THE OPTIMAL WATERLINIE TRAM ROUTE IN UTRECHT

Viewed from an accessibility perspective

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Preface

This is the report of my Bachelor Thesis as concluding part of the program Civil Engineering at the University of Twente. In this thesis *"The optimal Waterlinie tram route in Utrecht. Viewed from an accessibility perspective"*, possible alternative tram routes for the Waterlinie tram line have been assessed on the basis of accessibility. I have learned a lot during the period I worked on the thesis, especially regarding using ArcGIS and the writing of the report in front of you.

A special thank you goes to Rutger Meester and Jan Engels of Mott MacDonald and Baran Ulak of the University of Twente for their feedback, patience and the insights they provided me with. Additionally I would like to thank Martijn Donders from Mott MacDonald for sharing his expertise and guidance at the start of the project and Maike Brokken of the Province of Utrecht for providing the information I needed.

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Summary

The population of the municipality of Utrecht is expected to grow from 359.000 in 2021 to 478.000 inhabitants in 2040. This will result in increased traffic numbers and potentially congest the already stressed transport system. Part of the corresponding travel increase can be solved by adding an extra tram line (the Waterlinie line) to the current tram network that runs between Nieuwegein and IJsselstein in the South of Utrecht, via Utrecht Central Station, to Utrecht Science Park in the East. The new tram line aims to relieve pressure from Utrecht Central Station and increase accessibility both on a local and regional level. The objective for this report is to analyse the optimal tram route and tram stop locations, as well as the effects on accessibility in Utrecht when adding this new Waterlinie tram line.

Initially, various alternatives are proposed, which are then narrowed down to two alternatives via a multi criteria analysis. The number of tram stops for these alternatives are derived from the supply and demand of inhabitants and jobs in the vicinity among other requirements. This resulted in alternatives are via the ‘t Goylaan with 4 tram stops, via the A12/A27 with two stops and via the A12/A27 without tram stops. The accessibility of the three alternatives is compared with the current situation in ArcGIS. Accessibility is calculated as the zonal potential accessibility, as well as the location-based potential accessibility with competition effects.

The job accessibility within the three alternatives is compared with the current situation using a spatial multi-modal transport network in ArcGIS. Accessibility is calculated as the zonal potential accessibility, as well as the location-based potential accessibility with competition effects from other inhabitants. The results of this comparison has not clearly led to an overall best. Each of these three alternatives have their own advantages and disadvantages. The ‘t Goylaan alternative is most suitable for adding local public transport travel possibilities. The A12/A27 alternative without tram stops option is best suited for improving rapid public transport between Nieuwegein/IJsselstein and Science Park. The A12/A27 alternative with two stops combines both advantages, although limited compared to the other two alternatives.

A number of limitations have been identified within this research, as several input data was incomplete. The conducted research can be applicable for policy makers at the Province of Utrecht and used as a base for further Waterlinie tram line analysis. For practical application, economic aspects should also be evaluated in future studies regarding the Waterlinie line. As a general conclusion, the ‘t Goylaan option is best suited for up to 30 minute commutes and the A12/A27 options are better suited for longer (30 to 60 minute) commutes.

Keywords: location-based potential accessibility, Public transport, Waterlinie tram line, Zonal potential accessibility, Municipality of Utrecht, Tram.

Samenvatting [NL]

De bevolking van de gemeente Utrecht zal naar verwachting groeien van 359.000 inwoners in 2021 tot 478.000 inwoners in 2040. Dit zal leiden tot een toename van het verkeer en mogelijk tot overbelasting van het toch al overbelaste transportsysteem. Een deel van de bijbehorende verkeerstoename kan worden opgelost door een extra tramlijn (de Waterlinielijn) toe te voegen aan het huidige tramnet dat rijdt tussen Nieuwegein en IJsselstein in het zuiden van Utrecht, via Utrecht Centraal, naar Utrecht Science Park in het oosten. Het doel van de nieuwe tramlijn is het ontlasten van Utrecht Centraal en het vergroten van de bereikbaarheid op zowel lokaal als regionaal niveau. Het doel van dit rapport is om de optimale tramroute en tramhalte locaties te bepalen, evenals de effecten op de bereikbaarheid in Utrecht bij het toevoegen van deze nieuwe Waterlinie tramlijn.

In eerste instantie worden verschillende alternatieven voorgesteld, die vervolgens via een multicriteria-analyse worden teruggebracht tot twee alternatieven. Het aantal tramhaltes voor deze alternatieven is afgeleid van onder andere het aantal inwoners en arbeidsplaatsen in de omgeving van de tramlijn. Dit resulteerde in de volgende alternatieven: via de 't Goylaan met 4 tramhaltes, via de A12/A27 met twee haltes en via de A12/A27 zonder tramhaltes. De bereikbaarheid van de drie alternatieven is vergeleken met de huidige situatie in ArcGIS. De bereikbaarheid wordt berekend als de zonale potentiële bereikbaarheid en de locatiegebaseerde potentiële bereikbaarheid met concurrentie-effecten.

De bereikbaarheid van banen binnen de drie scenario's wordt vergeleken met de huidige situatie met behulp van een ruimtelijk multimodaal transportnetwerk in ArcGIS. De bereikbaarheid wordt berekend als de zonale potentiële bereikbaarheid en de locatiegebaseerde potentiële bereikbaarheid met concurrentie-effecten van andere inwoners. De resultaten van deze vergelijking hebben niet duidelijk geleid tot een algehele beste. Elk van deze drie alternatieven heeft zijn eigen voor- en nadelen. Het scenario 't Goylaan is het meest geschikt voor het toevoegen van lokale OV-reismogelijkheden. Het A12/A27-scenario zonder tramhaltes is het meest geschikt voor het verbeteren van snel openbaar vervoer tussen Nieuwegein/IJsselstein en het Science Park. Het A12/A27-scenario met twee haltes combineert beide voordelen, hoewel beperkt in vergelijking met de andere twee scenario's.

Er zijn een aantal beperkingen geïdentificeerd binnen dit onderzoek, aangezien verschillende invoergegevens onvolledig waren. Het uitgevoerde onderzoek kan van toepassing zijn voor beleidsmakers bij de Provincie Utrecht en gebruikt worden als basis voor verdere Waterlinie tramlijn analyse. Voor praktische toepassing moeten economische aspecten ook worden geëvalueerd. Een algemene conclusie is dat de optie 't Goylaan het meest geschikt is voor woon-werkverkeer tot 30 minuten en dat de opties A12/A27 beter geschikt zijn voor langer woon-werkverkeer (30 tot 60 minuten).

Contents

1 Introduction

1.1 Background

The municipality of Utrecht is growing rapidly. It is expected that the city will grow from 359.000 inhabitants in 2021 to over 474.000 in 2040 (U-Ned, 2021). This population growth is the biggest of the four biggest cities in the Netherlands and the expected number of inhabitants in 2040 is still increasing every year. Furthermore, this increase in inhabitants is an important factor for the expected increase of traffic movements of 35% by 2040 (U-Ned, 2021).

Making this increase in traffic movements possible, without congesting the city during large parts of the day, requires a boost in travel possibilities. Currently Utrecht Central Station is the largest and busiest station of the Netherlands. Passengers travelling between IJsselstein, or Nieuwegein, and Utrecht Science Park travel mainly via Utrecht Central Station, which is a detour and congests Utrecht Central Station.

1.1.1 Current public transport network Utrecht

The public transport network of Utrecht is based on three methods of transport: train, bus and tram. Each of them fulfils a distinct function. On the one hand trains mostly fulfil relatively long distance transport. Within the Netherlands, intercity trains are used for transport between cities and sprinters are for connecting both the smaller as well as the larger stations. Trains have a coarse transportation grid, but meanwhile they can transport a lot of people.

On the other hand, busses within the city of Utrecht mostly have a very local purpose: providing accessibility and connecting spots within and between neighbourhoods. Bus networks have generally a very fine transportation network, but can only transport a limited number of people.

Finally, trams can be seen as the in-between option of trains and busses: trams in Utrecht can carry from 221 (for the 5-part variant) up to 527 (a combination of the 5- and 7-part variants) people (CAF, 2023). At the same time, they have the advantage of connecting various parts of the city and a higher level of comfort than busses, because of often roomier interiors and more gentle (de)accelerating. One of the scenarios in which trams are used, is when busses do not provide enough capacity.

The current tram network is mainly focussed on connecting IJsselstein, Nieuwegein and Science Park to Utrecht Central Station, as can be seen in Figure 1 on the next page.

Figure 1: The current tram lines in Utrecht.

1.1.2 Public transport vision Utrecht 2040

The public transport vision of Utrecht for the year 2040 (Gemeente Utrecht, 2020) consists of both a high quality network to and from the city's Central Station (the spokes) as well as a wheel which connects the areas outside the city centre with each other without going via Utrecht Central Station such that it becomes more attractive to use the public transport system. This wheel will provide high quality transport possibilities as an alternative to traveling via Utrecht Central Station.

The public transport vision Utrecht 2040 focusses on increasing the public transport system to a next level in a way that it becomes more attractive to use the public transport system. The mobility plan Utrecht 2040 aims to increase the relative use of public transport from 13% in 2020 to 18% in 2040 (Gemeente Utrecht, 2020). To catch one part of the extra demand, the Waterlinie tram line is being considered between tram stop P+R Westraven and tram station Galgenwaard.

For the part between the tram stops P+R Westraven and Stadion Galgewaard various routes will be considered. The general map of the mobility vision can be found in Figure 2 on the next page. In this Figure, the purple lines represent the train lines. According to the vision of the municipality of Utrecht, every 10 minutes a train departs on every important train connection. Intercity trains will also stop at the stations of Leidsche Rijn, Overvecht and Lunetten. The blue, so called, wheel combined with the 'spokes' (the blue outward going lines/arrows) make sure people can easily access every part of the city from both within as well as outside of the city.

The value of building the Waterlinie tram line will be determined in terms of accessibility. To be more precise: how many jobs can inhabitants in the neighbouring areas reach within a certain amount of time. The objective of this report is to compare the possible future routes with each other and with the current situation of no extra tram lines. Other objectives are to check the feasibility of the new Waterlinie tram route in terms of optimal accessibility and to a lesser degree the technical feasibility. The reason for making this comparison is to give both the municipality as well as the province of

Utrecht insights into determining the best tram route. The reasons for choosing the best tram route are:

- To relieve Utrecht Central Station
- To integrate the tram line as efficiently as possible into the existing tram network
- To increase the public transport standard and make it an even better competitor compared to car traffic.
- To anticipate on increased population in the 2040 Public Transport Vision Utrecht
- To provide most value for tax payers money.

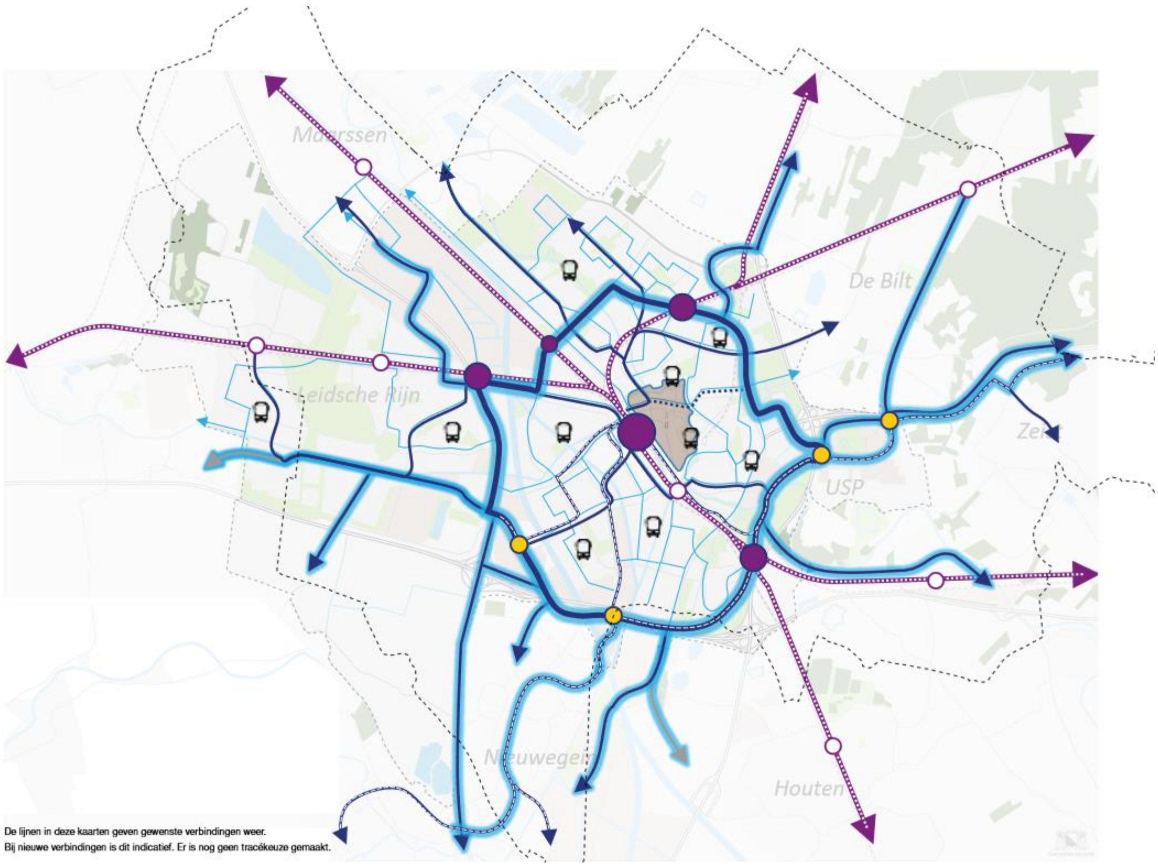

Figure 2: The possible tram routes according to the mobility vision 2040 of the municipality of Utrecht. (Gemeente Utrecht, 2020)

1.2 Problem and objective

1.2.1 Problem statement

The municipality of Utrecht is growing rapidly and is therefore looking for ways to accommodate the expected increase in traffic volume. One of the ways of making it possible to process more traffic is by increasing the public transport capacity. Within this report the focus is on building an extra tram line between P+R Westraven and connecting that tram line with the current Uithof tram line, North of train station Lunetten. There are plans to expand the train station of Lunetten to a more important intercity train station which will be called Koningsweg.

At the moment there is not enough information to determine the best route and tram stops. There are conflicting arguments to choose either a quick connection between Westraven and Science Park or a local connection serving the area of Lunetten. Among other aspects, it is not fully clear yet where the optimal tram stop locations will be and how the tram stops will technically fit in the environment.

1.2.2 Objective

The objective for this research is to find the best tram line between P+R Westraven and Lunetten train station, based on job accessibility: how many jobs can people access within certain time frames. For choosing the best tram line, several steps must be undertaken.

Firstly, the aim is to assess various routes between P+R Westraven and Lunetten train station. When these are drawn, for the most realistic routes the most suitable tram stops are determined based on nearby jobs, inhabitants and technical feasibility. The realistic routes, including stops, will then be compared based on accessibility: how many jobs can inhabitants reach within certain time frames.

1.3 Research approach

Based on the problems as formulated in section 1.2, in this section, the research framework will be explained. The research which will be conducted can be broken down into various questions supporting one main research question. The main question this research tries to answer is:

What is the optimal Waterlinie tram route between P+R Westraven and Stadion Galgenwaard, based on accessibility measures?

1.3.1 Sub-questions

To assist in answering the main research question some supportive questions are formulated first. The main research question will be answered using the concept of accessibility (see Section 2.2. for more information about accessibility).

First, more insight must be gained in what the accessibility is, and what determines it. This will provide better insight into what makes a good location for a tram stop. Based on this theoretical background information more practical questions can be answered later. The first sub-question is as follows,

What determines the accessibility and the suitability of tram stops and routes in general? (RQ1)

Now that there is a good understanding of what the accessibility and the suitability of tram stops defines, the possible routes of the tram line can be set. Determining the tram lines is needed before the tram stops of the new lines can be fixed. Therefore, the second sub-question is,

What are the most suitable routes for the future Waterlinie tram line, based on technical feasibility into the existing area? (RQ2)

After the most suitable routes have been made clear and it has been made clear where tram stops should be located, the additional practical issues of determining where tram stops should be located will be examined. The aspects of determining the location of a tram stop have been made clear in RQ1, but putting them in practise is up to the third research question. After this is done, we will look into more detail where the tram stops can be planned spatially.

What are the most optimal locations for tram stops along the potential routes in Utrecht? (RQ3)

After the tram stop locations have been determined, it is time to compare the possible routes amongst each other and each of them to the current situation (base scenario). Before this comparison can be made, the current situation must be assessed. After the current situation is assessed, the two other scenarios will be assessed individually. When the last research question is answered all information is available to answer the main research question.

What is the difference in public transport accessibility in Utrecht between the two possible tram routes and how do they relate to the base scenario? (RQ4)

2 Literature

The research consists of various parts. Each of these parts has their own theoretical background. In this chapter the relevant theoretical background of each of the parts will be analysed. First, literature regarding choosing tram stop locations will be considered. Lastly, literature on determining the accessibility will be discussed. In this chapter information will be presented to come to an answer to Research Question 1: "What determines the accessibility and the suitability of tram stops in general?".

2.1 Tram stop locations and tram routes

The number and locations of tram stops is often a balancing act of two factors: service area and travel time. On one hand, increasing the number of stops will increase the effective service area of the tram line. A service area is a surface area which is covered by, for this instance, the tram stops along a tram line, including a certain distance from the stops via a network. Increasing the effective service area helps increasing the number of users of the line and therefore makes the line more cost-effective.

On the other hand, increasing the number of stops has a downside as well: the travel time between the two ends of the line increases. Because this increase in travel time makes the tram less attractive compared to other modes of transport, the number of users could decrease and therefore the line will become less economically effective. (Murray, 2001)

As mentioned in the previous paragraphs, finding the best number of tram stops requires a balance. Traditionally, effective service area of rail stations is considered to be 800 meters (Alshalalfah & Shalaby, 2007) which is based on passenger behaviour in Toronto (Canada). It is shown that of the transit users 60% lives within 300 meters from their stop and 80% within 500 meters from their public transport stop.

It must be said that these research papers are based on US or Canadian research. In the Netherlands there is a different culture regarding acceptable walking distances and in the Netherlands it is considered normal to use a bicycle (Rietveld, 2000). More cycling in the Netherlands to tram stops, while walking shorter distances than in the US may cancel each other out, but it is not necessarily the case. According to Pritchard et al. (2019) a normal walking distance is considered to be 200 meters.

Apart from the distances to neighbouring homes and offices it is interesting to look beyond that. Cycling routes may also be a factor which could potentially increase the number of tram users (Pritchard et al., 2019). The potential added value in terms of accessibility of bike-and-ride compared to walk-and-ride is significant, i.e. 2 to 3 times more jobs can be reached within the same amount of time.

