This can help identify the current problems, to see whether they improve after the implementation. This sub question gives the basis for the comparisons of the future situations with the current situation.

  - How does changing part of a current bus route to an LRT effect the actual travel times to areas in East-Utrecht?

    This sub question provides the differences on actual travel times after the implementation of the LRT. These differences are analysed and assessed to see the effects the LRT has on the absolute total travel times to different areas in Utrecht East.

  - How is every part of a public transport trip perceived and what are the effects in the perceived travel time assessment of the LRT?

    This sub question provides an answer to the perceived travel time part of the main research question. The perceived travel time is a matter of how the travellers will react to the intervention. When the perceived travel time is better than the current perceived travel time, the people will accept the intervention.

  - What is the timetable where the total travel times for all passengers and general costs of travel are minimized?

    I. What is the optimal frequency of departures of the LRT for minimizing total costs?

    These sub questions help provide an optimal and more accurate estimation for the future travel times, as an optimal frequency will help provide an optimal timetable for the LRT. This gives the calculation of waiting times a higher accuracy and provides more significancy to the results.

1.5 Report structure

The report is build up to explain the research questions and the technique used to answer them. This chapter gives an overview of the contents, and what they will explain.

- Section 2 – Literature

The literature gives insight into the matter needed to assess the effects of changing from public transport vehicle. This includes information on every part of the door-to-door trip, with in-vehicle time variability and reliability, public transport transfers, transfer perceptions and access and egress time.

- Section 3 – Methodology and validation

The methodology explains the methods used to create and use the model, where the validation checks the validity of the model. The model is described in general first, whereafter all the values, formulas, and other input variables are explained. The validation looks at the first results and uses that to see whether the model gives reasonable results.

- Section 4 – Results

The results show the output of the model, this is done in maps of East-Utrecht. The multiple types of results are given so that all the research questions can be answered.

- Section 5 – Conclusion and recommendations

This section explains the answers to the research questions stated in the first section. The conclusions to these questions are explained and showed. Afterwards, recommendations are given to show what could be better during future research and how this research can be used by policy makes.

2. Literature

In this section different transport modes and their effects on actual and perceived travel time are assessed. The effects of changing a significant part of the public transport network can be large. Different transport modes or vehicles have different effects on travel time, travel perception, traffic volumes and many other factors. A door-to-door trip considered in this research includes an access and egress trip, an in-vehicle trip in various vehicles and a transfer.

2.1 Effects when changing from bus to metro

Changing transport modes is a large step within a public transport system. A metro and bus have the same function: A mode of passenger transport, linking various areas and their surroundings (Ferrovial, 2022). However, the two public transports modes are not entirely interchangeable. Metros can reach higher speeds in dense areas, while buses are more flexible in terms of times and routes. More than 93 percent of the travellers will switch from bus to metro when the fare of the metro is 1.5 times higher than the fare of the bus (Selvakumar et al., 2018). The scenario where this was studied has similar characteristics as the study area in this research; the traffic and number of inhabitants are growing relatively rapidly in Chennai, the bus network run is efficient. However, traffic congestion is still an issue and there are plans to implement the Chennai Metro Rail. The outcomes are that passengers, especially when having enough income, are likely to switch to metros as the other characteristics outweigh the characteristics of the bus network.

2.2 Door-to-door trip

Trips in public transport have more aspects than using personal vehicles or active transport modes as most public transport stations or hubs are not located at the start of the trips. A door-to-door trip consists of every part of a trip from origin, the start of the trip, to destination, the end of the trip. This can be seen in figure 6, which is a travel scheme when using public transport.

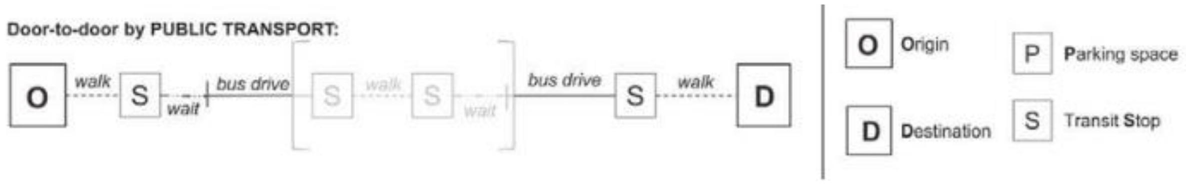

Figure 31, travel scheme using public transport (Source: Salonen & Toivonen, 2013)

2.2.1 In-vehicle travel time

In-vehicle travel time is the time spend during a trip inside of a vehicle. For a public transport trip this consists of the time spend after entering the public transport vehicle to the exiting the vehicle. To compare the intervention to the current situation, travel time is an important factor. GTFS data is an available source to analyse the variables and it stands for general transit feed specification. It is usually used for calculating possible trips for individuals. GTFS data shows numerical data for the following parameters:

- trip_id
- stop_id
- route_id
- arrival time
- departure time

However, these data sources are based on planned times and routes. This can change due to congestion, road work, or other factors. Haarsman (2009) found in Brazil that on an average bus trip of approximately 32 minutes, the arrival time could vary from 26 to 39 minutes. This means that buses cannot always be on time as the variables for the buses are too hard to predict. For Dutch public transport a study was performed in The Hague where the total trip time variability is shown in figure 7. The considered trips were public transport trips using metro, tram and bus. The trip time varied due to delays, reliability and other variabilities in public transport times. The standard deviation is almost 4 minutes, where the difference between the maximum and minimum length of a trip are almost 20 minutes (van Oort, 2011). In figure 7 this can be seen in a graph, where distance and time are plotted against each other, to show the variability in time each trip takes. In Santiago Chili, a strong relationship between standard deviation of travel times and mean travel time was found, where metro vehicle times are more stable. Also for door to door public transport trips, the total travel time variability is significantly explained by bus waiting and in-vehicle times (Durán-Hormazábal & Tirachini, 2016). To conclude, this means that trains/metros are more reliable than trams/buses.

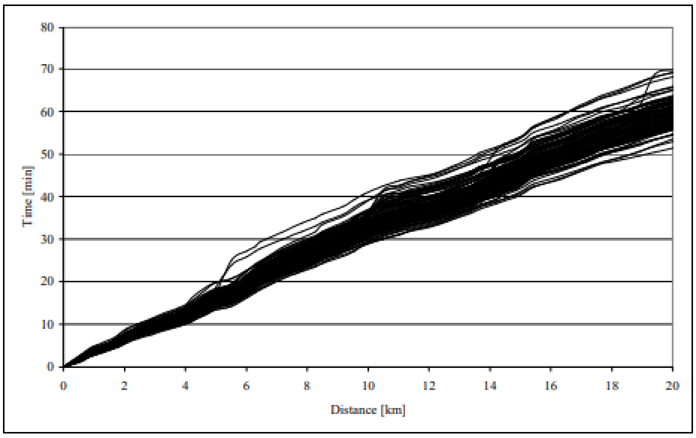

Figure 32 – example public transport total trip time variability (source: van Oort, 2011)

The in-vehicle time perception might also change from vehicle to vehicle. Figure 8 shows the boxplots of different public transport vehicles, where the perceived travel times are compared between different public transport modes. The difference between the researched vehicles is not significant as it only varies a few minutes in the Netherlands.

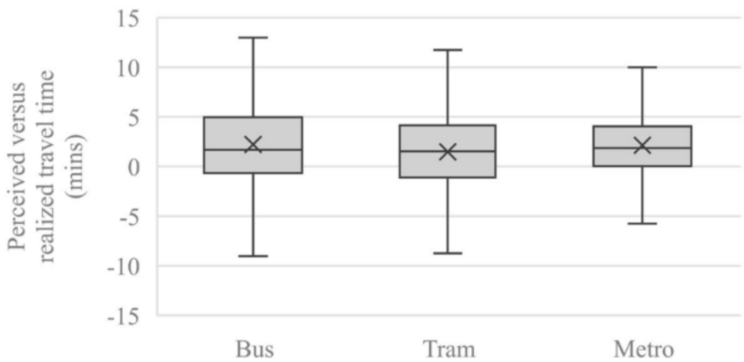

Figure 33 - boxplots vehicle perception (Source: Brands et al., 2022)

2.2.2 Transfer public transport

A transfer is common within public transport trips; however, it can influence the perception of the trip hugely. Within a transfer the commuter must move from vehicle to vehicle in a busy environment, which some people can perceive as negative. There are many variables on how a transfer is perceived as every station and transfer is different. This chapter talks about the literature on this topic.

2.2.2.1 Transfer perception

When a part of the bus route is changed to a metro route, passengers will have to transfer at a transfer hub. This transfer costs time and has other negative factors to the trips of passengers. The waiting time of a transfer in the UK is experienced as 1.7 times the in-vehicle time and the walking time as 1.65 times the in-vehicle time (Abrantes and Wardman, 2011). And the single transfer from train to train, is valued at 18 minutes of travel time (Wardman, 2004), while Arentze and Molin (2013) finds a train-to-train transfer with 10 minutes of transfer time equivalent to 22 minutes extra in-vehicle time in the Netherlands. Schakenbos et al. (2016) found that an average transfer between bus and train was found to have a disutility of 43 minutes perceived travel time and between metro/tram and train was found as 37 minutes in the Netherlands. However, it strongly depends on transfer time as changing transfer time from 15 to 8 minutes changes the perceived travel time from 39-51 to 29 minutes perceived travel time. Schakenbos et al. (2016) also found that short transfer times (<5 minutes) are perceived negative, as they are probably seen as stressful or as they might increase the risk of missing the transfer. The transfer penalty from train-to-metro ranges from 8.5 to 17 minutes while from subway-to-subway the transfer penalty was 7.3 minutes in the UK (Guo and Wilson, 2011), which indicates a higher penalty when switching vehicle type. Walking during a transfer showed a significantly higher sensitivity than at origin and destination ends, thus walking at transfer cannot be ignored (Hossain et al., 2015). Table 2 gives an summary of the perception penalties and factors found in literature. This gives a range of values, from where a conclusion is drawn which can be seen in the last row.

Table 2 - transfer perception outcomes

Studied by	Type	Waiting time	Walking time	In-vehicle time	Total transfer	Transfer penalty
Abrantes & Wardman 2011	Factor	1.7	1.65	1		
Wardman 2014	Factor	2.5	2			
Meng et al. 2018	Factor	1.11	1.07	1.02		
De Keizer et al., 2015	Coeff.				2 min = 0 2-5 min = -1.89 >5 min = 1.67	
Wardman 2004	Minutes					18
Arentze & Molin	Minutes					22 min for 10 min actual
Schakenbos et al., 2016	Minutes					LRT-train 37 bus-train 43
Guo & Wilson 2007	Minutes					Metro-metro 7.3 Train-metro 8.5 to 17
Conclusion		1.7	1.65			12

2.2.2.2 Platform and station design perception

The trip perception of the traveller can be influenced by many factors, especially within public transport trips. Public transport trips have the factor of station design which can influence the perception of the total trip. However, an ideal station is unrealistic and unfeasible because of space limitations and other factors. Ideally, public transport users in an underground station are able to find their way easily, thus and ideal station has a minimum numbers of direction changes and angular deviation along the route (van der Hoeven & van Nes, 2014). Also, the acoustical design of the metro station is important for the ambience of the station. As large groups of travellers can produce noise which reflects to the underground tunnel walls. This noise can be controlled by a good design and noise dampening materials (Sü & Çaliskan, 2007). The main goal of stations is providing boarding and alighting opportunities users of the public transport vehicle. This goes best if the distribution on the platform is evenly distributed thus there is the same numbers of passengers at each door. How this is distributed is hugely affected by the entrance to the platform (Krstanoski, 2014). Also, the entrance of the metro station has ideal various design parameters. Appearance design should pay more attention to characteristics and diversity, it is a combination of design business, culture art, technology and sustainable development ideas (Liang et al., 2023).

The route commuters must take during a transfer is hugely impacted by de obstacles on the route. Height difference in a station makes higher perceived travel times. This can be seen in modifiers compared to in-vehicle time for walking upstairs (4.0), walking downstairs (2.5), traveling on escalators (1.5) and traveling in lifts (2.0) (Wardman, 2014).

2.2.3 Access and egress time

An important factor of public transport is that this mode of transport cannot start or end at every location. The trip from the public transport station to the final destination is called the egress trip and from starting location to the public transport station is called the access trip. Door-to-door times increase as egress and access times have to be taken into account. People tend to walk longer distances to trains, than metro or LRT, and the shortest to buses. It could be stated that the longer the range of the mode, the longer the walking distances to and from that mode are acceptable (Krygsman et al., 2004). The status of the mode can partially attribute to the distance willing to travel to the station as there tends to be a preference to rail-borne transport (Anderson, Nielsen & Ingvardsson, 2016). Even the frequency of the public transport line has a positive impact on the preferred distance to walk (Alshalafah & Shalaby, 2007) as a higher frequency is associated with less waiting time and less planning effort. The willingness to walk a longer distance to the public transport stations also decreases if the density of public transport routes increases, thus more routes does not mean more public transport users (Alshalalfah & Shalaby, 2007). This also applies for PT stops, as Wang and Cao (2017) found a negative effect of the number of stops on the preferred walking distance to the stops.

Within the Netherlands walking is not the only access or egress transport mode. The use of bicycle as an access mode is very popular in the Netherlands as 40% of all home-based train trips has bicycle as access mode (van Nes et al., 2014). A study performed in Spain tells that almost 80% of the people that use walking as access mode to a tram, perceive the travel time of the tram trip longer than it actually is.

3. Model methodology

To analyse the research questions, research must be done. This will mostly happen through a model estimating the travel times in all the different situations. All the parts of the model and every parameter will be explained in this chapter.

3.1 Explanation of model

The model consists of multiple parts; the current situation analysis, the situation including the LRT and the perceived times of those situations.

3.1.1 Current situation analysis

The current situation is modelled in two parts; the bus trip and the egress trip. First, the egress trips per bus stop are calculated, then the shortest egress time is locked. The corresponding bus stop is taken as the end stop, where the first bus stop of the line is taken as the first bus stop. The time spend is calculated, and added up with the, shortest, egress time to calculate the total travel time.

3.2.2 New situations

The new situations are modelled in 4 parts; the bus trip, the transfer, the LRT trip and the egress trip. The bus trip is from the first station of the line to the station closest to the transfer station. For some lines, the bus must be rerouted to go to the transfer station, so the bus trip also consists of the rerouting time. The transfer consists of the walking time, and the time waiting for the metro. The egress time for every end destination from every metro station is calculated and the shortest is locked. The corresponding metro station is taken as end station and the LRT trip time is calculated. All the times of the parts of the trip are added up to calculate the total travel time.

3.2.3 Perceived situations

The perceived situations are modelled by using the absolute travel time part of the model. The durations of each part of the trip are already known, and are linked to perception factors to determine the perceived travel time. This also includes penalties for perceptions that are not linked to time but for example to the existence of a transfer in a trip.

3.2 Scenarios

To analyse the effects of the change, different scenarios will be used to create comparisons. What these scenarios are and what the differences are between them are explained in this chapter. The new scenarios are split into two locations, as those locations are the possible transfer stations.

3.2.1 Reference scenario

The reference scenario is the current situation. In this scenario, the only public transport used on the Binnenstadsas are buses. Eight different bus routes pass the Binnenstadsas are used in this scenario, to calculate the travel time to the different areas within Utrecht. It takes 12 minutes to travel by bus from Utrecht Centraal to Rijnsweerd-Noord.

3.2.2 Scenario Oorsprongpark

This scenario is a possible future scenario and uses Oorsprongpark as transfer station. This means that the current bus routes using the Binnenstadsas going into the city will be rerouted to Oorsprongpark. At Oorsprongpark, people will travel further to the city by LRT, which means that they will transfer from bus to LRT at Oorsprongpark. A visualization of the LRT network with Oorsprongpark as transfer station that is used in this model is shown in figure 9. Where the blue dots are the stations and the green dot is the transfer station Oorsprongpark.

Figure 34, scenario Oorsprongpark LRT

3.2.3 Scenario Rijnsweerd-Noord

This scenario is a possible future scenario and uses Rijnsweerd-Noord as transfer station. This is one station further from the city centre than Oorsprongpark. Again, the busroutes that use the Binnenstadsas currently will be rerouted to this transfer station. After this transfer station, the travelers will use the LRT to reach the city centre. A visualization of the LRT system used in this scenario is shown in figure 10, where the blue dots are stations, and the green dot is the transfer station Rijnsweerd-Noord. It takes 6.4 minutes to travel by LRT from Utrecht Centraal to Rijnsweerd-Noord.

Figure 35, scenario Rijnsweerd-Noord LRT

3.3 Frequency estimation

The frequency will be determined in two different approaches: the peak point approach and cost minimalization approach.

3.3.1 Peak point approach

The peak point approach uses the demand (q) and capacity (K) of the vehicles to determine the frequency of the vehicles on the route. Also, the percentage of passenger load in the most loaded section (θ) and the maximum occupancy rate (σ) are considered. This gives formula 1. The values for the parameters are given in appendix I - frequency optimalisation parameters.

$$F = \frac{\theta q}{\sigma K} \qquad \text{Eq. 1}$$

3.3.2 Cost optimization approach

The cost optimizing approach (Jansson, 1980) calculates the costs of the passengers and the operator to find a frequency where the costs are minimized. The costs for the passengers are divided in time spend waiting and in-vehicle time. How these parameters are determined will be discussed in the subchapters, whereas the formula is shown below.

$$C_{tot} = operator\ cost + waiting\ time\ cost + in\ vehicle\ time\ cost \qquad \text{Eq. 2}$$

$$C_{tot} = c * B + P_a * t_a + P_w * t_w + P_v * t_v \qquad \text{Eq. 3}$$

$$C_{tot} = R * F * C + \frac{P_w q}{2f} + P_v * u * R * q \qquad \text{Eq. 4}$$

3.3.2.1 Operator cost

The operator costs can be calculated using formula 5. The costs per hour (A) is calculated through roll stock, operating cost, crew, maintenance and infrastructure costs. The residual value (B) only considers the roll stock as the other materials do not have resale value. The discount rate (r) and life span (n) are used to consider the value changes in time.

$$C = (A - B)\frac{r}{1-(1+r)^n} \qquad \text{Eq 5.}$$

3.3.2.2 Waiting time cost

The waiting time will be estimated by a parameter for waiting time savings (P_w), the average waiting time and the number of passengers (q). The average waiting time is the headway divided by two as the arrival time of buses is almost random.

3.3.2.3 In-vehicle time cost

The in-vehicle time costs are estimated using a parameter for in-vehicle time savings (P_v), the average ratio time spend in the vehicle to total trip length (u), the number of passengers (q) and the running time (R).

3.3.2.4 Parameters

The final formula is shown below. The values for the parameters are given in appendix I - frequency optimalisation parameters.

$$C_{tot} = R * F * C + \frac{P_w q}{2f} + P_v * u * R * q \qquad \text{Eq 6.}$$

3.4 Travel time estimation

For the travel times in the new situation a model will be used to take all the parameters of the new situation into account. The model and its in- and output parameters is visualized in figure 11. The colours are used to show the different pillars, and to give clarity on dependencies. A larger version of this figure is shown in appendix II – model schematization.

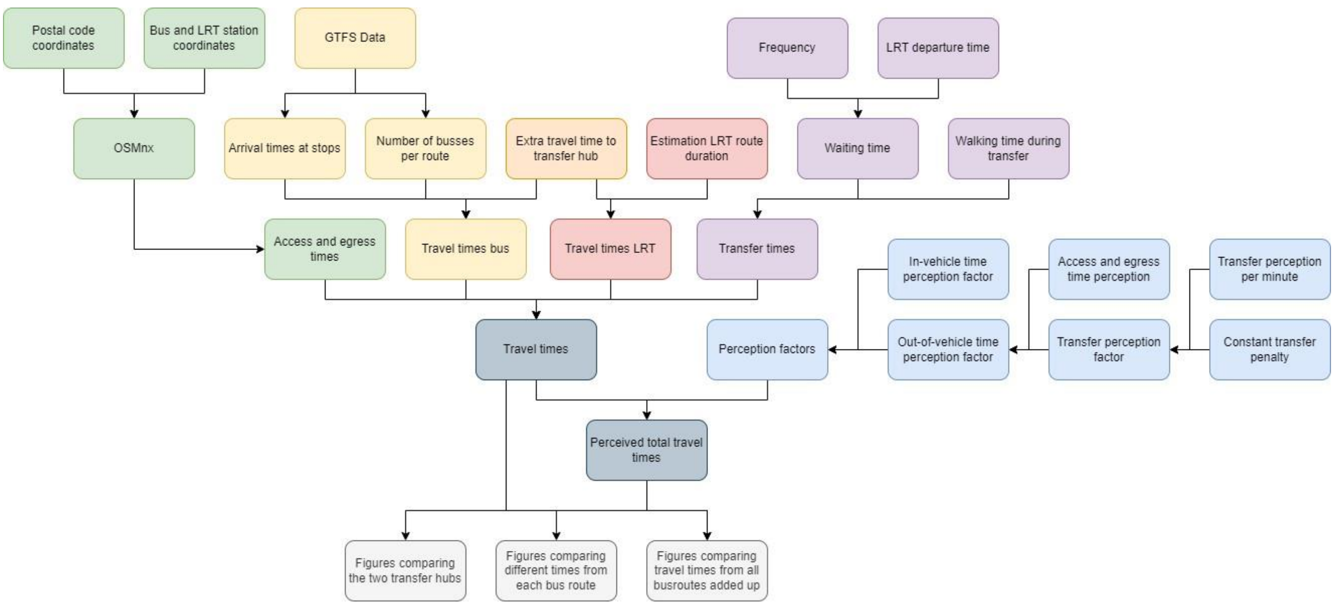

Figure 36, Schematization of Model

3.4.1 Access and egress times

The times walking from and to a station are calculated through OSMnx and will be used to calculate the door-to-door travel times.