In contrast, bus ridership decreases when new docks for bicycles have been placed in New York by Citi Bike (a drop of 2.42% of bus users per 1000 docks) (Campbell & Brakewood, 2017). Research whether shared bicycles are a complement or a substitute to public transport has been inconclusive (Nawaro, 2021). Besides the increased accessibility it also reduces the inequality in accessibility to jobs. However Pritchard, Stępniak & Geurs (2019) make clear that the added value of bike-and-ride is greatest for large transport hubs and heavy rail infrastructure. When trams are used to get to greater transport hubs, such as rail stations, bicycles are a competitor to trams (Rietveld, 2000).

Next to the number of tram stops, the process of choosing the optimum route is crucial for increasing safety and efficiency and reducing costs (Ahmed Eng & Asmael, 2009). Regarding the land use when determining the location of the track, the following aspects are recommended (Albubaisi, 2014):

- It is better to possess the land that the transportation authority owns to save costs.
- Land with a higher population density ought to be made accessible.
- The tramway travels through both attracting as well as generating areas.
- The tram track route should be clear of tunnels and bridges if possible.
- The track need to be safe and as far away from inhabitants as is practical.

2.2 Accessibility

There are multiple ways of determining the accessibility. Each of the different methods of assessing accessibility is briefly explained. The difference between accessibility and mobility is that accessibility says something about the extend to which people have access to opportunities, e.g. jobs from a neighbouring area, by developing infrastructure, while mobility is about connecting different areas.

In general, accessibility can be labelled as the physical access to goods, services and destinations (Saif et al., 2019). In more technical terms, accessibility can be described as the “attractiveness of the network node taking into account the mass of other nodes and the costs of reaching these nodes using the network” (Bruinsma & Rietveld, 1998). Following from this last definition, it can also be described as the extent to which destinations can be reached from origin(s) within certain costs (e.g. time) within a network of connected nodes.

Within this section the following ways of calculating accessibility will be explained: Zonal potential accessibility, person-based potential accessibility, the intra-modal Shen index and the multi-modal Shen index (Pritchard et al., 2019). In general, these models describe, respectively, the competition within one mode of transport (e.g. car, only describes car competition), and both within and between different modes of transport.

2.2.1 Potential accessibility

When the accessibility is measured as the effective available number of jobs j at location i, the zonal potential accessibility is calculated:

$$A_i^{m_x} = \sum_j O_j \cdot f(t_{ij}^{m_x}) \qquad \text{(Eq. 1)}$$

Equation (1) represents the zonal potential accessibility. $A_i^{m_x}$ is the potential accessibility by a particular mode (car or transit) at any origin i. O_j is the number of jobs at any destination j. $f\left(t_{ij}^{m_x}\right)$ is the impedance function based on travel time by the selected mode from origin i to destination j. The advantage of this function is that it is relatively straightforward since it calculates the accessibility per zone based on the number of jobs and travel times.

Another way of indicating the accessibility is determining the person-based potential accessibility. The difference between zonal potential accessibility and person-based potential accessibility is that the zonal potential accessibility tells us the magnitude of the number of accessible jobs in an area, while the person-based potential accessibility is more of an indicator of how competitive the area is in terms of jobs per person in an attainable time. The person-based potential accessibility can be computed by dividing the zonal potential accessibility by the population per originating zone:

$$A_{i\,person}^{m_x} = \frac{A_i^{m_x}}{P_i} \qquad \text{(Eq. 2)}$$

$A_{i,person}^{m_x}$ represents the accessibility in origin i per person by mode x. P_i is the population in origin i. The advantage of using the person-based potential accessibility is that it makes the definition of accessibility within a zone relevant per individual.

The previous ways of indicating the accessibility are based on dividing the total number of distance-weighted accessible jobs by the number of people living in a zone. Consequently, if two zones next to each other will likely have a similar distance-weighted amount of accessible jobs each can have a different person-based accessibility if one of these postal codes has significantly more inhabitants than the other. Therefore this way of determining the accessibility may not be appealing.

To overcome this problem, another definition of the location-based potential accessibility can be used:

$$A_{i\,person}^{m_x} = \sum_j \frac{O_j \cdot f(t_{ij}^{m_x})}{P_j} \qquad \text{(Eq. 3)}$$

$A_{i\,person}^{m_x}$ represents the number of people who can access a certain amount of jobs at a location O_j. By dividing the product of the number of jobs at a certain location and its impedance function by the number of people who live at the job location O_j, it tells something about the competitiveness of a certain job location. However, since no neighbouring locations are taken into account when considering the number of people (P_j), the possible improvement in determining the accessibility is limited. To further improve the definition of accessibility the total population which can access the jobs must be taken into account. In the next subparagraph the Shen index will take this into account.

2.2.2 Shen index

Apart from calculating zonal, person-based and location-based potential accessibility, the Shen index (Shen, 1998) can be used. This index provides a ratio between the accessible jobs and the population that can reach these jobs using a decay or impedance function for both. There are two variations for this index. There is the intra-modal, which only takes the competition of the mode of transport for which the accessibility is calculated into account, and the multi-modal, which also takes the competition of other modes into account.

The intra-modal Shen index can be calculated as follows:

$$A_{i\,shenIM}^{m_x} = \sum_j \frac{O_j \cdot f(t_{ij}^{m_x})}{D_j^{m_x}}, D_j^{m_x} = \sum_k P_k \cdot f(t_{kj}^{m_x}) \qquad \text{(Eq. 4)}$$

$A_{i\,shenIM}^{m_x}$ is the accessibility in zone i by mode x with competition only from mode x, P_k is the population in region k and $f(t_{kj}^{m_x})$ is the impedance as a function of the travel time between k and j using mode x.

The multi-modal Shen index can be calculated as follows:

$$A_{i\,shenMM}^{m_x} = \sum_j \frac{O_j \cdot f(t_{ij}^{m_x})}{D_j^{fastest}}, D_j^{fastest} = \sum_k P_k \cdot f(t_{kj}^{m_f}) \qquad \text{(Eq. 5)}$$

$A_{i\,shenMM}^{m_x}$ is the accessibility in zone i by mode x with competition from any mode. $f(t_{kj}^{m_f})$ is the impedance as a function of the faster travel time by any mode between k and j. The advantage of using the multi-modal Shen index instead of the intra-modal Shen index is that it provides a broader lens of the potential competition without the modal split to be known, i.e. the 'real' traffic does not need to be taken into account.

An overview of all 4 ways of calculating potential accessibility can be found in Table 1 on the next page. There is a relation between the data input and the difficulty of the process, and the significance of the output. More information can be obtained from a method with more data input and a more complex process, such as the multi-modal Shen index. The degree of significance (i.e. the degree of which the outcome says something potentially useful), the amount of data needed for the calculation, the workability (complexity) and the computational power required to do the calculations are given a relative indication in Table 1.

After considering all mentioned methods, zonal potential accessibility is chosen as the method to work with in this research, though with a simplification: Instead of a continuous impedance function, various time frames have been chosen. The reason for choosing potential accessibility is that the Shen may not be possible to work with. The set-up of the calculations for these indices are at such a complexity level that the focus will lie on a somewhat simpler approach: The zonal potential accessibility. These zonal potential accessibilities will be compared between the current situation and the different possible tram lines and stops. Also, the location-based potential accessibility will be used to give an insight into the extent to which competition plays a role.

Table 1: Summary of various ways of calculating accessibility.

Accessibility calculation	Degree of significance	Amount of data	Workability	Computational power required
Zonal acc.	Low	Low	High	Low
Person-based acc.	Low-Medium	Low-Medium	Medium-High	Low
Intra-modal Shen	Medium-High	Medium	Medium-Low	Medium-high
Multi-modal Shen	Very high	Medium	Low	High

3 Methodology

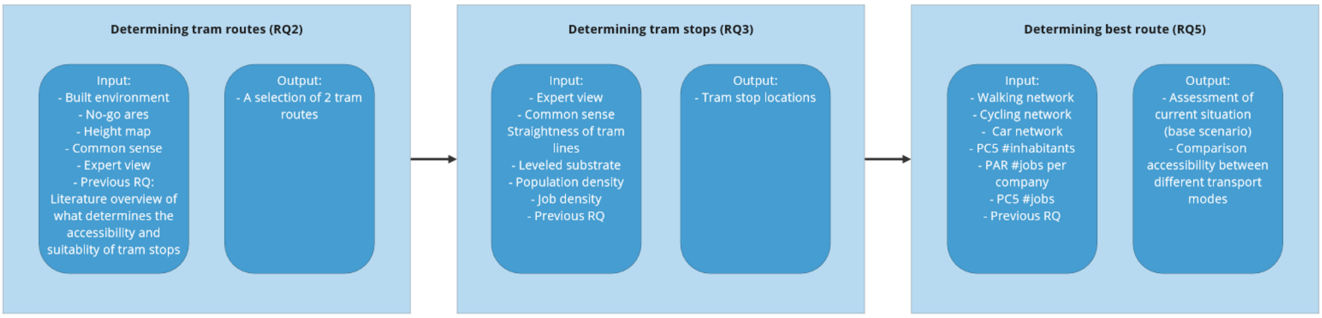

Figure 3: Research methodology. A magnified version can be found in Appendix A.

Since the research questions only provide a limited context on how they will be answered, an explicit research method is provided. A schematic overview of the necessary steps can be found in Figure 3.

3.1 Determining possible tram routes

The starting point of this research is finding routes for a new, direct, tram line between P+R Westraven and Galgenwaard. To make the constraints more clear, both hard as well as soft constraints have been defined. These are derived from literature and result in the limited number of chosen tram lines in this research. The first methodological step in answering the research questions is to determine a limited number of Waterlinie tram line options for research question two.

Before diving into influencing factors of choosing certain routes, it is good to be aware of the fact that a clear distinction between two kinds of passengers can be made. One of these kinds of passengers will be passengers with an origin and/or destination in the neighbourhood of the possible new tram routes. Besides the travel movements which start or end along the newly built track, there are also people travelling the whole newly built track; e.g. people travelling between Nieuwegein and Utrecht Science Park. Within this research they will be called ‘long distance commuters’.

The advantage for long distance commuters of building the new connecting tram line between P+R Westraven and Science Park is not having to take bus 31 or travelling via Utrecht Central Station. Alternatively, choosing for a route through the Lunetten area could potentially increase the total effective service area along the line. The following constraints are considered when determining possible tram routes:

Service Area

The effectivity of the service area of a tram line depends mainly on the number of people being served at the location of the tram stops. A denser population and a higher job density creates a more effective service area. Also, a good network between the tram stops and the population and jobs helps improving the effectivity of a service area. The service area is considered to be about 10 minutes walking.

Travel time

A rough estimation of the improved travel time for passengers making use of the complete new tram line section between P+R Westraven will be provided. Also, the connection of the Waterlinie line and the Uithof line will be made.

Environmental impact on built/green environment

Natura 2000 areas will be taken into account, although none are within the vicinity of the city of Utrecht (European Environment Agency, 2018). Also, monumental buildings and forts will be avoided and the impact on the environment, both built as well as open, will be low. Lastly, the urbanisation rate will be considered since a higher urbanisation rate gives a potential number of extra tram users, though often lower average travel speeds.

Technical Feasibility

The A12 and A27 highways and the connections between them will be taken into account while drawing possible tram routes. The future A12 and A27 highway widenings are taken into account as well.

The elevation and slope in the terrain in the vicinity of the project will be taken into account when looking at the technical feasibility of the lines. Also, the curve radii of the tram lines for different speeds are taken into account to get a course estimate for travel times on the different tram lines.

A general impression of the feasibility of the tram lines will be looked at. Dealing with points of conflict (e.g. waterways, buildings), if not avoided, may significantly increase costs and therefore decrease the feasibility.

3.2 Determining tram stops along the possible tram routes

After the appropriate literature has been found and the routes for possible tram lines have been determined, the third question can be answered: the most optimal locations of tram stops. To initially answer the third research question, several components are put into ArcGIS to make a suitability map of where good locations for tram stops are. ArcGIS is a spatial model to determine travel times. The tram stop locations will be determined for both of the two tram route scenarios. The components can be categorized into jobs and inhabitants determination, zone determination, travel demand calculation and the effective service area of tram stops.

Jobs and inhabitants determination

All jobs (Provinciaal Arbeidsplaatsen Register, PAR) as well as the number of inhabitants (on a PC6 level) have been included in the spatial model since both are relevant for determining the location of tram stops.

The locations of the number of jobs per postal-5-code (PC5) area are derived from the one PAR, which was supplied via email by the Province of Utrecht and supplemented by the PAR on the website of the province of Utrecht. This last PAR consists of data points, each containing the class of number of employees (see the first two columns in Table 2 on the next page).

The reason why the first PAR is supplemented by the second is that the first PAR has missing data due to privacy reasons: if only one company is located within a certain PC5 area, its privacy is violated if the number of employed is given of that PC5. The second PAR does not contain exact data of how many people are employed per company for privacy reasons, as there are only a few companies within that PC5 area.

Furthermore, the number of employees is given in classifications (e.g. from 1 to 3 employed). From these classifications a weighted average has been assumed according to Equation 6 as the weighted average of employed per class. $Class_{min}$ as the minimum value of the class and $Class_{max}$ as the maximum value of the class. The reason for taking the value of 0.4 in the formula above is that there are more companies with less employees than there are with more. For the class of more than 1000 employed a number of 2000 has been assumed.

$$W = Class_{min} + (Class_{max} - Class_{min}) * 0.4 \quad \text{(Eq. 6)}$$

The result of applying this formula can be found in Table 2. The empty PC5 areas within the first PAR are filled by adding all weighted averages per PC5 area of the second PAR. The result will be a complete map of the province of Utrecht filled with PC5 areas, each containing the number of people employed within it.

Table 2: Weighted number of employees

Class	Number of employees	Weighted averages of employees
1	0 emplyees	0
2	1 employee	1
3	2 – 4 employees	3
4	5 - 9 employees	7
5	10 - 19 employees	14
6	20 – 49 employees	32
7	50 - 99 employees	70
8	100 – 199 employees	140
9	200 - 499 employees	320
10	500 – 799 employee	620
11	800 – 999 employees	880
12	1000+ employees	2000

Zone determination

Firstly, an overview of points of interest will be created. This overview consists of a combination of the number of residents per PC6 area and the number of jobs per PC5 area. This difference in postal code detail is due to the available information. The number of PC6 areas with information regarding the number of residents is considered enough, while this is not the case for jobs per PC5 area. Also, points of interest such as shopping centres and other trip generating points near the possible Waterlinie tram line routes are considered when determining the ideal locations for tram stops.

Afterwards, by implementing the information into the spatial model, a heatmap will be produced. Suitable locations for tram stops will be determined based on this heatmap and Google Maps. The last step of using Google Maps is needed because it gives an impression of the practical integration of the tram stops. For a list of kinds of points of interest, including sources, see Table 3.

Secondly, an overview of future zoning plans will be taken into account. Within the relevant area of the Municipality of Utrecht, there are several building plans (intense coloured areas in Figure 4), as well as for Nieuwegein (Figure 5, next page).

Table 3: Various kinds of points of interest and their sources

Object type	Source
High schools	Provinciaal arbeidsplaatsen register (PAR)
Higher education	Provinciaal arbeidsplaatsen register (PAR)
Hospitals	Provinciaal arbeidsplaatsen register (PAR)
Office buildings	Provincie Utrecht (2022)
Supermarkets and other stores	Provinciaal arbeidsplaatsen register (PAR)
Future zoning plans	Gemeente Utrecht
OSM Layer for transport	Open street map (2022)

Figure 4: Future building zones Utrecht. (Gemeente Utrecht, 2020)

Figure 5: Zonal plans Nieuwegein 2030/2040 (Gemeente Utrecht, 2020)

Travel demand calculation

The travel time calculation is done by taking a linear scale because of practical issues in the spatial model. A more sophisticated manner cannot be implemented in the spatial model. The meaning of this linear scale is defined by what the weight of a person living or working in the proximity of a possible tram stop adds to the total realistic demand of that stop. E.g. the weight of a single person living or working close by could be 0.8 and a person living almost at the edge of the service area could be 0.2. This is because of the likeliness of someone living close by using the stop is greater than someone living further away. There are several travel time scenarios to determine the best possible tram stop locations. These travel times are taken as 5, 10 and 15 minutes and create the effective service areas of the possible tram stops. These times have been chosen because they are considered to represent a realistic walking distance to get to/from tram stops.

The effective service area of tram stops

The service area of tram stops is considered to be the area around tram stops from where people go to the tram stop. In reality, the total catchment consists of two service areas: one for pedestrians and one for cyclists. The service area for pedestrians is considered to be within 500 meters of the tram stops (Section 2.1), while the service area for bike users is considered to be 1200 meters (based on Figure 6, Rijsman et al (2019), see next page). However, as can be seen as well in the figure, the average distance people travel by bike is almost the same as for pedestrians. Only walking to and from tram stops will be considered.

Furthermore, it can be found in Figure 6 that the distance of people travelling to tram stops is non-linear. Therefore some research has been conducted. It turned out that the distance decay function of the feeder distance is approximately an e-function (see Figure 6). An approximation of the distance decay function of the walking line is $e^{-0.0022x}$. This e-function could be processed in the spatial model to determine the possible use of the tram stops, however a linear scale has been used for practical reasons.

The area around the two possible tram routes will be split up into postal code 5 areas. This matches the areas for which information can be found, concerning the amount of jobs and inhabitants. Based on these areas the locations of the tram stops and the accessibility level will be extracted.

Just like determining the tram routes, the locations of the tram stops also have some hard constraints. The main hard requirement is that a tram stop needs a straight section of 100 meters. These 100 meters are partly necessary for the trams themselves (75 meters) and some space is needed for passengers who want to cross the tram stop at the ends of each tram stop. Besides being straight, the tram track should also be completely level at the tram stops (Bestuur Regio Utrecht, 2013).

In addition to the effective service area, it is important to take the already existing infrastructure into account. This includes the following networks:

- Walking network Utrecht (Openstreetmap Province of Utrecht)
- Cycling network Utrecht (Openstreetmap Province of Utrecht)
- Bus (Geodata Utrecht)
- Tram (Geodata Utrecht)
- Train (Geodata Utrecht)

The combination of stops with the most added transportation value will be considered as the best. The most added transportation value will be seen as the point where demand is not significantly increasing compared to additional stops.