3.4.1.1 OSMnx

OSMnx is a python package for open-source transport network modelling which will be used to calculate the access and egress times between the bus stations and the areas around the Binnenstadsas (PT station and postal zone centre coordinates will be used).

3.4.1.1.1 Postal code coordinates

A file is created with all the centre point coordinates of the neighbourhoods in Utrecht city centre, Eastern Utrecht and North-Eastern Utrecht. Which will be used to determine the route and travel time from public transport station to living areas. The areas that will be used are PC5 areas in the Utrecht-East.

3.4.1.1.2 Bus and LRT station coordinates

A file with coordinates of the busstations and LRT stations on the Binnenstadsas. Which will be used to determine the route and travel time from public transport station to living areas.

3.4.2 Travel times bus

The travel times for the part of the trip that is done by bus will be calculated through GTFS data by using the departure times at bus stops. These travel times will be used to determine the travel time of the whole trip. GTFS data consists of all the public transport trips of the Netherlands of a certain time frame, with all the characteristics of the stops and arrival times.

3.4.2.1 Arrival times at stops

The arrival time at stops is gathered through GTFS data and is used to determine the travel times of the current routes, as well as the arrival time at the transfer hubs.

3.4.2.2 Number of buses per route

The number of buses per route per day can be determined by GTFS data and is used together with the capacity to determine the demand for public transport on that route.

3.4.2.3 Extra travel time to transfer station

As one of the transport hubs is not on the route of all buses, the rerouting increases the travel time to the transfer station. This rerouting will take 1 minute extra to the transport hub of Rijnsweerd-Noord than to Oorsprongpark. This does not apply for routes 27 and 28, as they already stop at Rijnsweerd-Noord. For LRT travel time, it takes approximately 2 minutes and 32 seconds to travel between the two stops. Also, some bus routes do not pass both transfer stations, meaning the rerouting will take longer, which specifically applies to route 55.

3.4.3 Travel times LRT

The travel times for the LRT part of the trip will be estimated by adding up the duration between stations. This will be used to determine the total travel time of the trip.

The duration of the LRT and the station is estimated by Mott MacDonald and can be seen in the figure below and the speed profile between stations is seen in table 3.

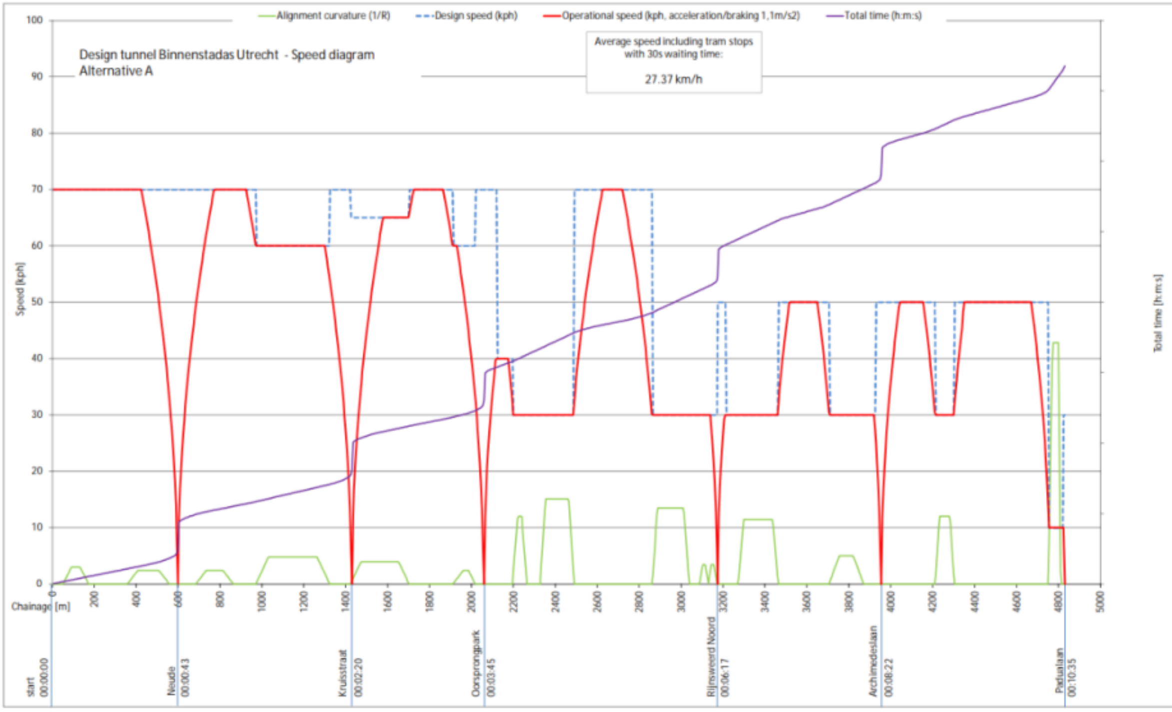

Figure 37, speed profile LRT with durations (Source: Mott Macdonald)

Table 3 - travel time of LRT

Departure station	Arrival station	Duration (s)	Duration (min)
Utrecht Centraal	Neude	43	0.72
Neude	Kruisstraat	97	1.62
Kruisstraat	Oorsprongpark	85	1.42
Oorsprongpark	Rijnsweerd-Noord	155	2.58
Rijnsweerd-Noord	Archimedeslaan	125	2.08
Archimedeslaan	Padualaan	133	2.22

3.4.4 Transfer time

The transfer time is the time spend between the bus and LRT vehicles. This transfer time is determined by adding the walking time and waiting time. The transfer time is used to determine the total travel time of the trip.

3.4.4.1 Frequency

The frequency optimisation is explained in the previous sub-chapter. It will be used to determine the waiting time, by dividing 1 by the frequency times two. This way the average waiting time can be determined.

3.4.4.2 Departure time

The timing of the LRT departure can influence the transfer times. Peak arrival moments of commuters ideally align perfectly with departure time of the LRT.

3.4.4.3 Walking time within station

The walking time is the time it takes to walk from the arriving vehicle to the departure vehicle, this depends on station design. As the designs of the stations consist of either an inter- or cross platforms, the walking distance will be around 30 meters. With an average walking speed of 1.2 m/s (Montufar et al., 2007) and delays due to congested flows this means an average walking time of one minute. A walking time of 1 minute is considered in this research for walking time during the transfer.

3.4.4.4 Waiting time

The waiting time is the time the transfer takes without walking time. This will be calculated in the model by calculating the difference between arrival and departure time and subtracting the walking time. It is determined by dividing 1 by the frequency times two, to calculate the average waiting time.

3.4.5 Perception factors

To estimate perceived travel times, factors will be used to transform the actual travel time and trip to the perceived travel times. How will be explained in this chapter.

3.4.5.1 In-vehicle time perception factor

As explained within the literature chapter, the in-vehicle perception can differ between vehicles. However, the perception of bus and LRT is not significantly different (Brands et al., 2022) thus a factor of 1 will be used.

3.4.5.2 Out-of-vehicle perception factor

The factor for perceived travel time when not inside the LRT or bus is mostly larger than in-vehicle perception. This will be explained in the various factors.

3.4.5.2.1 Access and egress time perception

The time spend walking from and to stations is considered to be less likeable than in-vehicle travel time as they lower a commuters satisfaction level (Lam and Xie, 2002). The factor for this can be seen in table 4, as walking time.

3.4.5.2.2 Transfer perception factor

The transfer perception consists of an absolute penalty due to the inconvenience of having a transfer within the trip and a penalty per time unit as a longer transfer is less convenient. The transfer penalty from train-to-metro ranges from 8.5 to 17 minutes while from subway-to-subway the transfer penalty was 7.3 minutes (Guo and Wilson, 2007), which indicates a higher penalty when switching vehicle type. This is why a constant transfer penalty of 12 minutes will be assumed. The penalty per minute will be based on Abrantes & Wardman (2011) and can be seen in table 4, here it is also visible that those values seem accurate based on other research.

Table 4 - transfer perception outcomes

Studied by	Type	Waiting time	Walking time	In-vehicle time	Total transfer	Transfer penalty
Abrantes & Wardman 2011	Factor	1.7	1.65	1		
Wardman 2014	Factor	2.5	2			
Meng et al. 2018	Factor	1.11	1.07	1.02		
De Keizer et al., 2015	Coeff.				2 min = 0 2-5 min = -1.89 >5 min = 1.67	
Wardman 2004	Minutes					18
Arentze & Molin 2013	Minutes					22 min for 10 min actual
Schakenbos et al., 2016	Minutes					LRT-train 37 bus-train 43
Guo & Wilson 2007	Minutes					Metro-metro 7.3 Train-metro 8.5 to 17
Conclusion		1.7	1.65			12

As there are stations in the new design that are located underground, there will be a higher perceived access/egress time as the public transport vehicle is only reachable by using stairs or escalators. As the multipliers for these are between 1.5 and 4.0 of the actual travel time. As the height difference between the surface level and the metro stations is around 35 meters, a penalty of 6 minutes will be given to stations underground, which are Neude and Kruisstraat. Oorsprongpark is a station located 15 meters below surface level, which gives a penalty of 3 minutes. The access and egress time factor is based on the literature study shown in the earlier chapter. The summary of all the perception factors is shown in table 5.

Table 5, Factors and penalties perception

Bus	Transfer, walking	Transfer, waiting	Transfer, penalty	LRT	Access/egress time	Access/egress penalty underground
1	1.65	1.7	12 minutes	1	1.5	3-6 minutes

3.5 Assumptions

As the model should not be overfitted to the data, it must be simplified. This is done by making assumptions, so that the model does not have an excess number of parameters. The assumptions of the model are described separately.

3.5.1 Shortest egress time

The model assumes people chose the route with the shortest egress time. This may not always be the shortest route in terms of total travel time, however it is best in terms of travel time perception as the egress time has a large perception factor.

3.5.2 Starting at first station

The model assumes every trip starts at the first station of the bus line. This is done to easily compare the trips people make between the different scenarios. Also, this makes sure the same trips are used, and the comparison is not influenced by different trips used.

3.5.3 Buses rerouted to transfer station

As already mentioned, the buses will be rerouted to the transfer station. This is done so that the transfer station serves its purpose as transfer station. The current bus routes and timetables are still used, as that comes closest to the new situation.

The bus routes using the Binnenstadsas all come from different directions, this is visualized in figure 13. Also route 55 will be rerouted to the transferstation, even though it is closer to the station at Kruispark. This is done because Kruispark is located at a narrow location, which is not ideal for the bus to use as transfer station, because the bus cannot turn around there.

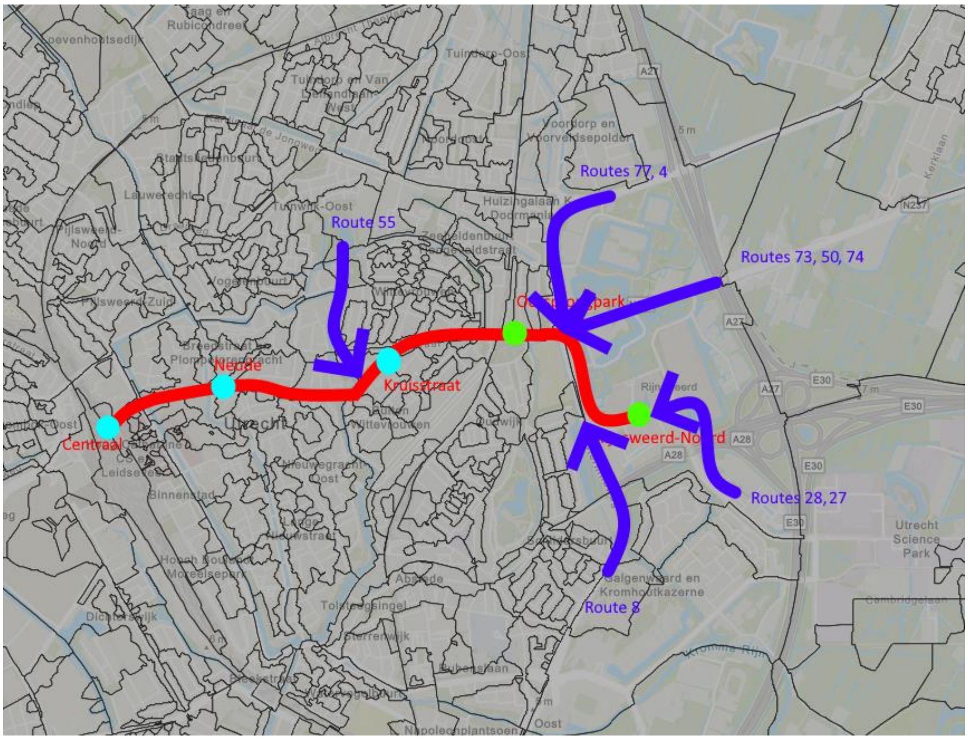

Figure 38, incoming bus lines

3.5.4. Only buses between 6h and 23h

Only buses between 6h and 23h are considered, as the model had problems with analysing the results for bus trips that started before midnight and ended after midnight.

3.5.5 Average of the 8 bus routes that use the Binnenstadsas

The model calculates the travel times per area, however the multiple bus routes give different travel times as the starting location is different per route. This is why the average of all the bus routes is used, so that all the bus routes are considered, but also not have a misinterpretation.

3.5.6 Only into Utrecht City

For all the travel times, only incoming trips to Utrecht city are considered. This is done to make the comparison easier. Also, for outgoing trips this is the same, as the transfer and the vehicle trips are the same.

3.6 Validation off the model

To ensure the quality of the model, the model is tested by logical consistency. The outputs of the comparable subparts of the model should be logical. This will be done by comparing the time spend in the bus, before and after the implementation of the LRT.

3.6.1 Bus times

Figure 14 shows the differences between the absolute time spent in only the bus. The blue areas show that after the implementation less time is spent in the bus, yellow areas show that more time is spent in the bus after the implementation. The time spent in the bus should get lower when a part of the bus trip is substituted to a metro trip. This means that no yellow areas should appear in a model, as it is not logical. Figure 14 shows multiple yellow areas. This means the model needs a revision during the research.

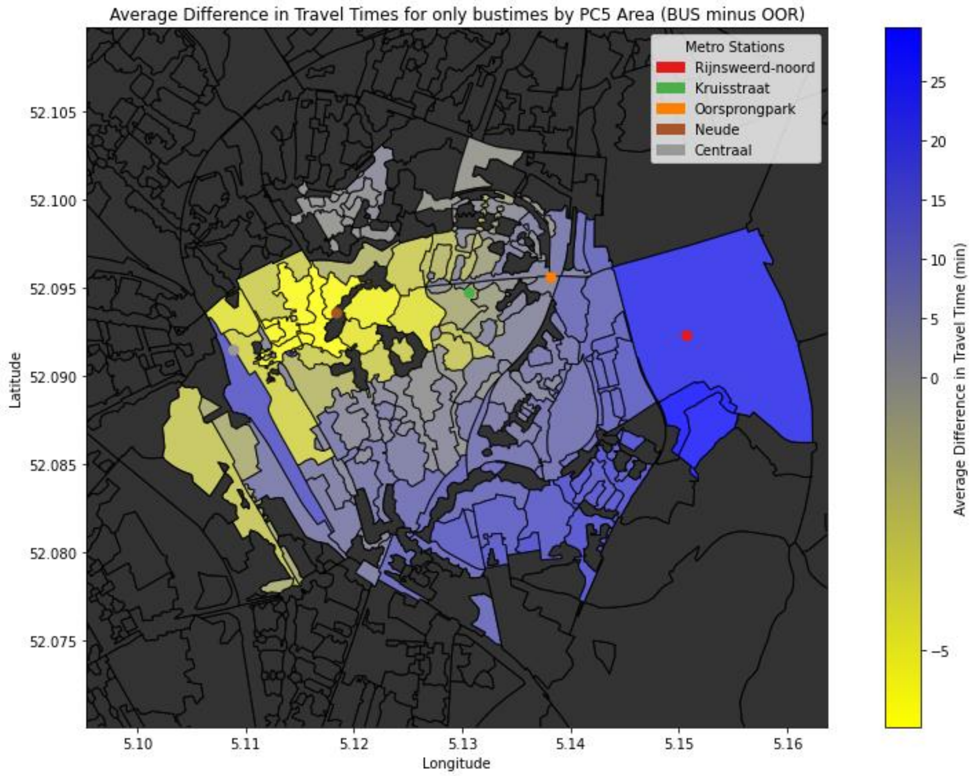

Figure 39, in-vehicle bus times

After a revision during the research, the interpretation of the data was changed. This was that the outgoing trips and incoming trips from Utrecht where both used and considered for the average times. This created non-valid results. After removing the outgoing trips, figure 15 was plotted. Here, no yellow areas are shown, which means a valid result on this part.

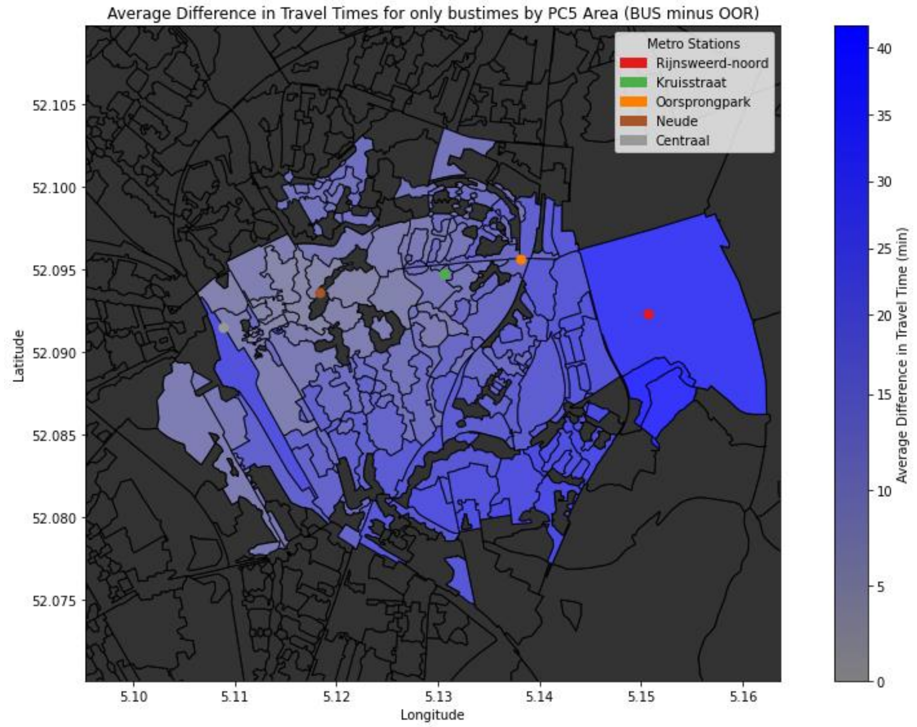

Figure 40, in-vehicle bus times after revision

3.6.2 Egress times

The egress times from the different egress stations should not differ too much. As there are only two less stations in the new scenarios, the differences should not exceed 10 minutes. This plot shows the shortest egress times from the bus stations subtracted by the shortest egress times from the LRT stations.

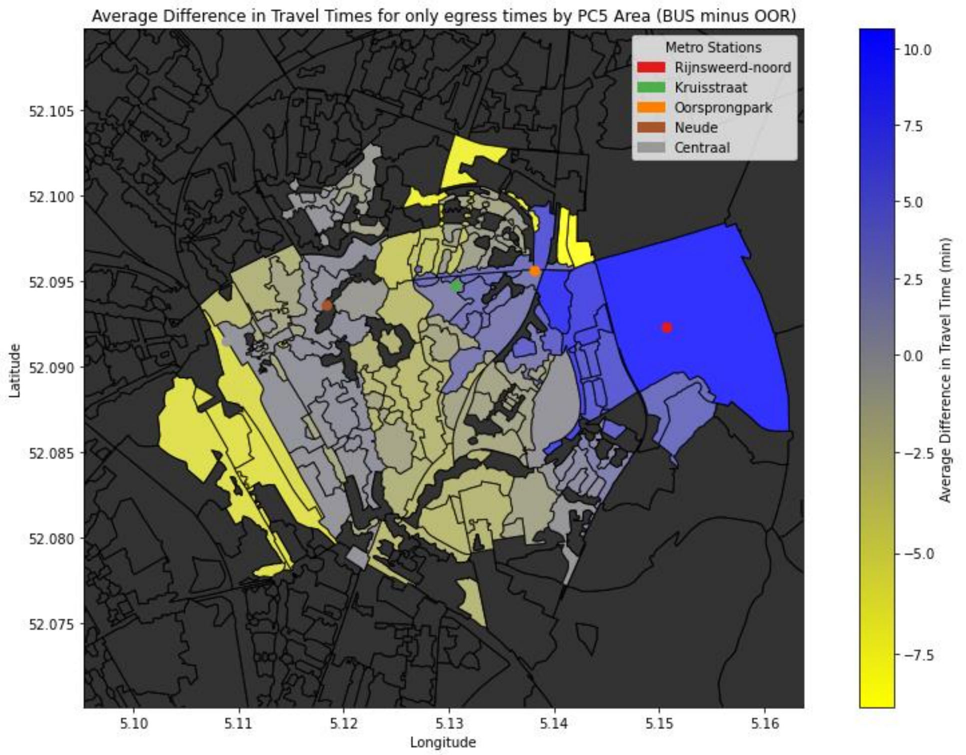

Figure 41, egress times comparison

Figure 16 shows the difference between before and after implementation, where blue stands for a faster egress time after implementation and yellow for a faster egress time before implementation. The areas differ in terms of which situation is more ideal in terms of egress times, but there is no large difference. Only areas far from the Binnenstadsas show a large difference, especially the area in the east. However, that can be explained by that some bus lines do not pass that region, thus have a higher egress time to that region. That means that the egress time of the model is visually valid.

4. Results

In this chapter the results of the model will be explained. This is divided in multiple sections to show the different scenarios, where the current and possible future situation will be analysed. The situation after implementation of the metro line will have 2 possible scenarios, namely with Rijnsweerd-Noord and Oorsprongpark as transfer station. All the scenarios are broadly explained in chapter 3.2.