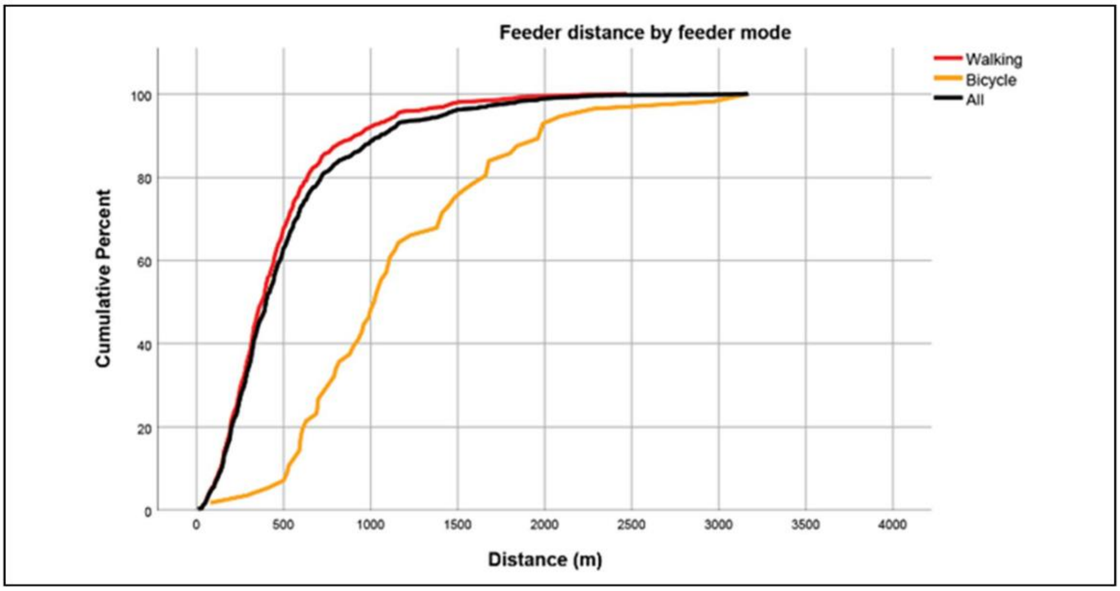

Figure 6: Distance-decay function of feeder distance, per feeder mode (Rijsman, et al., 2019)

After these potential stops have been determined, the cumulative stop demand per walking distance to the potential tram stop locations has been determined. The demandpoints consist of two kinds of demands: Centroids of postal code-6 locations with the number of inhabitants (CBS, 2022) and the PAR of the province of Utrecht (Provincie Utrecht, 2021), which contains the number of employees per company (see Table 2 in Section 3.2). Not all inhabitants are employed and not every employed person at a company works full time. Therefore they are considered equal in creating demand. The term stop demand can be described as the number of jobs or inhabitants a demandpoint contains, divided by the distance from that demandpoint to the potential tram stop:

$$Stop\ Demand = \sum \frac{x * (D_{max} - D)}{D_{max}} \qquad \text{(Eq. 6)}$$

Where:

- x: number of jobs or inhabitants at a given point.
- D_{max}: The maximum distance from a potential tram stop
- D: The distance via the network between the job location or PC5 centroid and the potential tram stop.
- $D < D_{max}$

The stop demand is cumulated per number of potential stops between, and including, Kanaleneiland Zuid and station Lunetten. Based on the change of the cumulated stop demands, the number of tram stops are determined. For each travel time (5, 10 and 15 minutes walking to/from the potential tram stops), the ideal locations are considered together with future building plans. This will result in the final locations of the tram stops for the two potential tram lines.

3.3 Comparing accessibility

The fourth research question is about comparing the accessibility in the current situation with the accessibility in the Waterlinie tram line alternatives. The accessibility in both the current situation as well as the Waterlinie alternatives is determined by using the spatial model. The accessibility is calculated in two ways: by using Equations 1 (zonal potential accessibility) and 2 (location-based potential accessibility) from Section 2.2.1. The location-based potential accessibility will only be shown on maps which compare tram route scenarios with the current situation.

After considering all mentioned methods of Section 2.2, the zonal potential accessibility is the chosen method to work with, though with a simplification: instead of a function, four time frames (10, 15, 30 and 60 minutes) have been chosen. Within each of these time frames the tram line scenarios will be compared. The reason for choosing these two methods is that the Shen-indices is considered unworkable due to its needed computational power.

This workability of the calculations for these indices are at such a complexity level that the focus will lie on a somewhat simpler approach: the zonal potential accessibility and the location-based accessibility. These potential accessibilities will be compared between the current situation and the different possible tram lines and stops. Also, the location-based potential accessibility will be used to give an insight in the extent to which competition plays a role.

For research question four, three scenarios are considered: the base scenario of the current situation and two alternatives with each another Waterlinie tram line. Of each of these scenarios the accessibility is derived by using the base scenario and implementing the tram lines and their respective travel times in the public transport network. The final goal of the report is to have made a comparison between the different scenarios (tram routes) based on how it affects the accessibility.

3.3.1 Modelling the transport network in Geographic Information System

A spatial network is the initial piece of data required to do an analysis. For this, the OpenStreetMap (OSM) data is used. This network is quite detailed regarding roads, although it is not fully complete for walking. After the network is implemented, the walking speed is assumed at 5 km/h (Jonkeren et al., 2021). It is assumed that there is no congestion and 5 km/h is an average walking speed, independent of crossings and other delaying factors. Next to a walking network, the cycling network has been created the same way with an assumed cycling speed of 15 km/h (Jonkeren et al., 2021). These transport speeds are converged to travel times per distance in the network.

Thirdly, a car network has been created to simulate the accessibility for car users. The basis for this network is also the OSM network. This network features the maximum car speeds of a lot of roads. However, the data is incomplete and is therefore complemented with maximum speeds of 60 km/h where no data was available in the original OSM-network. This is assumed to be about right, since most missing data is outside built-up areas. Although, some missing information was in neighborhoods where the standard maximum speed is 30 km/h. Based on the given maximum speeds and the lengths of the road segments, each road segment is given a certain travel time in minutes. To further make the car network realistic, for the intersections of the car network delays have been assumed for making turns. The corners which are considered and the according assumed delays can be found in Figure 7.

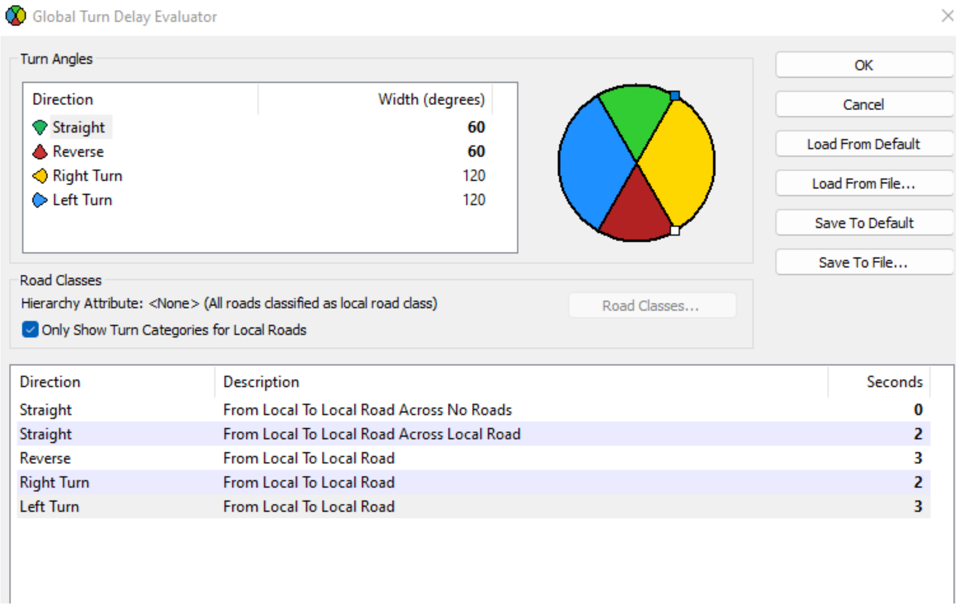

Figure 7: Car traffic settings

Fourthly, a public transport network is modelled. This network is a combination of two different networks: the public transport network itself and a walking network. For the public transport network, the used general transit feed specifications (GTFS) is implemented in GIS. Since this data does not contain links to the walking network, these are created by making virtual transit stops on the walking network and connecting those points with stop connectors. These stop connectors are only created between the virtual stops with the on streets projected stops and not between the virtual stops themselves. Theoretically this could be a limitation on the network since it virtually takes extra time for public transport users to change from one bus/tram/train to another, while in reality waiting on the same platform or changing to a platform in very close proximity. However, since it almost always takes longer until a new bus/tram/train arrives than following the stop connectors, this is not considered a problem.

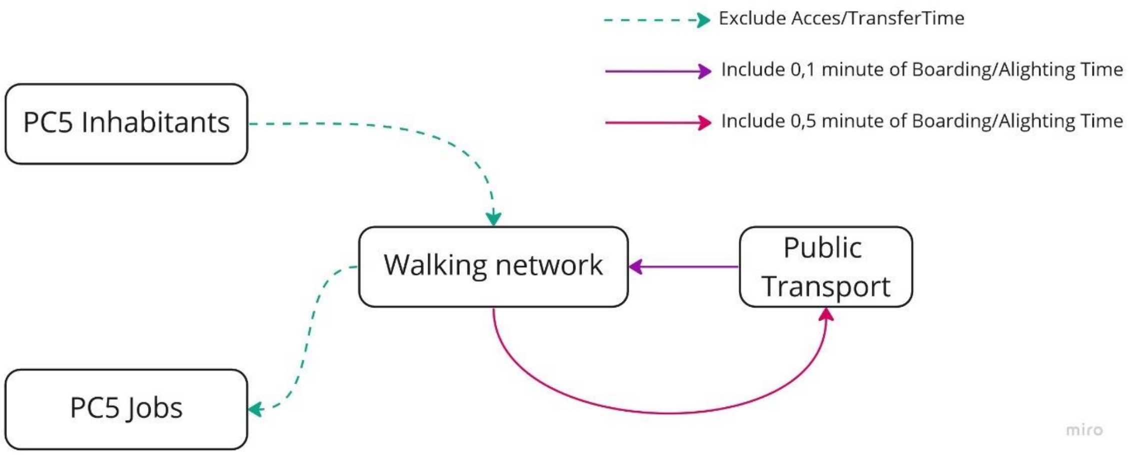

Figure 8: Public transport connectivity.

In Figure 8 the public transport connectivity, including transfer delays, is shown. On the left the 'from' (PC5 Inhabitants) and 'to' (PC5 Jobs) are shown. These locations are the centroids of the postal code 5 areas in the province of Utrecht. When inhabitants travel to a job, they first use the walking network. If public transport gives a faster connection for inhabitants to reach jobs than using the walking network only, an extra 0.6 minutes of boarding/alighting time is added to their travel time. When transferring between public transport, both within a mode of public transport as well as between modes of public transport, an extra loop is created via the walking network but without walking time.

Finally, the rise in accessibility can be calculated using the public transport base scenario, the used routes and stops. Besides, these scenarios can be compared with the car and walking scenarios. This will give an overview of how the accessibility of different modes and travel times compare.

4 Results

This chapter answers research questions 2 to 4:

- “What are the most suitable routes for the future Waterlinie tram line, based on technical feasibility into the existing area?” (RQ2),
- “What are the most optimal locations for tram stops along the potential routes in Utrecht?” (RQ3),
- “What is the difference in public transport accessibility in Utrecht between the two possible tram tracks and how do they relate to the base scenario?” (RQ4).

4.1 *What are the most suitable routes for the future Waterlinie tram line, based on technical feasibility into the existing area? (RQ2)*

First of all, the two best possible tram routes are decided upon. This is done by first setting a list of factors which influences making choices about whether a route is a viable alternative. These factors (see Section 3.1) are both considered while making all possible routes and when making a multi criteria analysis. This multi criteria analysis will give the two best routes.

Before routes are compared in detail, different tram route possibilities are identified based on expert judgement, routes provided by the municipality of Utrecht and own interpretation. These routes (Figure 9) are considered based on various factors mentioned in Section 3.1.1. The mentioned curve radii (Figure 21), monuments (Figure 22), forts (Figure 22), highway expansion (Figure 22) and elevation map (Figure 23) can be found in Appendix B. The elevation map may not look like it is significant, however the maximum desirable slope is 1:30 (3.3%) (Nederlands kenniscentrum voor ondergronds bouwen en ondergronds ruimtegebruik, 2023). In Figure 9 the drawn possible tram lines are shown.

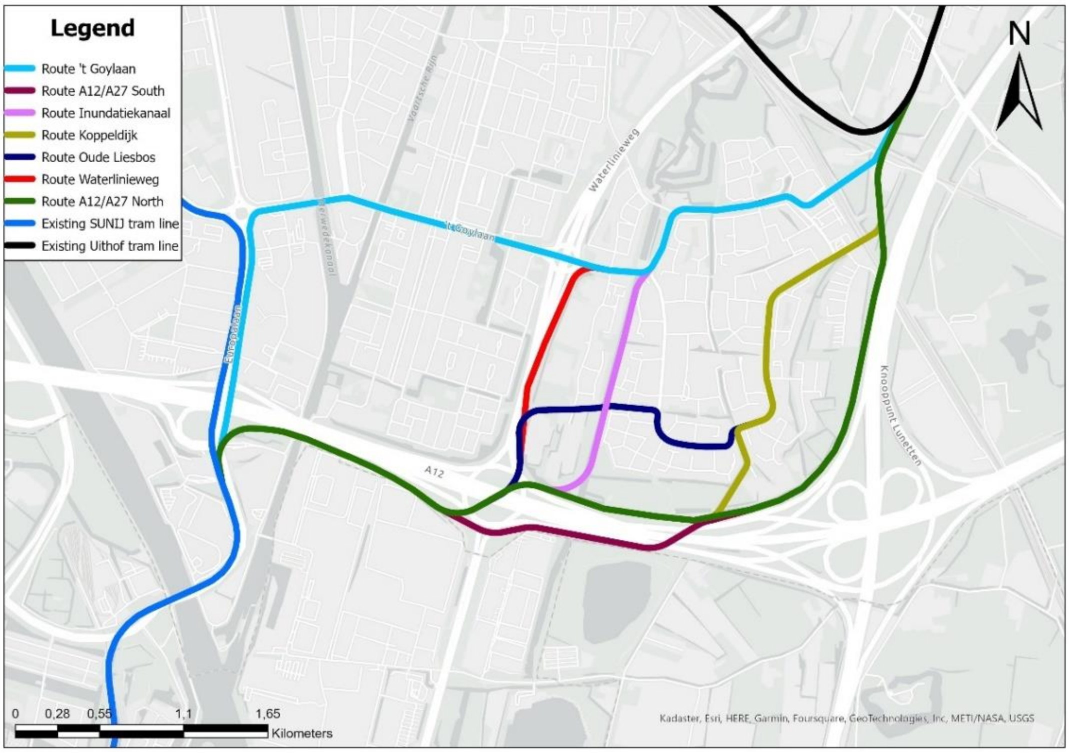

Figure 9: Routes possible tram lines

After seven considered routes have been drawn (Figure 9) the routes have been compared to narrow down the selection to two for further examination. This has been done by applying a multi criteria analysis (Table 4). The seven initial routes each have their own strengths and weaknesses. These are considered: Service area, total travel time between Westraven and train station Lunetten, the impact on the current environment and the expected technical feasibility based on horizontal and vertical profile of each line. For each of these factors a 5-degree scale has been set up (++, +, +/-, -, --), after which they have been counted and have given multi criteria score (MCA-score). Concluding from Table 4, the alternatives A12/A27 South and ‘t Goylaan scored best and is further examined.

The ‘t Goylaan tram route is considered the most promising route based on this MCA, mainly because of its potential service area it is expected to cover and in lesser extend its reasonably low impact on the built and green environment and its feasibility. Moreover, the A12/A27 South option is deemed suitable, mainly because it is expected that the trams may drive at relatively high speeds and therefore have low travel times. Also, the feasibility is considered good and the impact on both green and built environment low.

Table 4: Multi criteria analysis of various route alternatives.

Route	Tram stop service area along route	Travel time	Impact on built/green environment	Technical feasibility	**MCA-score**
A12/A27 South	-	++	+	+	**3**
t Goylaan	++	+/-	+	+	**4**
A12/A27 North	-	++	+	-	**1**
Inundatiekanaal	+	+	+	--	**1**
Koppeldijk	+/-	+/-	-	+/-	**-1**
Oude Liesbos	+	-	--	--	**-4**
Waterlinieweg	+	+/-	+	-	**1**

4.2 *What are the most optimal locations for tram stops along the potential routes in Utrecht? (RQ3)*

As mentioned in Paragraph 4.1, each tram line has its own strengths and weaknesses. The ‘t Goylaan tram route has potentially more travellers to serve along its tracks, while the A12/A27 South alternative has its strength of providing a fast connection between Westraven and train station Lunetten. In ArcGIS the location-allocation tool has been used to allocate the best locations for tram stops along the ‘t Goylaan tram route. It had been chosen for to not fully analyse stops along the A12/A27 route because of the very few possible and necessary locations for tram stops along this route.

Firstly, the sites of possible tram stops have been identified, based on a qualitative assessment using the criteria mentioned in Section 3.2. Each of these sites (14 in total), including the tram station Lunetten and the existing tram stop Kanaleneiland Zuid, have been analysed using the location-allocation tool, after which for every number of tram stops the tool calculated the ideal tram stop locations. This was repeated for 5, 10 and 15 minutes walking to the potential tram stops.

An example of the use of the location-allocation tool can be found in Figure 10 on the next page. The demand points represent both all locations of working places as well as the centroids PC6 areas. Each chosen location is connected to all demand points with a distance of 5, 10 or 15 minutes via the walking network. The total value of the candidate location is given as the distance via the lines between the demand points and the chosen stops times the number of inhabitants or jobs at a demand point (see Section 3.2)

Figure 10: Example of Location-Allocation tool in ArcGIS.

After these potential stops have been located, the cumulative stop demand per walking distance to the potential tram stop locations has been determined, as explained in Section 3.2.

Figure 11 on the next page shows the total potential passenger demand for the number of tram stops. Figure 12 shows the added value per additional tram stop along the route. This is due to competition between tram stops that are located close to each other. In Figure 11 it can be seen that almost no demand is generated after 8 stops in the 15 minute linear scenario. Also, Figure 12 shows a competition effect already at 3 stops, especially in the 15 minute scenario.

After creating Figure 11 and Figure 12, the number and locations of tram stops are decided upon. In those figures local maxima can be found at 8 tram stops for 15 minutes walking, 7 tram stops for a walking distance of 10 minutes and 6 for 5 minutes walking to/from the tram stops. Therefore the 6, 7 and 8 tram stops alternatives of the 5, 10 and 15 minutes walking scenarios are considered.

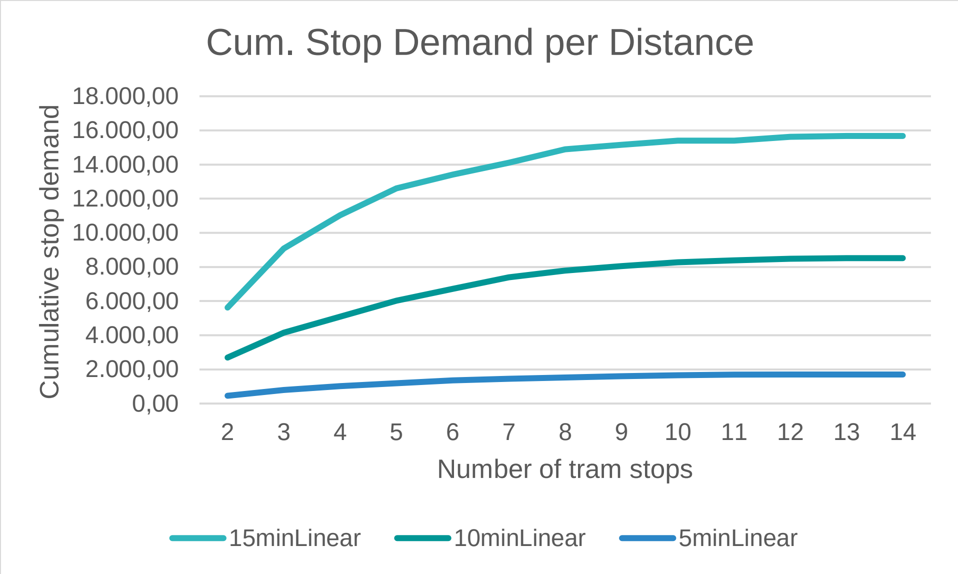

Figure 11: Cumulative stop demand per walking distance to potential tram stops.

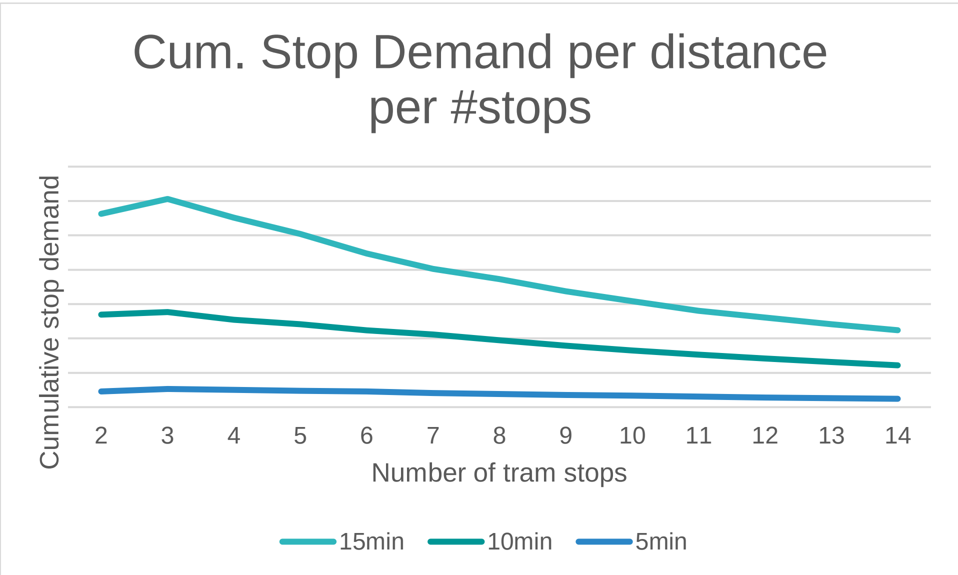

Figure 12: Cumulative stop demand per walking distance to potential tram stops per number of served tram stops.

For locating the final tram stops, the three walking distance scenarios are looked at (Figures 13 to 15, next pages). Firstly, all scenarios with tram stop less than 200 meters apart have not been accepted as a solution so the tram does not take too long to get between train Westraven and train station Lunetten. It could be that the location-allocation tool gives a solution with two stops very close to each other (see Figures 13b and 13c) because the walking distances are only 5 minutes to the stops and in the proximity of those two stops there are relatively a lot of jobs available. The location-allocation tool does not consider the proximity of other stops. Because stops closer than 200 meters of each other are considered undesirable, a maximum of 7 tram stops, including Kanaleneiland Zuid and station Lunetten, has been chosen for.

Furthermore, the stop directly west of the Merwedekanaal has been regarded as needed because of the significant future increase in residents near the stop. One stop between the Waterlinieweg and station Lunetten is regarded as adequate. Lastly, the stop between the Vaartserijn and the Graaflandstraat has been excluded in order to decreasing the travel time between Westraven and station Lunetten. For the ‘t Goylaan tramroute, this resulted in the alternative of Figure 15b without the stop between the Vaartserijn and the Graaflandstraat to be considered most desirable.

a
b
c

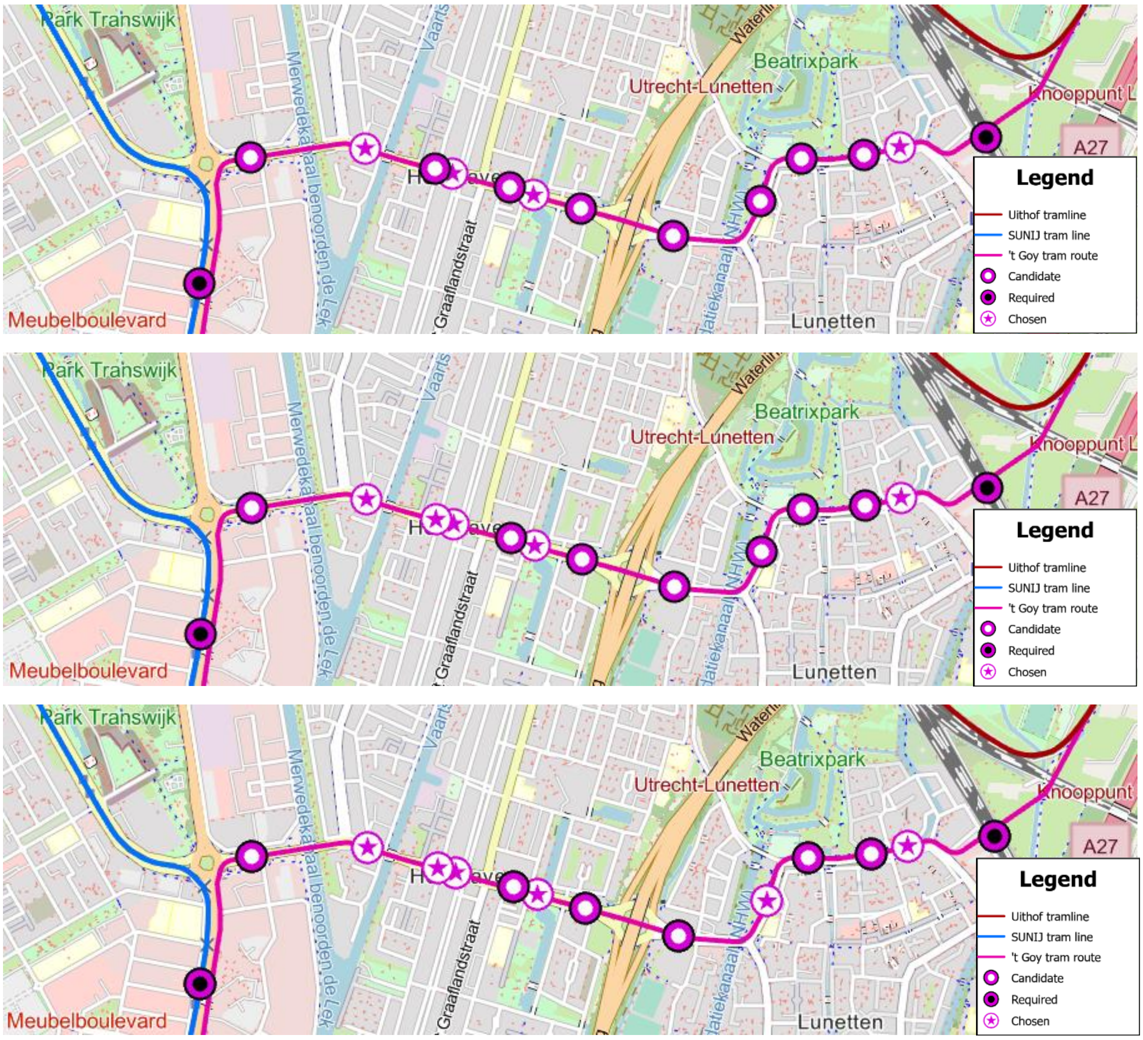

Figure 13: 6 (a), 7 (b) and 8 (c) tram stops for 5 minutes walking reach to stop locations.

Figure 14: 6 (a), 7 (b) and 8 (c) tram stops for 10 minutes walking reach to stop locations.

a
b
c

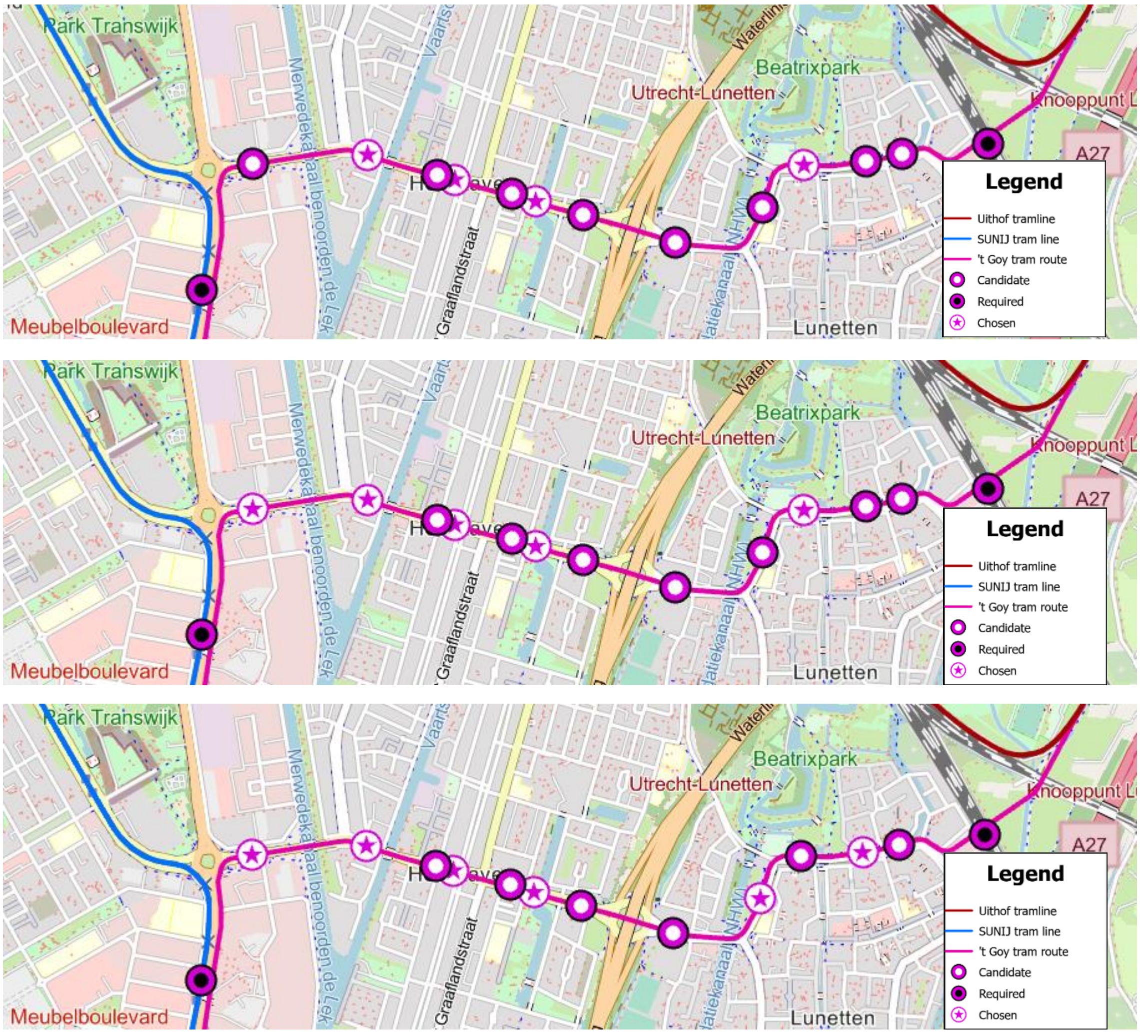

Figure 15: 6 (a), 7 (b) and 8 (c) tram stops for 15 minutes walking reach to stop locations.

For the A12/A27 route there are fewer options regarding tram stop locations because a lot less jobs and inhabitants can be found within a close proximity of the route. Therefore this scenario has been split up into two scenarios: A12/A27 without stops and A12/A17 with two stops (Figure 16). The two stops for the A12/A27 route are chosen for based on that they are far enough from other (existing) tram stops and train stations, but close enough to jobs and inhabitants. Station Lunetten is chosen for in every alternative due to its train connection. The A12/A27 route without stops (but including station Lunetten) was considered because this is considered to be the fastest link between Westraven and Lunetten.

In contrast, this does not serve the local households and businesses between these places. Therefore an extra two stops have been chosen in another, second, scenario. The stop of this route North West of the A12/A27 junction is placed so it is not too close to Lunetten train/tram station and therefore limiting the mutual competition effect. Also, stationing too many stops along the route will increase travel times between Westraven and Lunetten station while the attractiveness of the stops is limited since they will only be accessible from one side and the closest inhabitants/jobs are not directly situated to the stops.

The other tram stop is situated South of the A12 next to the Merwedekanaal. South of the tram stops there are various businesses which are expected to gain an advantage from this stop. Finally, the stops of Figure 16 have been chosen for as a second alternative. This alternative will be used in the accessibility analysis in Section 4.3. The 't Goylaan tram route (Figure 17, next page) will also be used in the next Section.

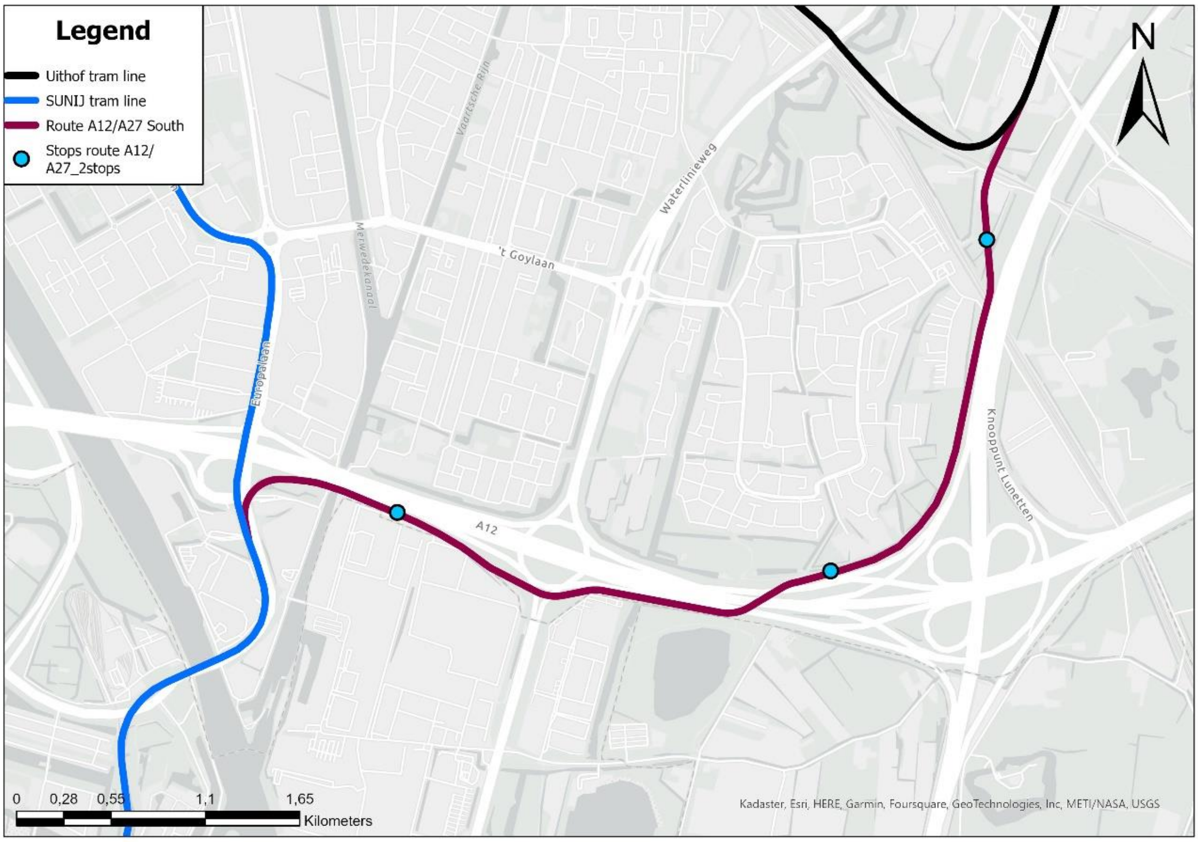

Figure 16: Tram stops along the A12/A27_2stops tram line. The A12/A27_0stops scenario is the same line, although without the shown stops.

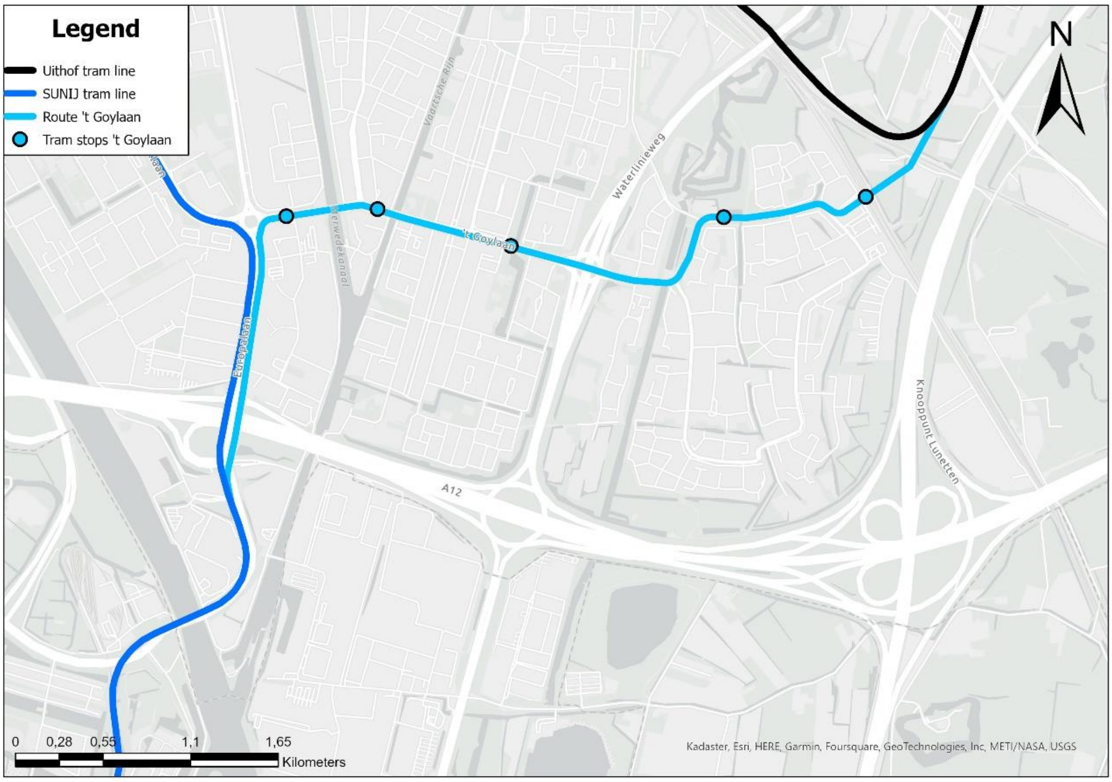

Figure 17: Tram stops along the 't Goylaan tram route, including station Lunetten.

4.3 *What is the difference in public transport accessibility in Utrecht between the two possible tram tracks and how do they relate to the base scenario? (RQ4)*

The current accessibility has been assessed for various scenarios: car, walking and public transport, each for 10, 15, 30 and 60 minutes. All maps with resulting accessibilities can be found in Appendix C. The results of the various time scenarios of the car increase directly from the 10 minutes scenario onwards.