4.1 Current situation analysis

The current situation of the public transport using the Binnenstadsas only uses bus trips as public transport mode to reach the destination of the trip. The results of the travel time analysis are plotted in figure 17. The red lines show the Binnenstadsas, between four of the potential metro stations. Included in this trip are the bus trip from the first station on the bus route, and the egress time to the centre of the PC5 area of Eastern Utrecht city.

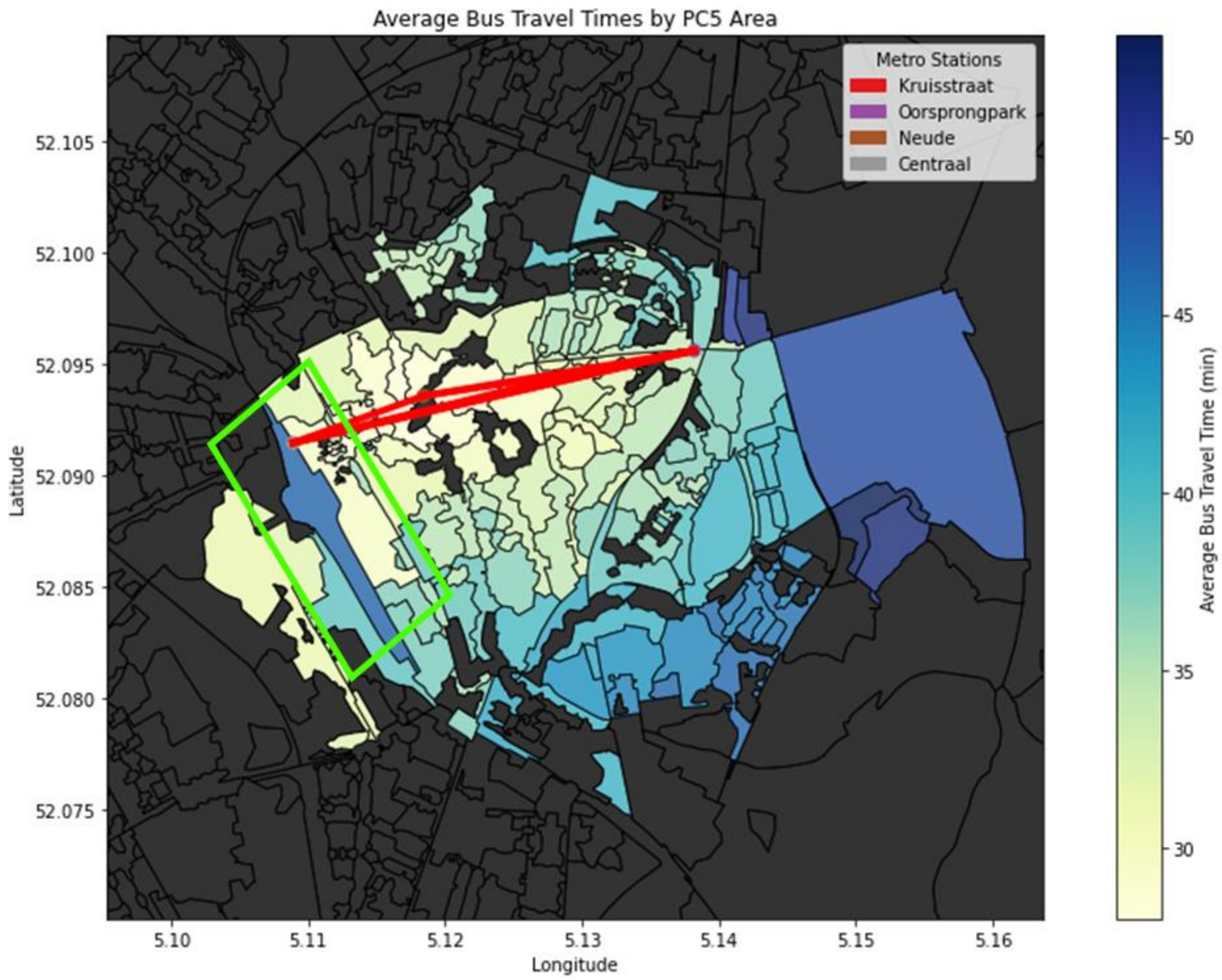

Figure 42, Travel times current scenario

The plot shows the lighter areas as areas that are faster to reach, and the bluer the area is shows the area takes more time to reach. According to this plot, the areas close to the Binnenstadsas are easier to reach. The areas further from the bus stations take more time to reach. Within the Binnenstadsas are some subtle colour differences; it seems that the centre part of the Binnenstadsas, around Neude, has the lowest average travel times.

The area surrounded by the green rectangle is the Utrecht Central Station area. This area gives a large variation in travel times between adjacent PC5 areas.

4.2 Situation after implementation

The situation after implementation is modelled using the difference in total travel time of the complete trip between the current situation and the situation where part of the bus route is changed to an LRT. This new situation includes the parts of the trip: bus time to transfer station, transfer time, waiting time, in-vehicle metro time, extra egress time due to the station to exit the (underground)-station and egress time to the centre of the PC5 areas. The two transfer stations used are Oorsprongpark (OOR) and Rijnsweerd-Noord (RIJ). They will both be analysed with the current situation and with each other.

4.2.1 Comparison between current and possible future situations

Figures 18 & 19 show the differences between the current situation and the new situation, with on the left side the comparison for actual travel time using Rijnsweerd-Noord as transfer station and on the right side using Oorsprongpark as transfer station. The total travel time in the current scenario is subtracted by the total travel in the new scenarios. The more yellow the areas, the better the current situation is in terms of total travel time and the more blue the better the new situation is in terms of travel time. Both of the plots show a majority of yellow areas meaning the current situation has a lower average total trip time than the situation including a LRT part of the trip. Only in the area including Rijnsweerd-Noord, where Rijnsweerd-Noord is the transfer station, the new situation creates a faster total travel time.

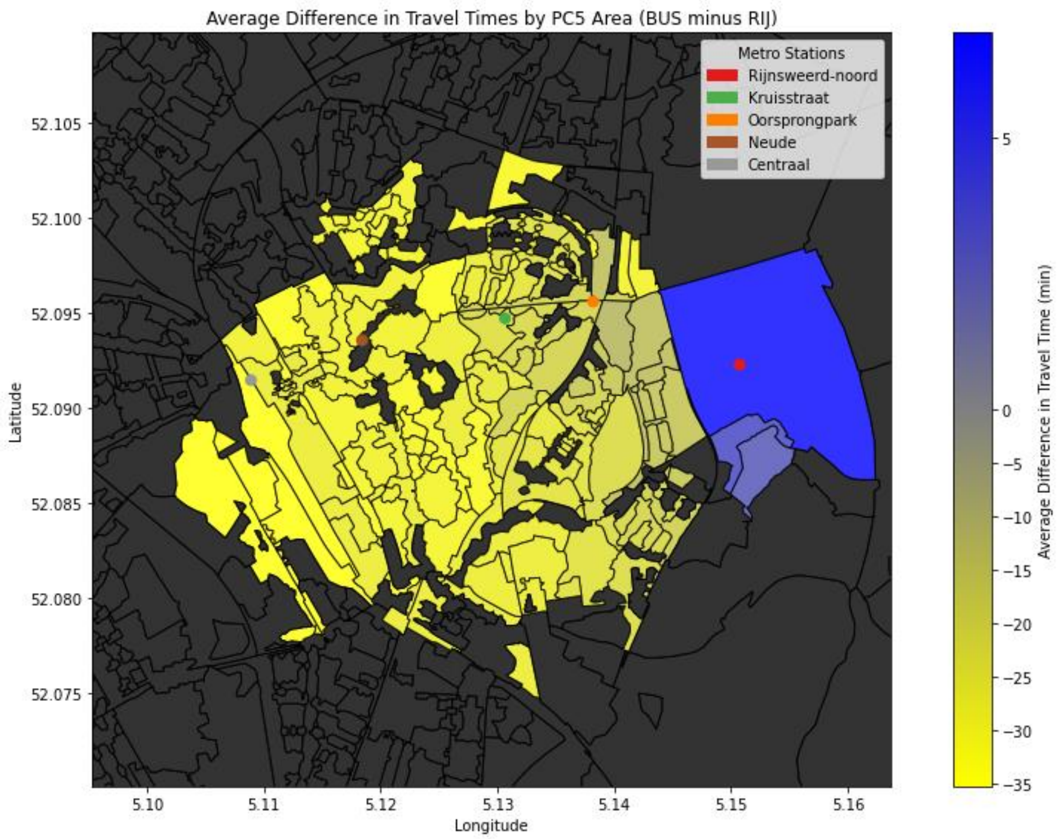

Figure 43, Travel times comparison current and Rijnsweerd-Noord scenario

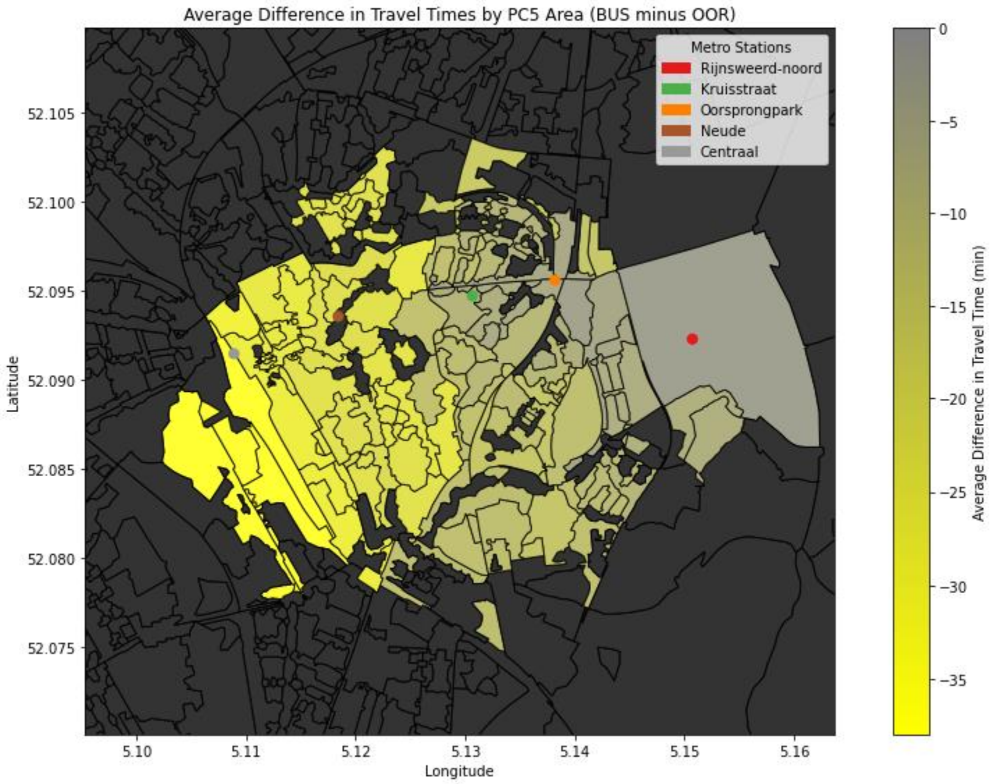

Figure 44, Travel time comparison current and Oorsprongpark scenario

Both before and after the implementation, the scenarios have positives and negatives. These are shown in table 6. This table shows the differences in time between bus and LRT on this section, where the new scenario travel times are subtracted by the current scenario times. The LRT is quicker at the section, however it has the delays of the exit times of the underground end stations and the transfer time. Also, because of the less stops, the egress time is more likely to be higher as the stops will be further from the end destination.