Both the 10 as well as 15 minutes scenarios are almost the same as equivalent walking scenarios. This is because 10 and 15 minutes are mostly not enough to walk to a public transport stop, take the public transport and get to a destination within that time. The 30 and 60 minutes are enough to make the complete journey between PC5 centres via public transport. In addition to Appendix C, a numerical summary is also shown in Table 5.

The 4 transport scenarios (10, 15, 30 and 60 minutes) each have been brought back to one value per scenario, so the networks in RQ4 can be compared with a base scenario.

After having calculated the base scenarios of different modes of transport, the three public transport scenarios have been compared with the current situation (lower half of Table 5). For the A12 tram line with 0 stops along the new route (A12_0) it is noticeable that within 15 minutes there are no changes in relation with the base scenario. When longer travel times (30 and 60 minutes) are allowed, significant changes start to occur.

In the A12 with 2 stops scenario (A12_2) less jobs are available in the 0 to 10 minutes travel time scenario, according to the results. This should not be possible because the network has only been extended and no lines have been erased. As shown in Table 6, the number of jobs available in the 15 minute scenario of A12_2 does not deviate from the base scenario. Longer travel times make the A12 scenarios have more added value, both in absolute terms as well as relative to the base scenario, more added value.

The figures in Appendix C and Appendix D give a more detailed view on where the number of jobs increase in a percentual manner and how they change per inhabitant compared to the current situation. The image given by the figures in both Appendices confirm the tables above. A specific and interesting figure is the one below (Figure 28): the percentual increase in accessibility for the A12_0stops with 60 minutes travel time scenario.

In many PC5-areas within the municipality of Houten the accessibility increases by over 50%. This is mainly caused by the transit function of Lunetten station to Science Park. Though in lesser degree regarding number of extra available jobs, the direction of Nieuwegein and IJsselstein also becomes more accessible.

Table 5: Reachable jobs within certain time frames.

		0-10 min	0-15 min	0-30 min	0-60 min
Base scenario	Base scenario	2190895	3948117	20051089	214196625
	Car	142715025	344247009	1077119203	1769600218
	Walking	2158229	3846314	13673052	50759829
Waterlinie Line Scenarios	A12_0	2190895	3948117	20339638	223499759
	A12_2	2186120	3948117	20693808	224158481
	t Goylaan	2191177	3957339	20468711	217065865

Besides the numbers in Table 5, the relative changes compared to the base scenario are shown in Table 6. As can be expected from Table 5, the percentual increase in reachable jobs in all time frames is considerable. Furthermore the increasing percentual difference in accessibility between the walking scenarios and the public transport base scenarios increases when travel time increases. The car scenario does not take congestion into account.

The three future public transport alternatives only give significant changes in reachable jobs in the 30 and 60 minutes travel time scenarios. The different percentages in these scenarios change significantly among them; e.g. the A12_2 and ‘t Goylaan alternatives in the 0-60 minutes scenario. In this scenario, and a to a lesser degree in the 30 minute scenario, both A12 scenarios perform significantly better than the ‘t Goylaan alternative. Instead, in the 15 minute scenario the ‘t Goylaan scores higher.

Table 6: Change in reachable jobs compared to the public transport base scenario.

	0-10 min	0-15 min	0-30 min	0-60 min
Car	+6414,0%	+8619,3%	+5271,9%	+726,2%
Walking	-1,5%	-2,6%	-31,8%	-76,3%
A12_0	0,0%	0,0%	+1,4%	+4,3%
A12_2	-0,2%	0,0%	+3,2%	+4,7%
‘t Goylaan	0,0%	+0,2%	+2,1%	+1,3%

In the following Figures 18, 19 and 20, the results of the 60 minutes travel time scenario are shown. The results in the A12_0stops and A12_2stops have a lot of overlap. On the contrary, the outcome of the ‘t Goylaan alternative differs significantly from the other two alternatives in the 60 minute scenario when comparing the percentage change to the base scenario.

In all three scenarios the increase in accessibility in Houten increases significantly compared to other parts of project area. All other scenarios, including the comparison of the alternatives to the base scenario on a change of accessible jobs per inhabitant per PC5 area can be found in Appendix C.

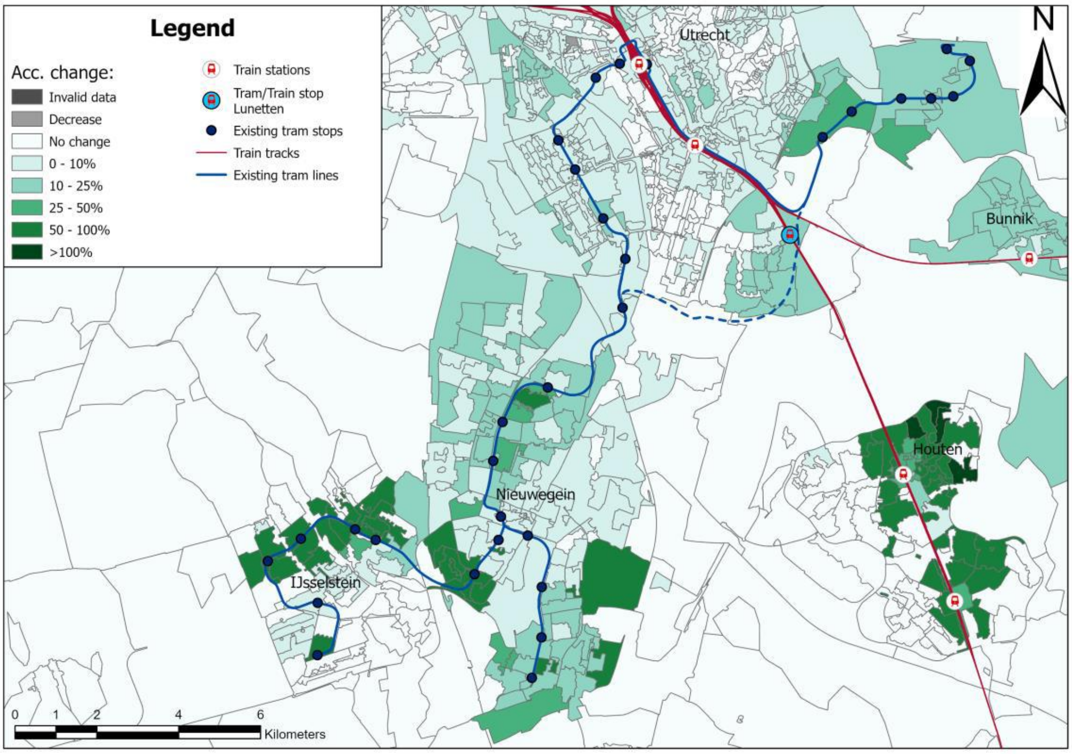

Figure 18: A12_0stops %Change in the 60 minutes travel time via public transport scenario.

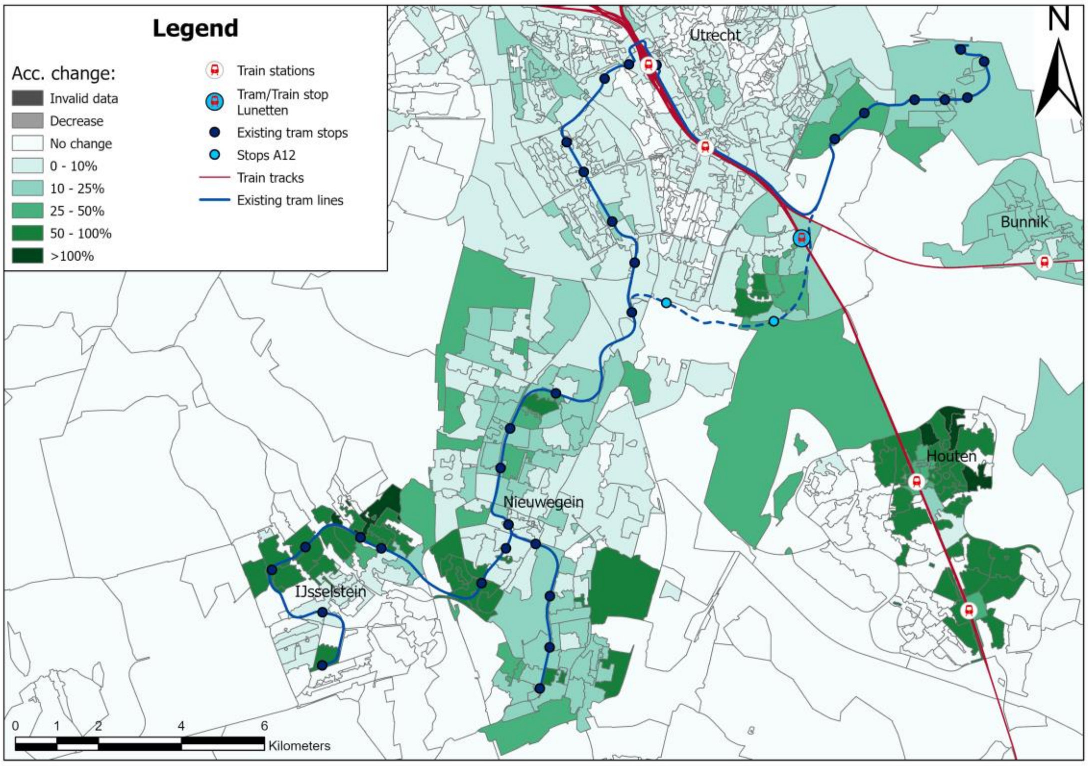

Figure 19: A12_2stops %Change in the 60 minutes travel time via public transport scenario.

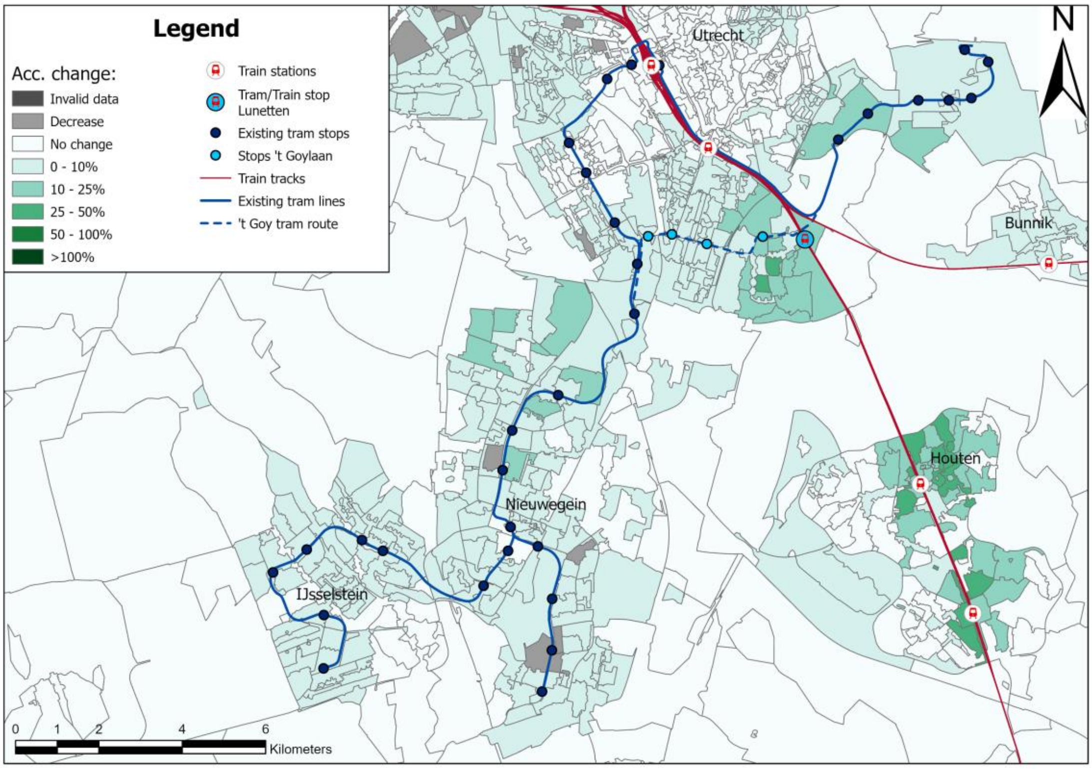

Figure 20: 't Goylaan %Change in the 60 minutes travel time via public transport scenario.

5 Discussion

This reserach looks at the possibilities for adding an extra tram line in Utrecht between Westraven and Lunetten, so Utrecht Central Station is relieved in terms of number of passengers. During the process, several strengths and limitations arose which are identified and discussed in this chapter. At the end, possible future work is discussed.

5.1 Strengths

The work being done has a number of strengths. First of all, the origins and destinations are on a relatively detailed level (centroids of PC5 areas) instead of the more basic PC4. This also meant that more work was needed to accumulate the necessary information to get fruitful results. No similar work for the Waterlinie tram line has been found during the starting phase of this report, especially calculating the accessibility for different time scenarios. This research has shown that potential local and regional impact of the Waterlinie tram line is considerable.

This research could also have added value for the municipality and province of Utrecht in regards of gaining a better understanding of the added value and limitations of the Waterlinie tram line. The province of Utrecht, and possibly other authorities, can make a clear choice about choosing for a quick connection between the South of Utrecht and Utrecht Science Park (one of the A12/A27 alternatives), or choose for a more local solution (‘t Goylaan tram route).

5.2 Limitations

The results contain uncertainties that are not clear in their origins, as all scenarios were set up in the same way with the same data. With the same input (jobs, inhabitants and networks) for all scenarios, except for the addition (never removal) of extra transportation options, there should be no decrease in accessibility compared to the scenario without added routes. However, this is not the case; in several scenarios, a reduced number of reachable job opportunities have been found. This not only affects the areas where these decreases are observed but also introduces inaccuracies in areas where an increase in job opportunities is expected.

Furthermore, it should be noted that the literature found is based on American research from about 25 years ago. The American perception of acceptable walking and cycling distances differs from the current standards in the Netherlands. Additionally, public transport is used by a broader scope of society within the population in the Netherlands compared to the United States. For example, taking public transport is more common among commuters than in the US. Future work could take into account this Dutch perception.

As already mentioned in the report, input speeds from Open Street Maps for highways and some other roads are incomplete and have been supplemented. This number is an approximation. Detailed information is needed to make the car speeds more accurate and thus this research more reliable. In the report, a speed of 60 km/h was assumed for roads where maximum speeds were missing.

Apart from the missing speed limits, the network itself is also not complete, especially the walking network. In practice a walking network includes some shortcuts. These are often relatively short, but can sometimes save pedestrians several minutes. Also, shortcuts for pedestrians will be made while a new tram stop is being constructed. In the OSM data these shortcuts obviously do not exist yet. This is one of the main reasons for choosing for the tram stop between the Merwedekanaal and the roundabout in the ‘t Goylaan alternative in Section 4.2. These shortcuts can be made manually. However, this must be done consequently over the entire walking network. The result of the lack of shortcuts may result in fewer available jobs for an area than expected.

There is another reason for choosing this tram stop of the ‘t Goylaan tram line. Directly both North and South of the tram stop the number of inhabitants will increase significantly in the coming 5 to 10 years.

This has not been taken into account in the report, but could make a decisive impact on whether or not to build this line.

The way the information gap of the number of employees from the PAR which was supplemented (Section 3.2) with the numbers from Table 2, was a coarse estimation. This could have been performed in a better way by first plotting all numbers, then note the approximate graph this makes and finally take the median number per category. This median number then be added to the map which gives a total number of employed persons.

5.3 Recommendations and future work

The conducted research could be applied as a base for further Waterlinie tram line analysis. For practical application, the economical side should first be evaluated. The economical side of the project has not been significantly taken into account while it is vital for decisionmakers to consider. Where needed and appropriate, some economical estimations have been made in this report for choosing between various routes. A more in depth analysis is advised. This analysis should mainly focus on the added economical value of different possible Waterlinie tram lines and compare it with the expected costs of the various tram line options.

Also, a more detailed feasibility study should be carried out which includes the special integration of the Waterline tram line options. In the end, it is also a political question: What is considered more valuable: extra tram stops in the Lunetten neighbourhood or a (even) faster connection between Westraven and Science Park?

6 Conclusion

This research compares various options for the possible Waterlinie tram line. The five sub-questions have been answered, followed by the main research question.

What determines the accessibility and the suitability of tram stops in general? (RQ1)

The zonal potential accessibility, the location-based potential accessibility, the intra-modal Shen index and the multi-modal Shen index have been considered. Both the zonal potential accessibility as well as the person-based accessibility have been chosen for, due to their simplicity compared to the computationally expensive alternatives. The suitability of tram stops depends on various factors, such as the distance and density of the built environment, the straightness and steepness of the track and the distance to other public transport stops.

What are the most suitable routes for the future Waterlinie tram line, based on technical feasibility into the existing area? (RQ2)

The six initial routes have been compared in a multi criteria analysis. This resulted in the ’t Goylaan and A12/A27 South options as the best tram routes. The ‘t Goylaan route is considered most promising, mainly due to the potential service area it is expected to cover. The A12/A27 South route looks promising as well, because of its relatively short travel times between P+R Westraven and Lunetten. Four other possible tram routes have been discarded due to a combination of their small or impractical service area, the long travel times, their impact on the built or green environment or their feasibility.

What are the most optimal locations for tram stops along the potential routes in Utrecht? (RQ3)

The possible tram stops locations along the ‘t Goylaan route have been compared in a location-allocation tool in ArcGIS based on the weighted number of reachable inhabitants and jobs. Jobs and inhabitants are weighted linearly less when further away from tram stops with cut-off walking travel times of 5, 10 and 15 minutes. This resulted in 4 tram stops (Figure 17, page 29). The A12/A27 tram route stops have been chosen based on the vicinity of jobs or inhabitants (Figure 16, page 28). The choice is up to the municipality: Does it primarily want to serve the people directly along the tram line or does through traffic count more heavily?

What is the difference in public transport accessibility in Utrecht between the two possible tram tracks and how do they relate to the base scenario? (RQ4)

The accessibility provided by several modes of transport have been compared: car, walking, current public transport (called the base scenario) and the three previously mentioned Waterlinie tram line alternatives. The modes of transport give different levels of accessibility. For instance, the model the car reaches most destinations within all time frames while the base scenario (public transport) does second best and walking is considered to have the least accessibility. Public transport gets progressively better results when travel time increases, compared to the other means of transport.

The change in accessibility between the base scenario and all Waterlinie tram line alternatives seems insignificant in the 10 and 15 minute travel time scenarios. On the contrary, the 30 and 60 minute scenarios show a considerable change in travel time for all three Waterlinie alternatives. Compared to the base scenario, the accessibility in the 30 minutes travel time scenario changes most for the ‘t Goylaan tram line while the accessibility in the 60 minutes travel time scenario changes most in the A12_2stops and A12_0stops alternatives (Table 6, page 29).

What is the optimal Waterlinie tram route between P+R Westraven and Stadion Galgenwaard, based on accessibility measures?

All three options are considered possible: the ‘t Goylaan tram route, A12_2stops and A12_0stops. ‘t Goylaan tram route is most suitable for adding local public transport travel possibilities. The

A12_0stops option is best suited for improving rapid public transport between Nieuwegein/IJsselstein and Science Park. The A12_2stops combines both advantages, althoughh limited compared to the other two scenarios.

References

AHN. (2022). Actueel Hoogtebestand Nederland. Amersfoort, Utrecht, Nederland.

Ahmed Eng, N. G.; Asmael, N. M. (2009). A GIS-assisted optimal urban route selection based on multi criteria approach*. IJMME, Special Issue (D)556*, University of Babylon, Iraq.

Alshalalfah B. W., Shalaby A. S. (2007). Case Study: Relationship of Walk Access Distance to Transit with Service, Travel, and Personal Characteristics. *Journal of Urban Planning and Development.*

Bestuur Regio Utrecht. (2013). Integraal Programma van Eisen Tramvervoersysteem Regio Utrecht. Retrieved from https://www.crow.nl/getmedia/081a5a5e-c08d-4ddd-8760-a719b15c9a8a/131003-IPvE-Tramvervoersysteem-Regio-Utrecht_5-0.pdf.aspx?ext=.pdf

Bruinsma, F., Rietveld, P. *The Accessibility of European Cities: Theoretical Framework and Comparison of Approaches.* Environ. Plan A 1998, 30, 499–521

CAF. (2023) THERE IS AN URBOS FOR EACH TYPE OF CITY*.* Retrieved from https://www.caf.net/en/soluciones/familia/urbos/descripcion/gama_urbos.php

CBS. (2022). Kerncijfers per postcode*.* Retrieved from https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/gegevens-per-postcode

European Environment Agency. (2018). Retrieved from Discomap: https://discomap.eea.europa.eu/Index/

Gemeente Utrecht. (2020, 11). Mobiliteitsplan Utrecht 2040.

Jonkeren, O.; Kager, R.; Harms, L. et al. The bicycle-train travellers in the Netherlands: personal profiles and travel choices. *Transportation* 48, 455–476 (2021).

Nederlands kenniscentrum voor ondergronds bouwen en ondergronds ruimtegebruik. (2023). *Hellingen tram- en metrolijnen*. Retrieved from Handboek Tunnelbouw: https://www.handboektunnelbouw.nl/introductie/geometrische-profielen/tram-en-metrolijnen/hellingen-tram-en-metrolijnen/

Murray, A. T. (2001). Strategic analysis of public transport coverage. *Socio-Economic Planning Sciences*, *35*(3), 175–188.

Pritchard, J. P.; Stępniak, M.; Geurs K. T. (2019). Equity analysis of dynamic bike-and-ride accessibility in the Netherlands. *Measuring Transport Equity.*

Pritchard, J. P.; Tomasiello, D.; Giannotti, M.; Geurs K. T. (2019). An International Comparison of Equity in Accessibility to Jobs: London, São Paulo, and the Randstad. *Transport Findings.*

Provincie Utrecht. (2021). *Provincieaal Arbeidsplaatsen Register (PAR) 2021. Retrieved from* https://nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/c60f9763-5bfd-49c1-8a86-f3e9552860e6

Rietveld, P. (2000, 1). The accessibility of railway stations: the role of the bicycle in The Netherlands. *Transportation Research Part D: Transport and Environment*, pp. 71-75.

Rijkswaterstaat. (2020). *Aanpassing A27/A12 Ring Utrecht.* Retrieved from https://a27a12ringutrecht.nl/

Saif, M. A.; Zefreh, M. M.; Torok, A. (2019) “Public Transport Accessibility: A Literature Review”. *Periodica Polytechnica Transportation Engineering*, 47(1), pp. 36–43.

Shen Q. (1998). Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environment and Planning B: Planning and Design.*

U-Ned. (2021). Ruimtelijke strategie Utrecht 2040.

Appendices

Appendix A: Research methodology

Appendix B: Factors for considering tram routes

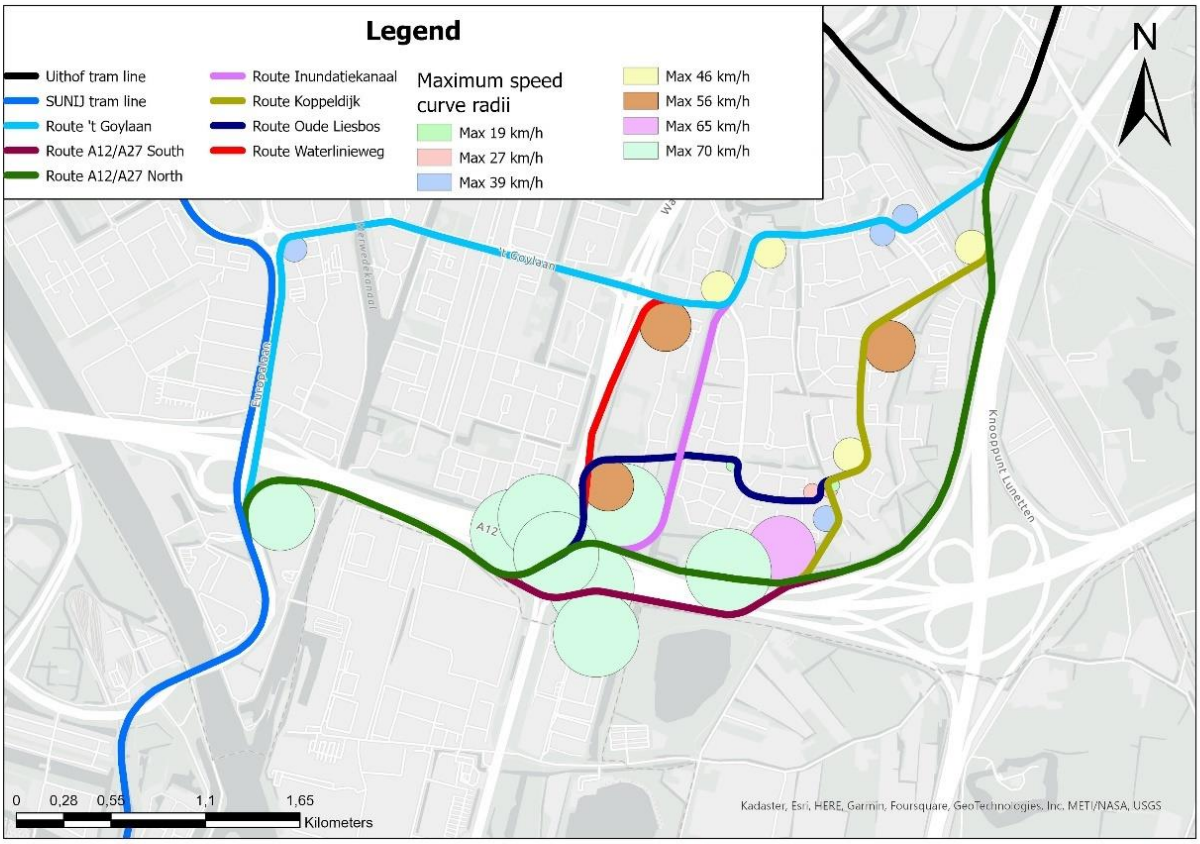

Figure 21: All considered tram lines, including curve radii. Note: The bigger the circle's radius, the higher the maximum speed.

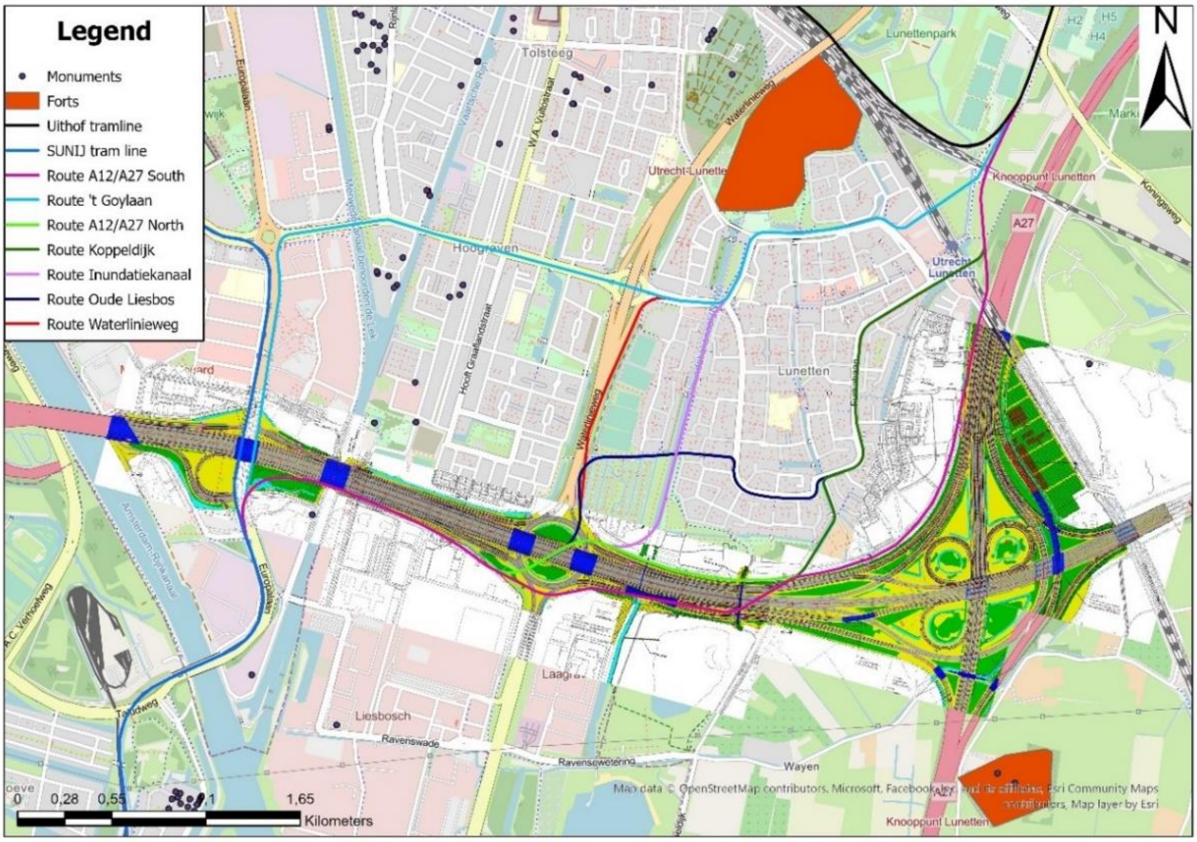

Figure 22: All considered tram routes with monuments and forts, including the overlay for the future A12 and A27 highway expansion.

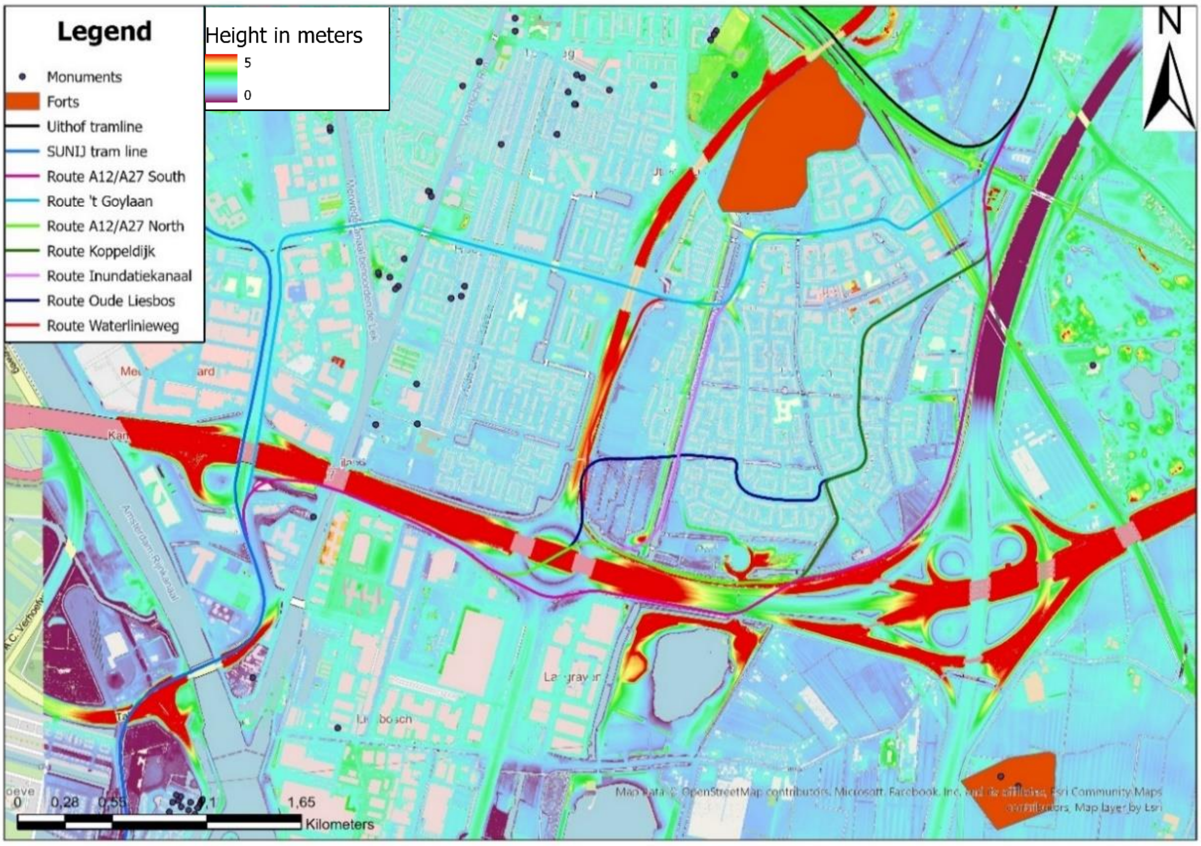

Figure 23: All considered tram routes, including elevation map: Purple (≤0 meters +NAP) to Red (≥5 meters +NAP) (AHN, 2022)

Appendix C: Maps of resulting accessibilities expressed in percentage of change compared to the base situation

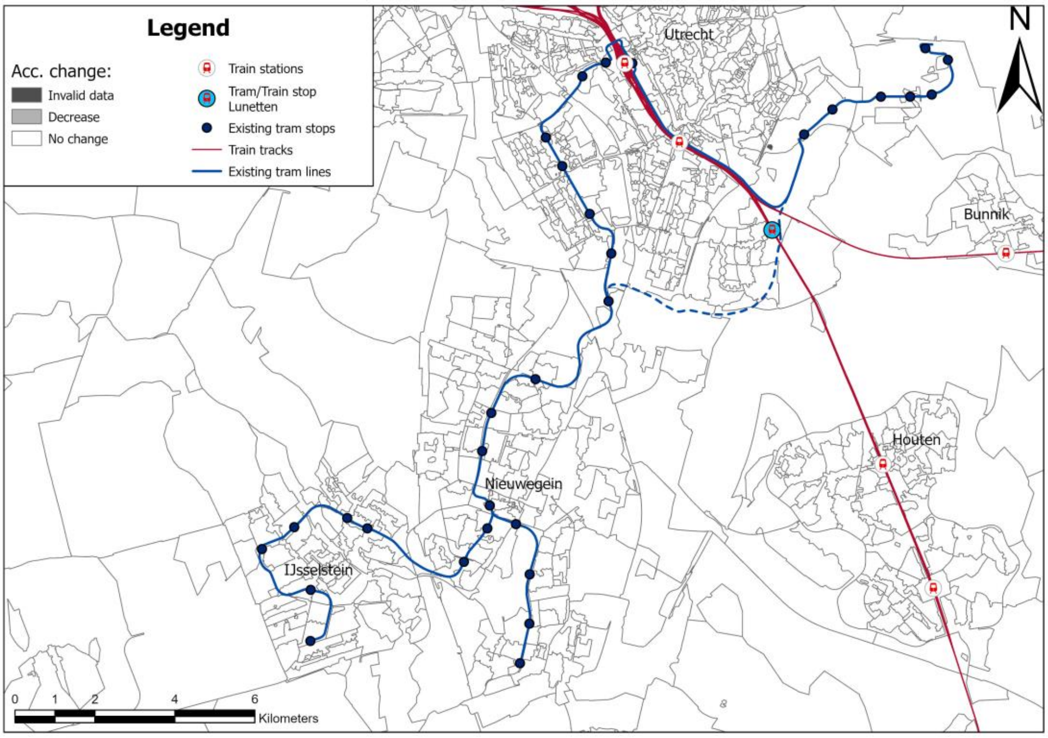

Figure 24: A12_0stops %Change in the 10 minutes travel time via public transport scenario.

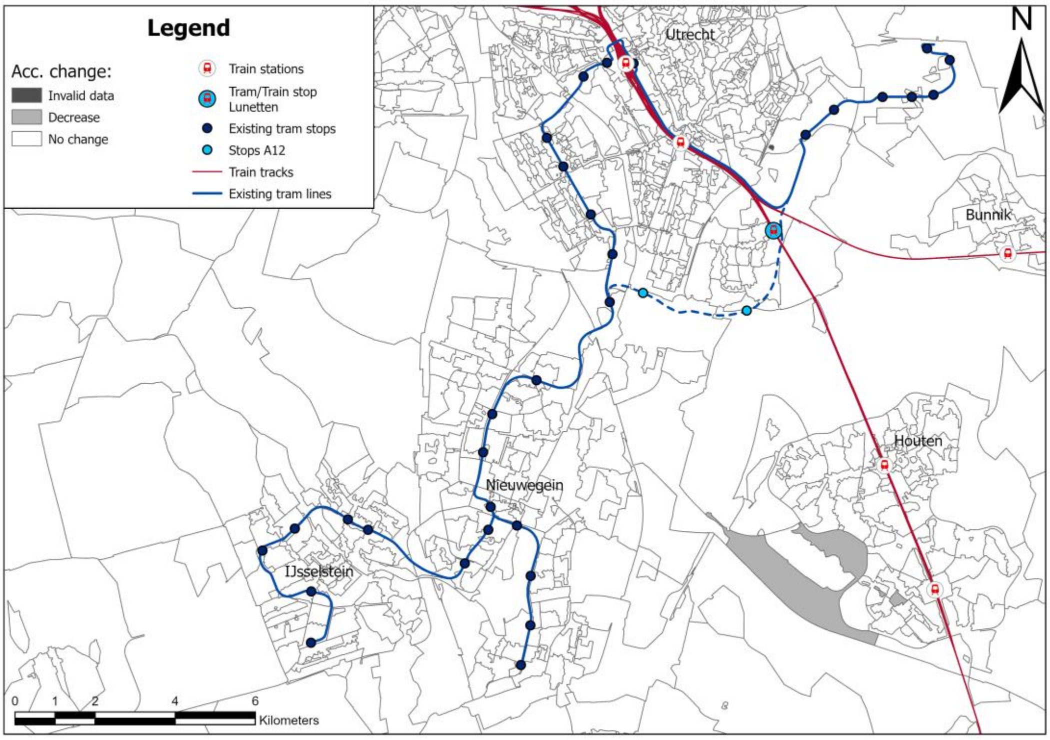

Figure 25: A12_2stops %Change in the 10 minutes travel time via public transport scenario.