Table 6, Characteristics comparison scenarios

Characteristics time bus		Characteristics time LRT	
In-vehicle time Centraal to Rijnsweerd-Noord	12 minutes	In-vehicle time Centraal to Rijnsweerd-Noord	6.4 minutes
Exit time at end-station	0 minutes	Exit time at end-station	2-4 minutes
Transfer time	No transfer	Transfer time	3-5 minutes
Stops between Centraal and Rijnsweerd-Noord	5 stops	Stops between Centraal and Rijnsweerd-Noord	3 stops

4.2.2 Comparison between possible future situations

The comparison between the implementations of using Oorsprongpark and Rijnsweerd-Noord as transfer stations shows which station is better in terms of total travel time. The total travel time in the scenario with Rijnsweerd-Noord as transfer station is subtracted by the total travel in the scenarios with Oorsprongpark as transfer station. The difference between these stations lays in the rerouting of the bus routes leading to the transfer station and the in-vehicle LRT time from Rijnsweerd-Noord to Oorsprongpark.

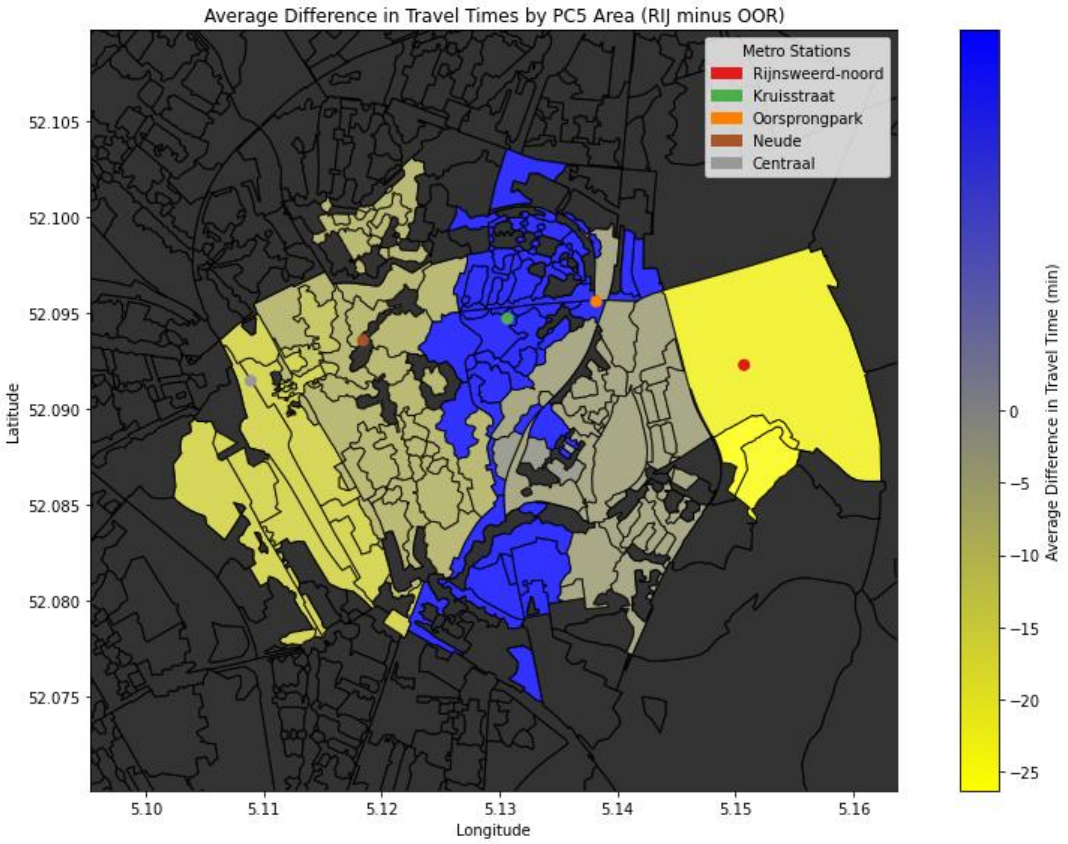

Figure 45, Comparison actual travel time future scenarios

Figure 20 shows the plot of the difference in total travel time between the two different transfer stations. The Oorsprongpark scenario travel times are subtracted from the Rijnsweerd-Noord scenario times. The blue areas show that the Oorsprongpark-scenario has a lower total travel time, and the yellow areas show that the Rijnsweerd-Noord-scenario has a lower total travel time. The majority of the areas in this plot is shown yellow, which indicates that Rijnsweerd-Noord as a transfer station leads to faster total travel time to those areas. The blue areas in the centre of the plot show that Oorsprongpark as a transfer station is better for those areas in terms of total travel time with a maximal difference of 1.2 minutes faster. Those areas only exist in a vertical column in the plot surrounding the stations Kruisstraat and Oorsprongpark. It is expected that closer to Utrecht Centraal the area will be more yellow as the LRT trip gets longer and will benefit more from the LRT being faster than the bus. The yellow areas in the east will most likely be caused by Rijnsweerd-Noord not being an exit station in the Oorsprongpark model.

4.3 Perceived situations

The actual travel time is only part of the complete analysis. The perception of the travellers can also play a role in the implementation of the LRT. The changes compared to the actual times are factors used for the different parts of the trip, meaning that the transfer time, egress time and the station egress time will have factors to the time to calculate the perceived travel time. There is also a constant transfer penalty time for when a transfer occurs during the trip. Every one of these parameters is explained in chapter 3.4.

4.3.1 Comparison between current and possible future situations

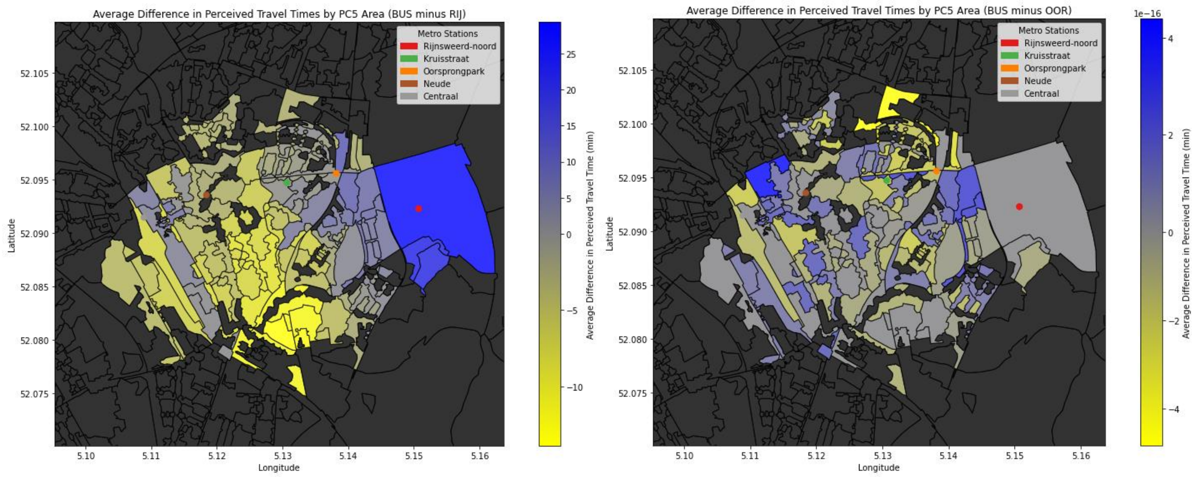

Figure 46, Perception comparison future scenarios with current scenario

Figure 21 shows the plots of the differences between the current and possible future situations. The total perceived travel time in the current scenario is subtracted by the total perceived travel in the new scenarios. The left plot is the current situation compared to a situation where Rijnsweerd-Noord is used as transfer station and the right plot has Oorsprongpark as transfer station. In both plots the blue colour stands for the new situation being perceived better, and the yellow colour stands for the old situation being perceived better. Both plots show a variety of perceptions in the areas. The area including Rijnsweerd-Noord prefers the new situation the most in the situation where Rijnsweerd-Noord is used as transfer station. Whereas the more western areas in that situation prefer the current situation more. As for the situation where Oorsprongpark is used as a transfer station, the plot seems to be more spread in terms of average perception of travel time.

4.3.2 Comparison between possible future situations

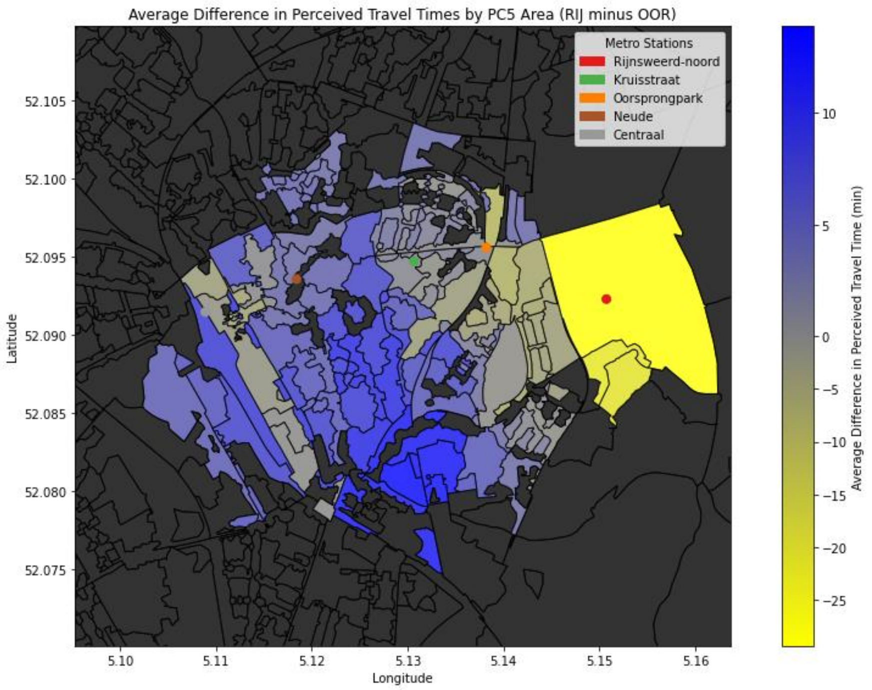

Figure 47, perception comparison future scenarios

Figure 22 shows the plot of the difference in total travel time between the two different transfer stations. The total travel time in the scenario with Rijnsweerd-Noord as transfer station is subtracted by the total travel in the scenarios with Oorsprongpark as transfer station. The blue areas show that the Oorsprongpark-scenario has a lower perceived total travel time, and the yellow areas show that the Rijnsweerd-Noord-scenario has a lower perceived total travel time. Again, the area including Rijnsweerd-Noord has a positive perception of travel time in comparison. The further to the west, the more the perception is in favour of using Oorsprongpark as transfer station. The most southern areas that are considered have the most positive perception of Oorsprongpark as transfer station.