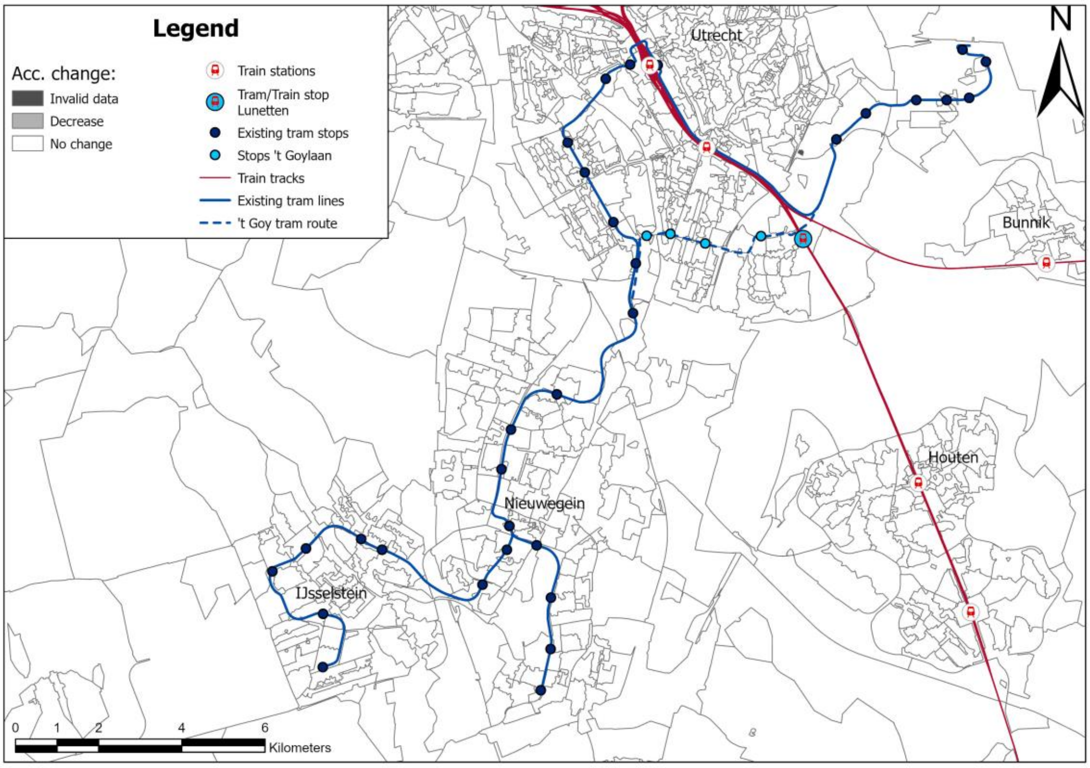

Figure 26: 't Goylaan %Change in the 10 minutes travel time via public transport scenario.

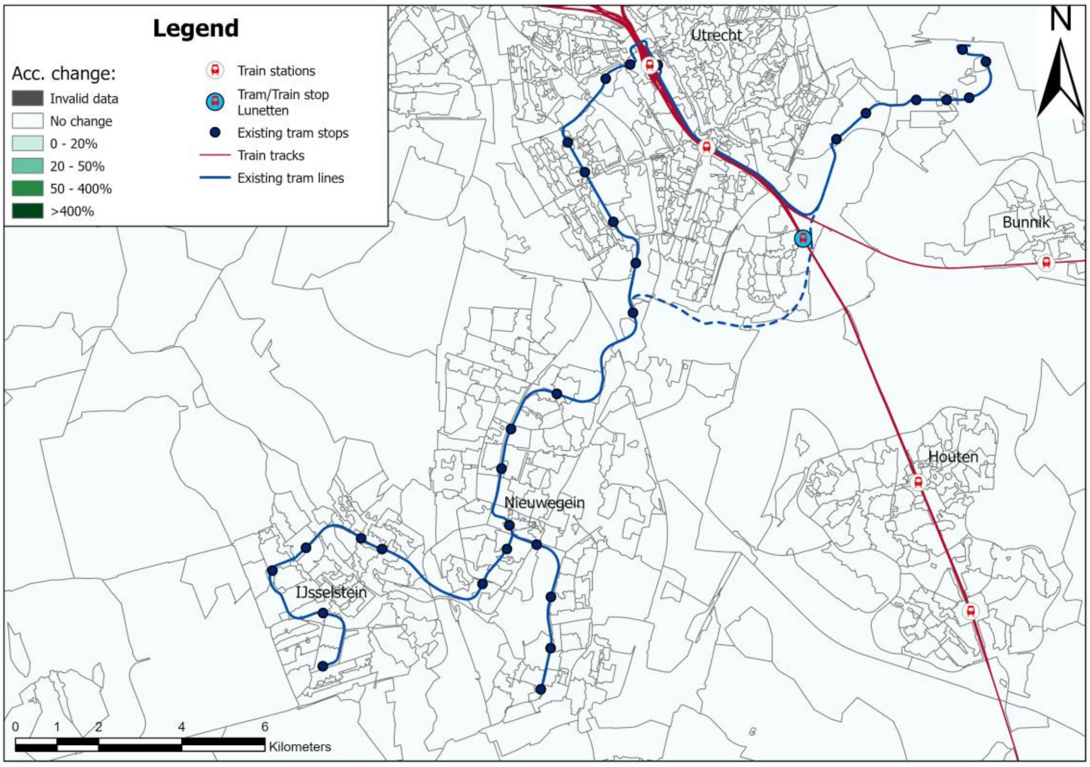

Figure 27: A12_0stops %Change in the 15 minutes travel time via public transport scenario.

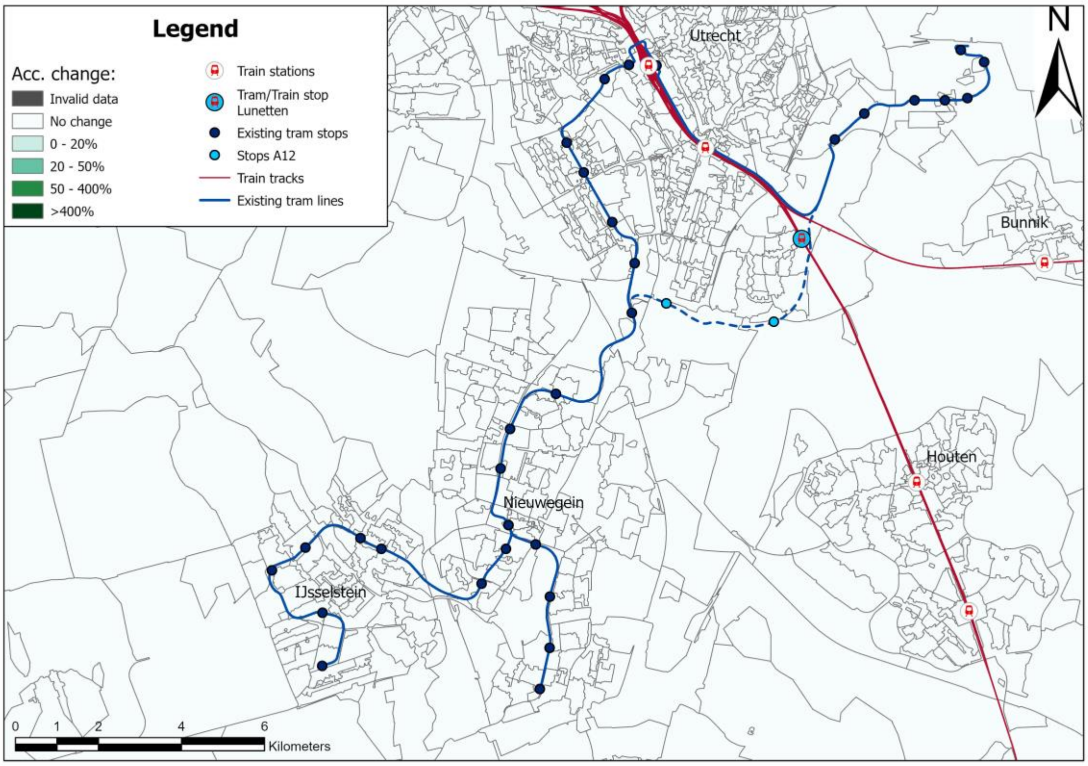

Figure 28: A12_2stops %Change in the 15 minutes travel time via public transport scenario.

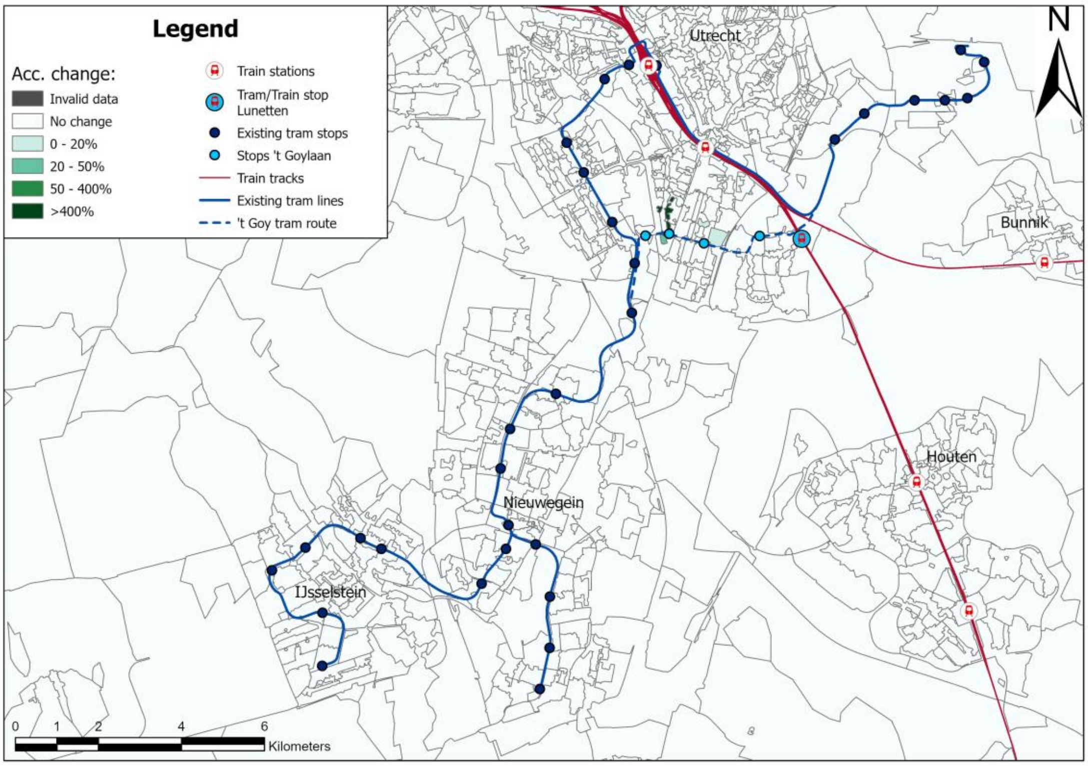

Figure 29: 't Goylaan %Change in the 15 minutes travel time via public transport scenario.

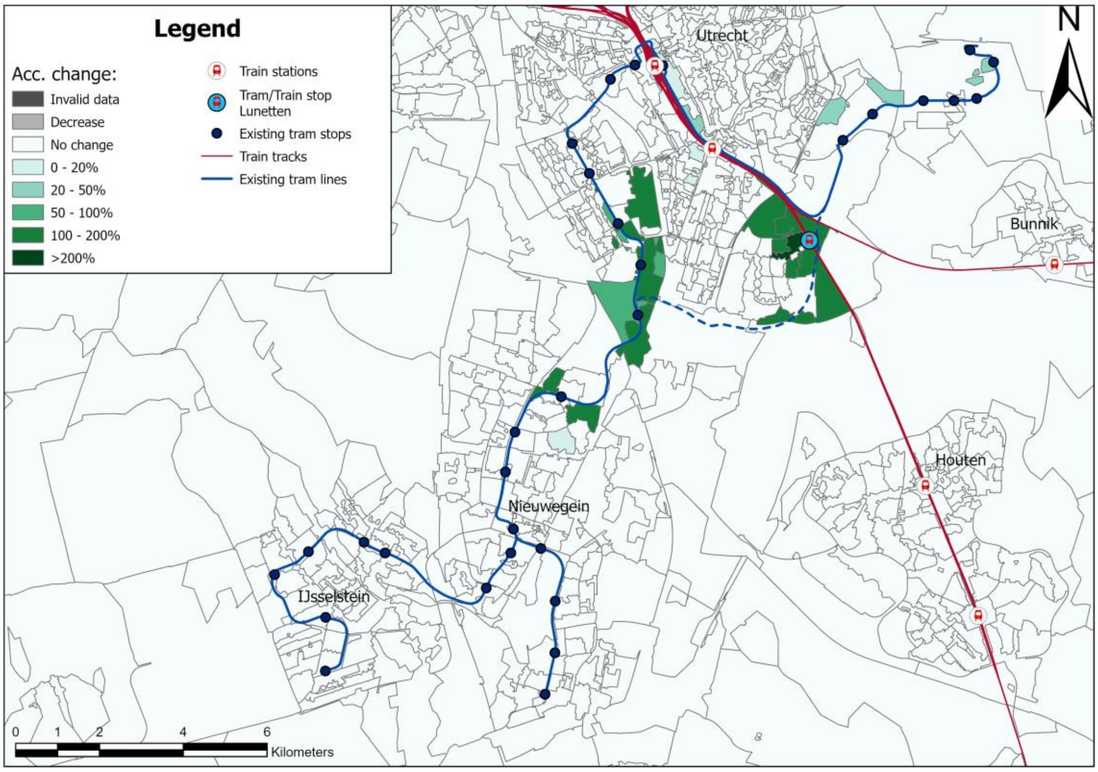

Figure 30: A12_0stops %Change in the 30 minutes travel time via public transport scenario.

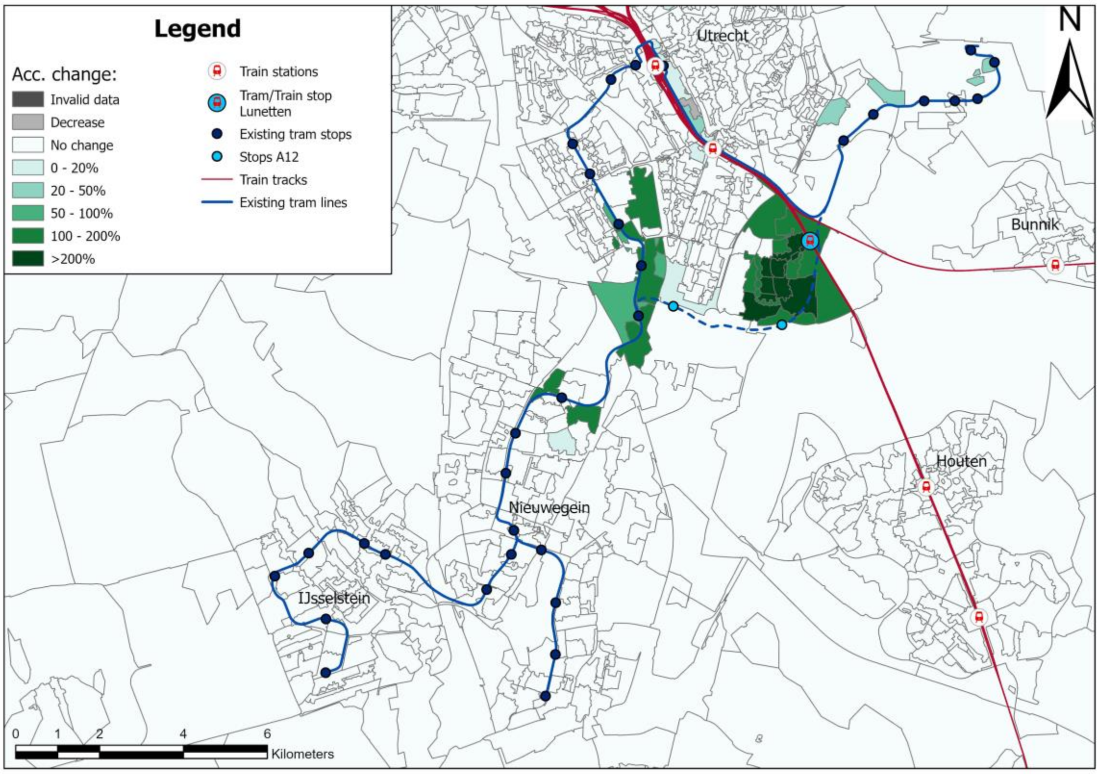

Figure 31: A12_2stops %Change in the 30 minutes travel time via public transport scenario.

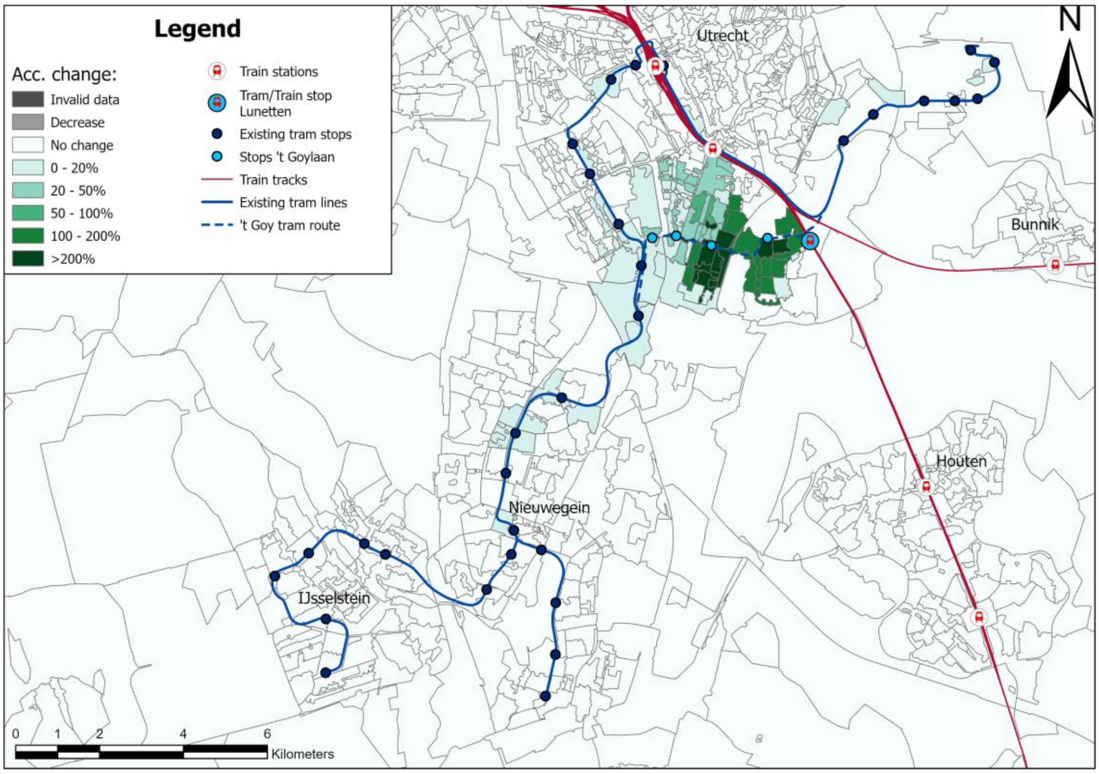

Figure 32: 't Goylaan %Change in the 30 minutes travel time via public transport scenario.