4.4 Frequency estimation

The frequency of the LRT is estimated by two different approaches: the peak point approach and the costs optimization method. The results of these methods are shown in table 7.

Table 7, Frequency optimalisation results

Peak Point approach	Costs optimization method
28 per direction per hour	30 per direction per hour

These results show high frequencies as estimations of the optimal frequency. This is caused by the high demand predicted for the future by the municipality. However, the maximum designed frequency is 24 vehicles per direction per hour because of safety. This means this 24 vehicles per direction per hour will the frequency used.

With this frequency, the capacity per hour is lower than the optimal in the approaches. The capacity with a frequency of 24 pdph is 13000. This means the occupancy rate for the vehicles in peak hours is 87.5%. This means the vehicles will be packed, however there is enough place for the estimated demand.

5. Conclusion and recommendations

Within this chapter, the research questions will be answered by using the results explained in the previous chapters. Each research question will be explained separately. Lastly the main research question will be answered based on all the sub questions. Every research question also has a specific limitations alinea, to explain limitations of that part of the model results more accurately. Finally, these limitations will be summarized. Also, these limitations will be used to write academic recommendations for further research. Additionally, recommendations for how to use this report are addressed.

The buses routes using the Binnenstadsas are considered in this research. A part of their total bus route might be changed to an LRT, which has large effects on the travel time. To compare the new scenarios to the current one, the current scenario needs to be analysed. Afterwards, two approaches are used to determine the optimal frequency of the LRT. Then the new scenarios are compared to the current scenario to show the differences. All the scenarios used for the comparisons are shown in chapter 3.2. This is done by using the actual travel time and the perceived travel time. This way the total effects of the intervention of an LRT can be analysed.

5.1 What is the current door-to-door travel time on the bus routes that use the Binnenstadsas?

The current travel time for passengers that use buses from the eastern areas around Utrecht City that use the Binnenstadsas is modelled and plotted in figure 23. This was modelled by finding the shortest egress time exit bus station of the bus route per destination area, and then finding the in-vehicle and egress times to calculate the total travel time. The average times differ per area between approximately 30 and 60 minutes. The closer to the Binnenstadsas, the quicker the areas can be reached as the bus stations are closer to those areas so the egress time is less than for the areas further from the Binnenstadsas.

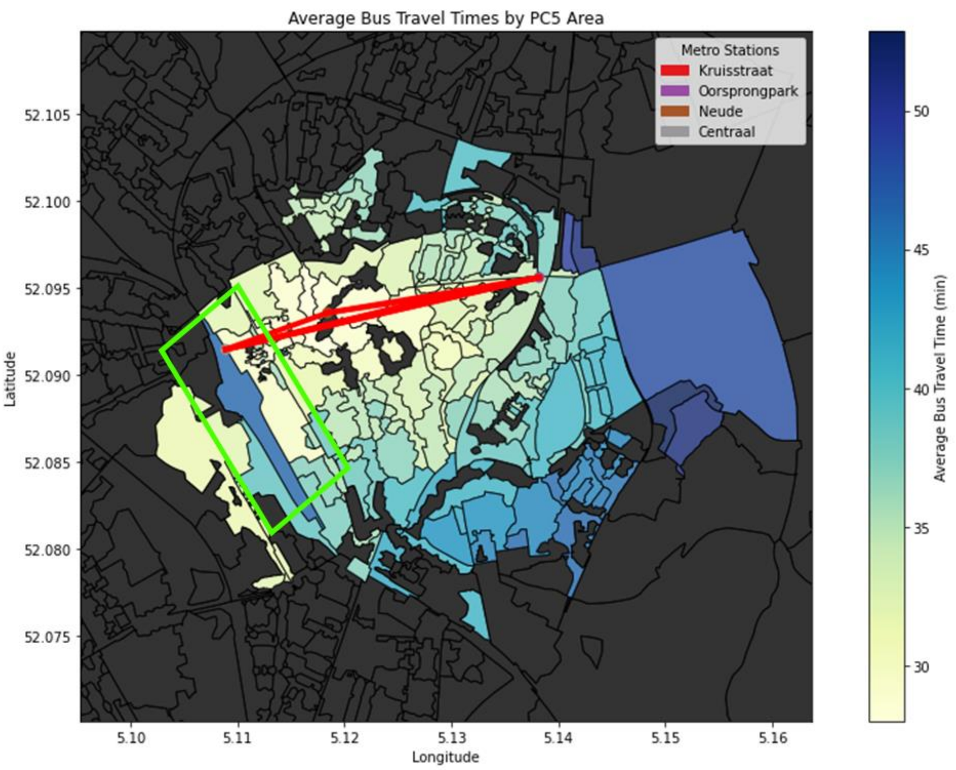

Figure 48, Analysis travel times current situation

These results are biased for the western regions, as bus route 55 joins the Binnenstadsas at the centre of the Binnenstadsas as shown earlier in chapter 3.5.3. This creates high egress time to the areas in the east. This is because no transfers are allowed in this scenario. For more accurate travel times, bus-to-bus transfers can give lower total travel times to the eastern regions. The green rectangle, Utrecht Centraal, has high variations. This is probably caused by the OSMnx network not being correct around the large station. This causes a high difficulty of reaching the centre point of that area, thus a larger egress time.

5.2 What is the timetable where the total travel times for all passengers and general costs of travel are minimized?

The optimal timetable is made based on the optimal frequency of departures of the LRT. Thus, first the sub-sub research question about the optimal frequency will be explained, followed by the timetable conclusion.

5.2.1 What is the optimal frequency of departures of the LRT for minimizing total costs?

The optimal frequency of the LRT is estimated by the use of two methods: peak-point approach and cost-optimization method. Respectively, 28 and 30 vehicles per hour per direction were the optimal results. This high number is caused by the extremely high expected demand the municipality of Utrecht estimated. However, for this specific case the design limit of the infrastructure is reached. This limit is 24 vehicles per hour per direction due to safety reasons. This is why this number will be and was used in this report.

As making variations in a timetable with these frequencies has little significant effects, the timetable optimalisation seemed optimalisation does not provide any added value to the outcome of the analysis.

5.3 How does changing part of a current bus route to an LRT effect the actual travel time to areas in East-Utrecht?

The new scenarios are modelled in multiple stages, as the trip includes many parts. The trip includes a bus trip, transfer, LRT trip and an egress walking trip. The current bus lines are rerouted to a transfer station, Rijnsweerd-Noord or Oorsprongpark, and from there the trip will continue by LRT. The model first finds the shortest egress trip, with the corresponding LRT station. Then the trip time of the LRT is calculated. Also, the travel time of the bus trip to the transfer station is calculated. These times, including transfer time are added up to calculate the total travel time per destination area. This total travel time is compared to the current scenario by subtracting the total travel time of the new scenario from the current scenario.

The differences in actual travel time are plotted in figure 24. Within these plots it is visible that the actual travel time increases by 10 to 35 minutes depending on transfer station used and destination area. This might be caused by the transfer time, and extra egress time for exiting the underground stations. Also, the metro does not appear to be faster than the bus, making up the loss of time. It even seems to increase during the travel to the west, which might make sense, due to the relatively long stop time of the LRT, 30 sec, compared to the planning of the buses that sometimes only have a minute between stops, including stopping. The only blue area can be explained by that 2 bus routes do not travel further east than Kruisstraat, thus the travel time to eastern regions from those bus routes is relatively high. When Rijnsweerd-Noord is the transfer station, the buses are rerouted there making that situation favourable looking at actual travel times.

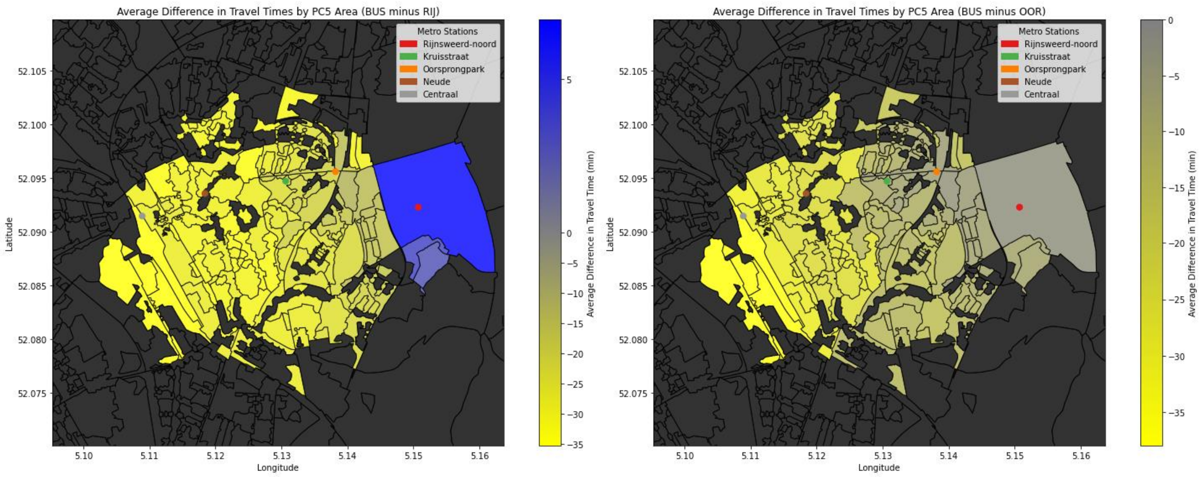

Figure 49, Comparison travel time future scenarios with current scenario

This result is again influenced by the same limitations as given in chapter 5.1. The eastern regions do not favour the bus, as line 55 is not close to the eastern areas. When comparing the bus routes to the LRT, it is also visible that there are more bus routes, also shown in chapter 3.5.3 that do not pass all the areas the LRT passes.

Also, in this comparison only trips that need the transfer are compared. However, when the trip does not need to go further than the transfer station, the differences in travel time should be more in favour of the LRT, as the transfer takes up lots of time. This research only analyses the worst case for the travelers, as that has the most negative effect.

5.4 How is every part of a public transport trip perceived and what are the effects in the perceived travel time assessment of the LRT?

The perception of the trip is modelled and analysed and compared to perception of the current situation. The factors are based on literature, and the actual travel times to accommodate the factors are previously calculated. The perception actually has quite a large effect on the most favourable situation. As most areas require a long egress time in the current situation, the new situation becomes equal or even more favourable than the current situation in some areas. Especially the situation where Oorsprongpark is used as transfer station, the perception of travel time for most areas becomes in favour of the new situation. Thus, looking at perception of total travel time, the implementation is successful for some areas.

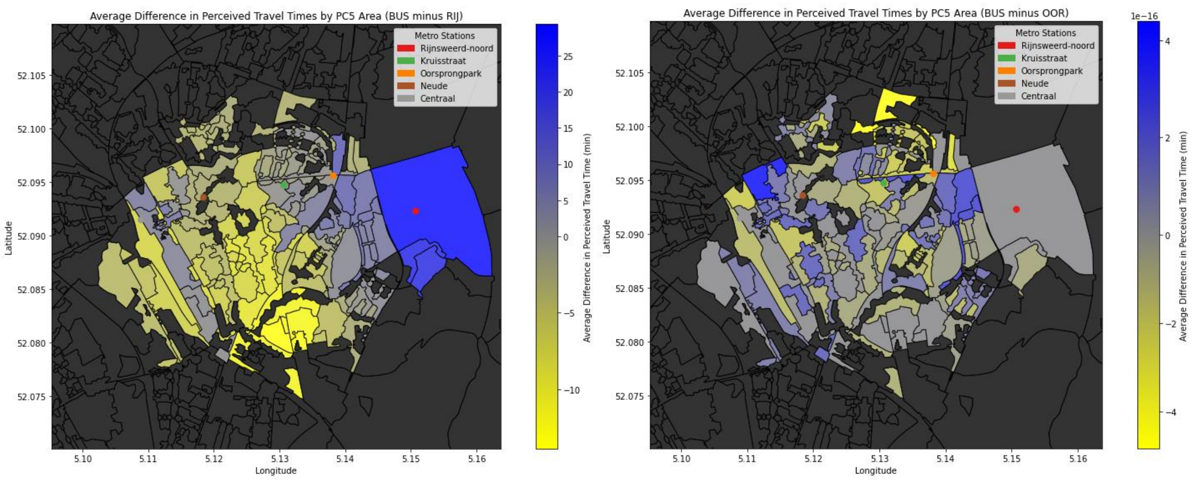

Figure 50, comparison perceived travel time future with current scenario

The perception maps are hugely influenced by the egress time, the egress time has a perception factur of 1.7, which is high compared to the allready high egress times for most areas. This creates the effect of the locations of the stations being an important aspect of these maps, as the location of the stations has a large effect on the egress times.

5.5 How does changing part of a current bus route to an LRT affect the absolute and perceived travel time on the Binnenstadsas in Utrecht?

The total effects of changing part of a bus route for an LRT route has multiple effects. Firstly, the actual total door-to-door travel time increases with more than 15 minutes, while the perception of the travel time seemed to have no significant effect, especially for areas that have a larger egress time.

5.6 Limitations summary

The model seemed to give results that seemed logical. However, some assumptions seemed to have a large effect on the results, which can still be improved to make the model more accurate.

Firstly, the effect of the assumption of the options for egress stations in the new situations is a limitation. As the model only uses metro stations as egress stations, the eastern regions gave inaccurate results. This was amplified by the effect that only in the Rijnsweerd-Noord as transfer station situation, the Rijnsweerd-Noord station was available as egress station. This gave this situation in comparison a large advantage compared to the current situation and scenario considering Oorsprongpark as transfer station.

The bus routes not passing through the same areas as the LRT gives questionable results especially for the areas in the east. The bus stations are located far from the eastern areas and create large egress times to these areas.

Also, the optimal frequency estimation is too high to be realistic. Not even in large cities, frequencies of this level are reached, thus in Utrecht this will be even more expensive and thus unrealistic.

The perception was expected to be more in favour of the current situation as most people perceive a transfer as negative. However, the perception of egress time took the overhand in the model, which needs a bit more calibration with questionnaire. This way, the factors can be calibrated to this exact situation, not the general perception of LRT which is more large scale in most research than applied in Utrecht.

5.7 Recommendations

This research has flaws and needs further research to predict the outcomes of the intervention more accurately. This chapter explains multiple changes that can positively effect the outcomes of the research.

The model can be improved by adding some parameters, with the first being the travel demand. The accurate travel demand can give a realistic frequency. Also, the travel demand gives trips not only starting at the begin station, but also at other stations. As there are probably many trips that only use the LRT after implementation, this would give more accurate results that are more in favour of the LRT system because without the transfer, the LRT is faster. In this research this was not used as there was no data available for this.

A second parameter to be added is the transfers in the current situation. This gives lower total travel times for the current situation, especially with more eastern end destinations. This can give a better representation of the comparison between the scenarios.

Something else that can be improved in the model is whether bus line 55 actually should be rerouted to the transfer station, or whether it is faster to reroute it to Utrecht Centraal. As it takes a large detour going to the east first, and then going to the west by LRT. This means that for this bus line, alternative options should be considered when this intervention takes place.

5.8 Policy implementations

As this report is a case study, the results of this research can be used for taking a decision in solving the problem on the Binnenstadsas. How can policymakers interpret this research and how should they use this?

5.8.1 Should this solution be implemented?

As the results show, the LRT might be faster, however it is not faster when looking at the total travel times. There is also for perceived travel time no clear improvement. However, this modelled situation is the most negative one, when people need to travel from Utrecht Centraal to an area in Utrecht East, while only using the LRT this will most likely be much faster as they will not use a transfer or rerouting from the bus routes. Also, the transport capacity of the Binnenstadsas will increase, which is good for future growth of the city, it can even offer enough capacity for the immense growth expected by the municipality. Thus, taking into account the multiple factors, the implementation will be useful. This research has shown that for the most negatively influenced travellers, the impact is acceptable.

5.8.2 Which transfer station should be used when implementing the LRT?

The transfer stations considered in this research are Rijnsweerd-Noord and Oorsprongpark. When looking at the comparisons between the stations, Oorsprongpark is much slower in terms of actual travel time, but much quicker in terms of perceived travel time. This means that people will accept the implementation of Oorsprongpark as transfer station more, while it may not be quicker for people. As there are many other factors that need to be considered while deciding between the transfer station, the results from this research do not have a significant preference for one the stations as both have their better characteristics according to this research.

6. Appendices

6.1 Appendix I - frequency optimisation methods

The parameters used for the peak point approach can be seen in table 8.

Table 8, parameters Peak Point approach

Parameter	Value
θ, Ratio of passenger load in most loaded route section	0.85
σ, maximimum occupancy rate parameter	0.7
K, capacity of vehicle	550, capacity of a linked metro
Q, demand	Peak hour, peak of normal distribution of 65000. As there are 2 peak hours a day, a total volume of 65000/2 is used meaning a peak hour with 11375 pax/h

The parameters used for the cost optimisation method can be seen in table 9.

Table 9, parameters Costs Optimization method

Parameter	Value	Source
A	**Number of hours in a year:** 16 hours a day * 365 = 5840 hours **Roll stock:** 3.5mln $/veh 30 year life span of vehicle 30 vehicles at all times **Operating cost:** 1.83 $/km 5 km 25 vehicles active **Maintenance:** 1078 $/h **Infrastructure:** Underground: 90mln/km Above ground: 7.5mln/km 2.5 km underground 2.5 km above ground 250mln total	Mott MacDonald
B	5% of roll stock	
r	7%	
n	50 years	Mott MacDonald, infrastructure life span
q	As there are two peaks in demand during the day, the day will be split in two. Normal, lognormal and gamma distribution are good probability functions for inter-day variability of traffic flow at a given time of day (Mikolášek, 2022). Thus normal distribution is used to estimate the peak hour demand = 11375 pax/h	(Mikolášek, 2022)

P_w	1.7 times the in-vehicle time	(Abrantes & Wardman, 2011)
P_v	10 eu/h	
u	0.8	
R	60/10 minutes 35 seconds=0.177 hours	

6.2 Appendix II – Model Schematization

Figure 26 shows the schematization of the model larger than shown in the report.

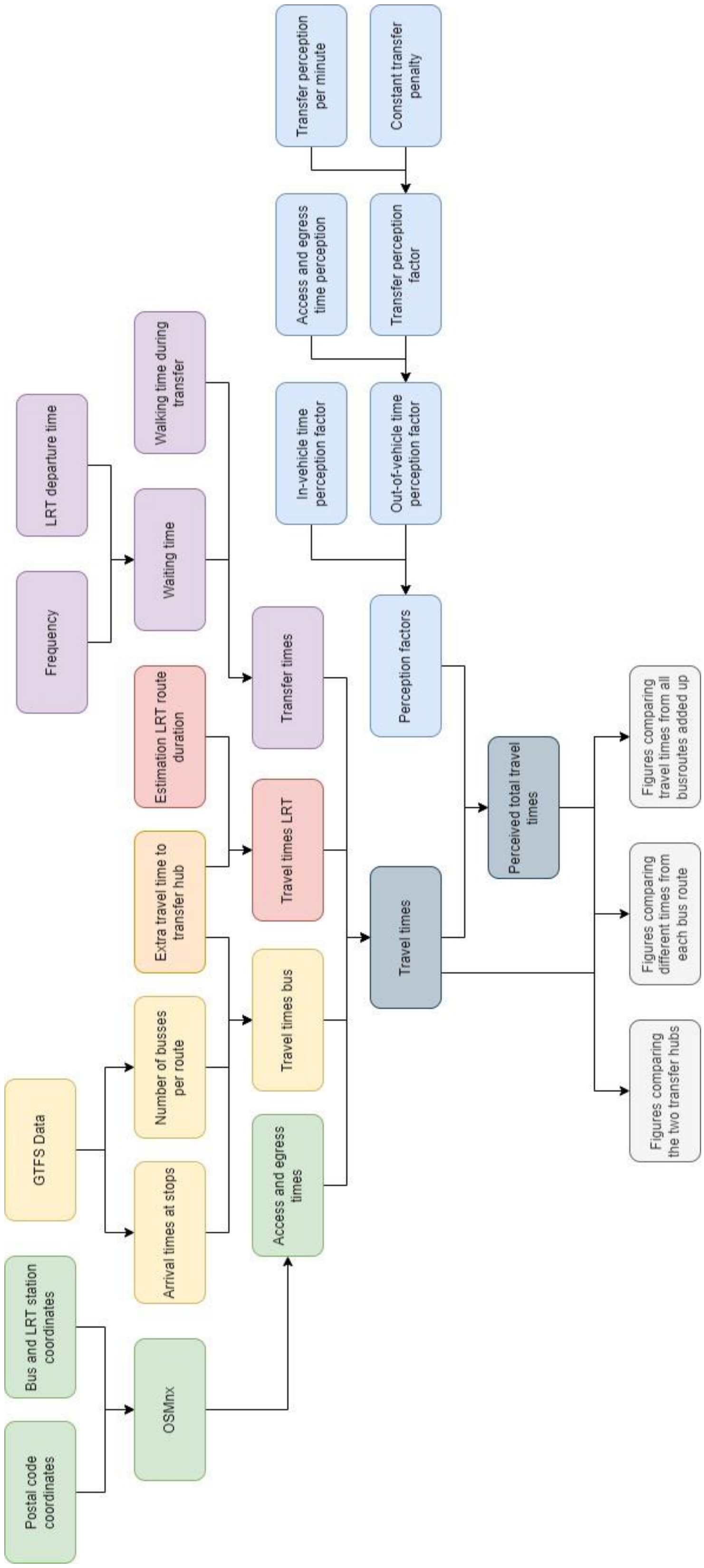

Figure 26, larger version of model schematization

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