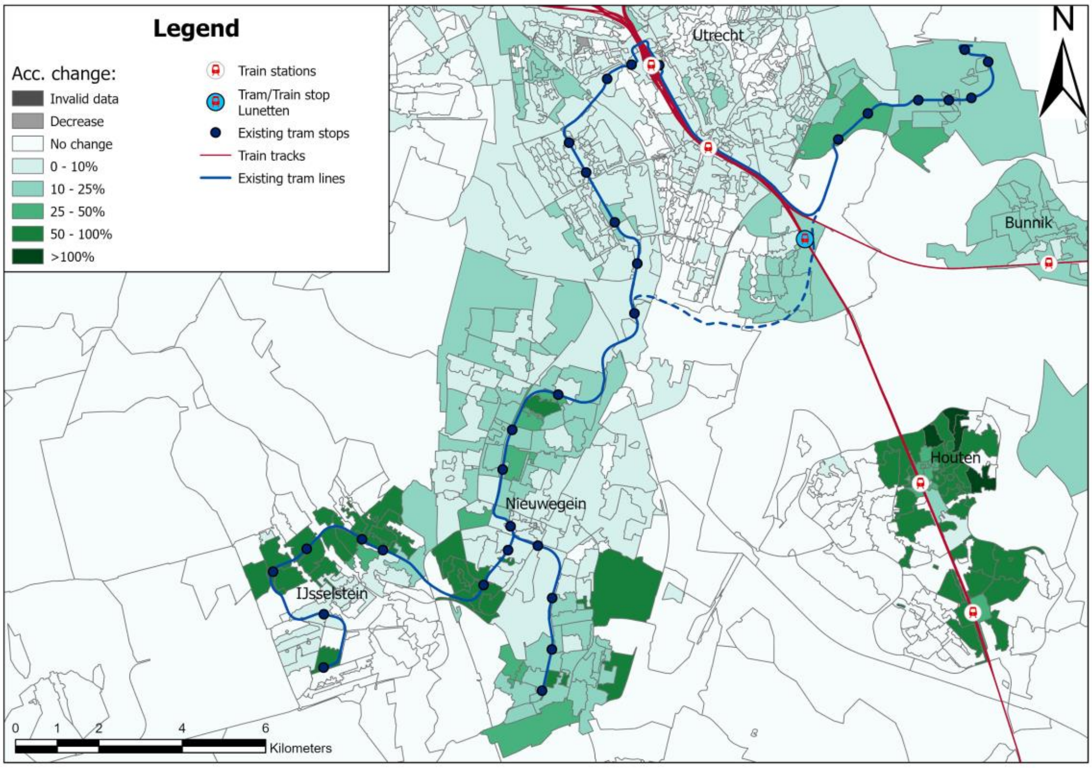

Figure 33: A12_0stops %Change in the 60 minutes travel time via public transport scenario.

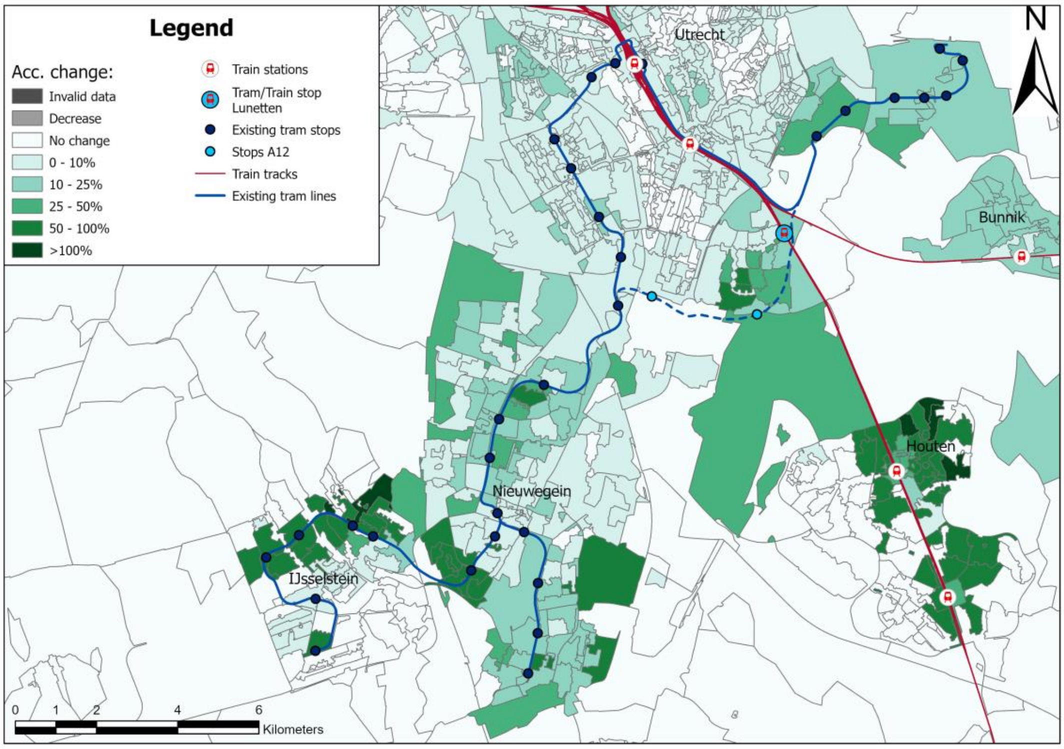

Figure 34: A12_2stops %Change in the 60 minutes travel time via public transport scenario.

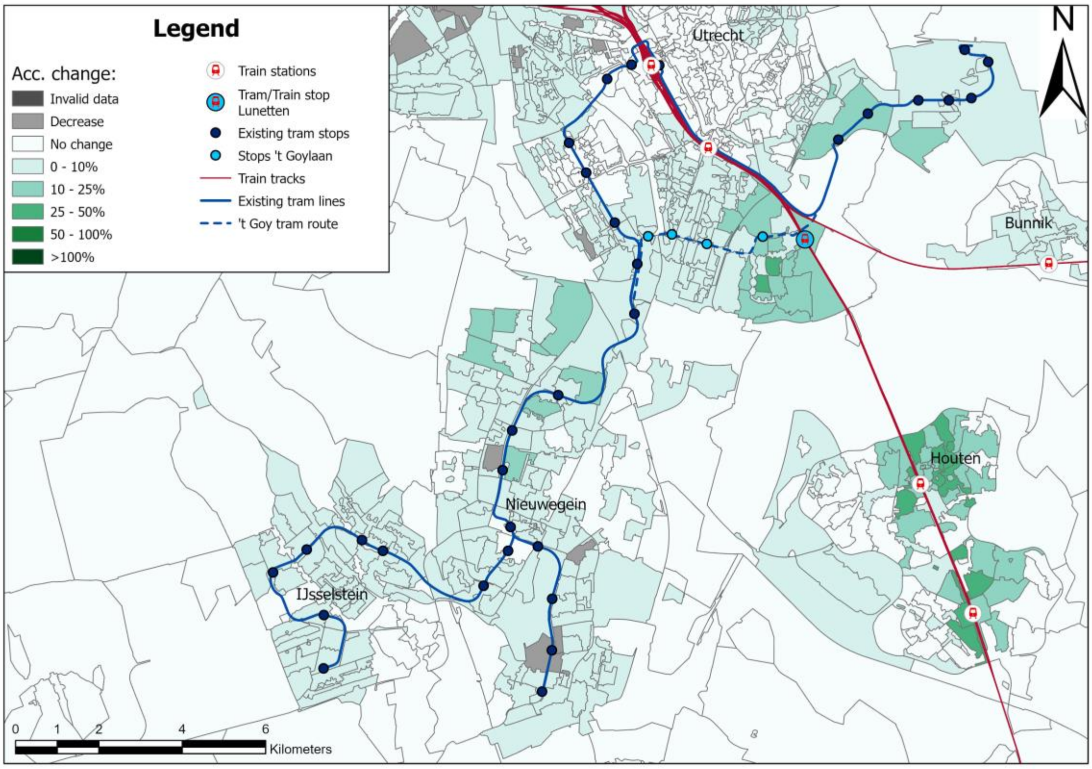

Figure 35: 't Goylaan %Change in the 60 minutes travel time via public transport scenario.

Appendix D: Maps of resulting accessibilities expressed in changed number of accessible jobs divided by the number of inhabitants

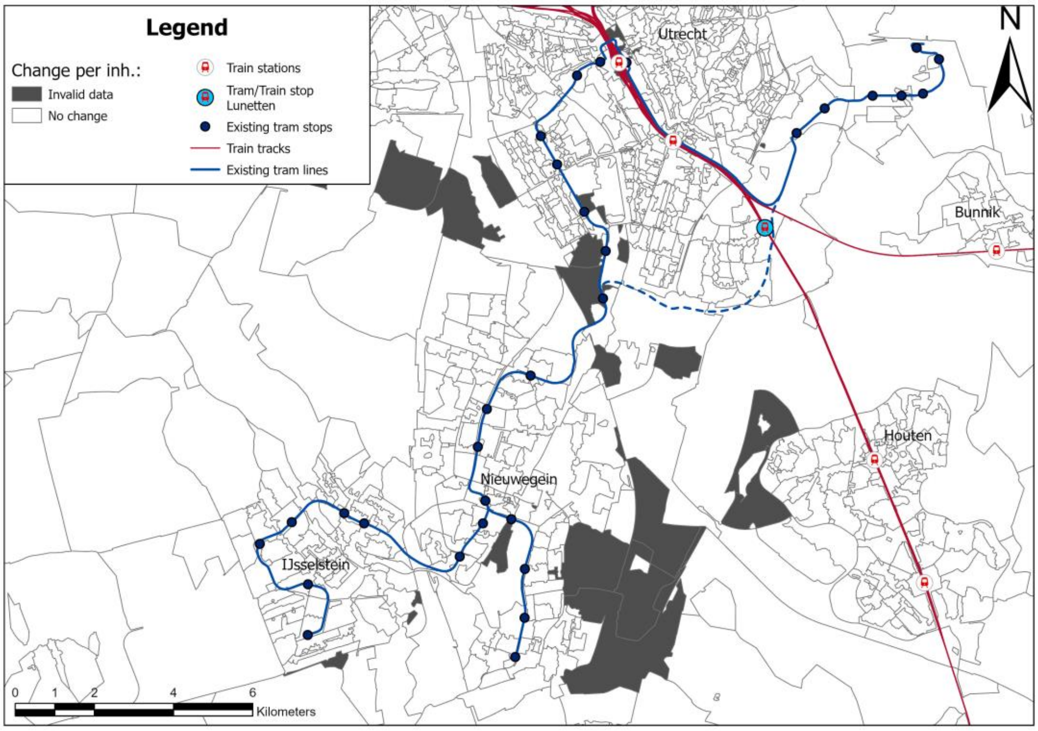

Figure 36: A12_0stops #jobs per inhabitant in the 10 minutes travel time via public transport scenario.

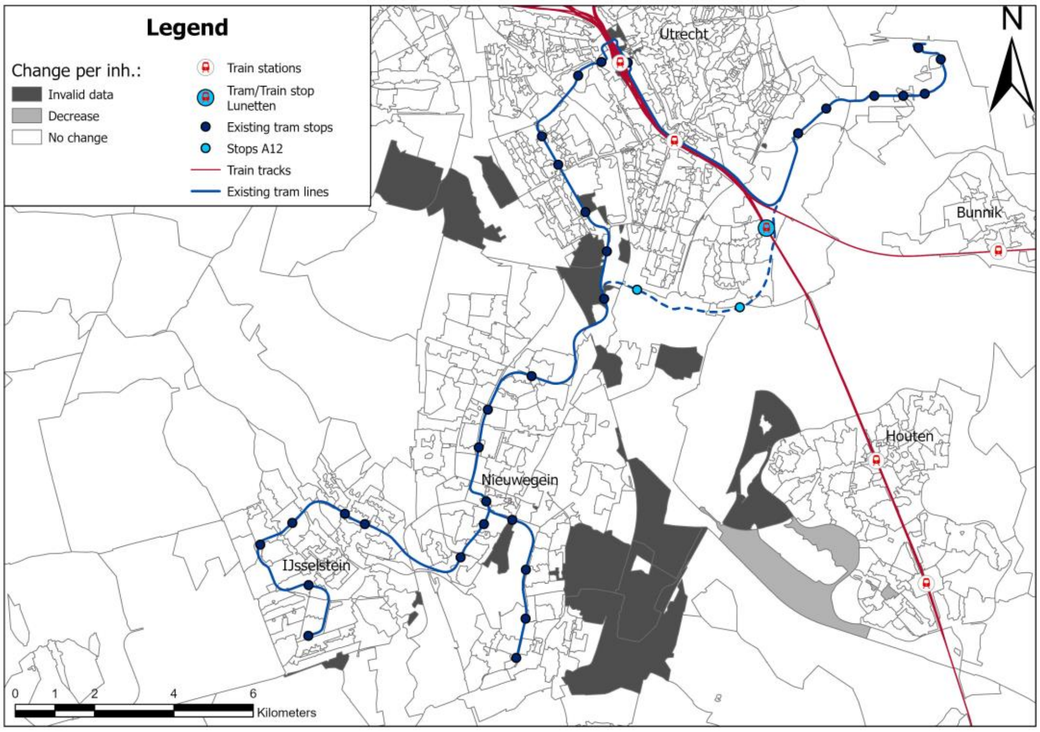

Figure 37: A12_2stops #jobs per inhabitant in the 10 minutes travel time via public transport scenario.

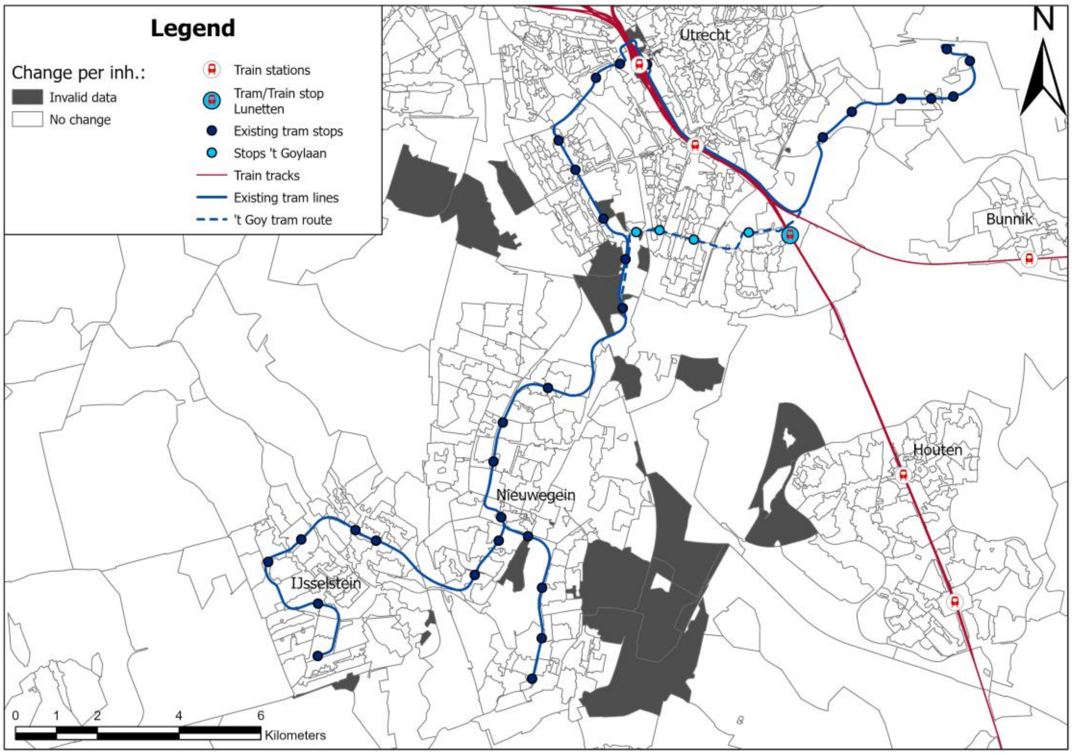

Figure 38: 't Goylaan #jobs per inhabitant in the 10 minutes travel time via public transport scenario.

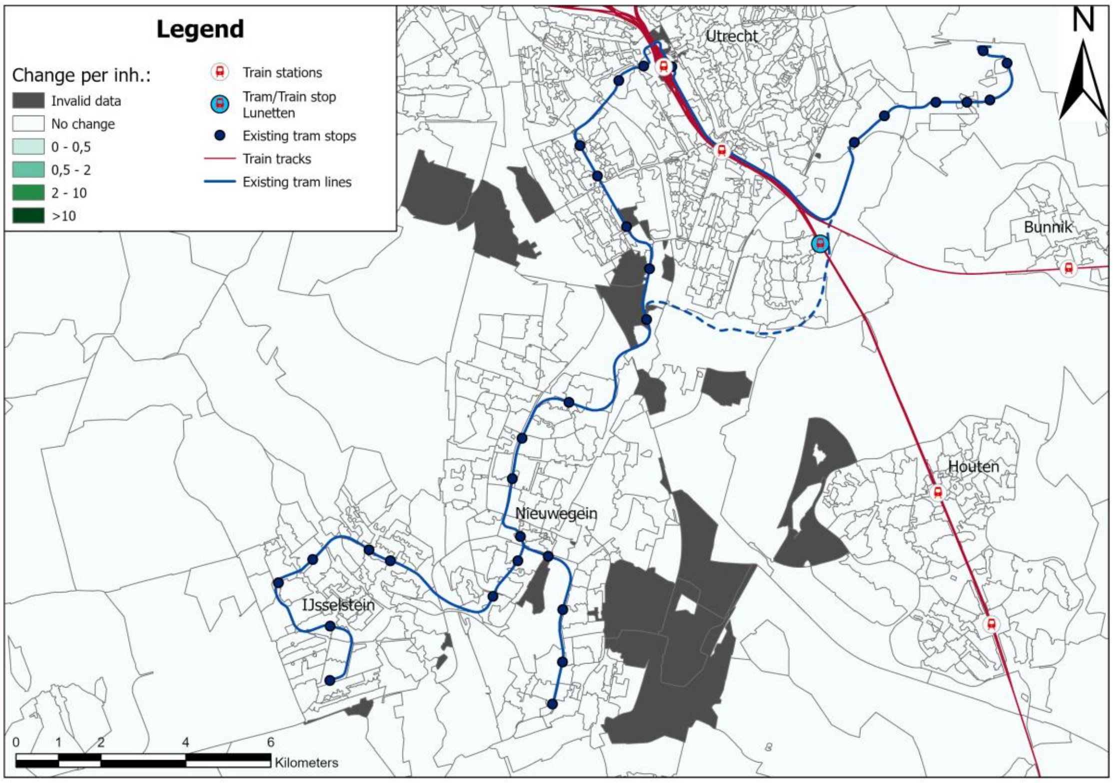

Figure 39: A12_0stops #jobs per inhabitant in the 15 minutes travel time via public transport scenario.

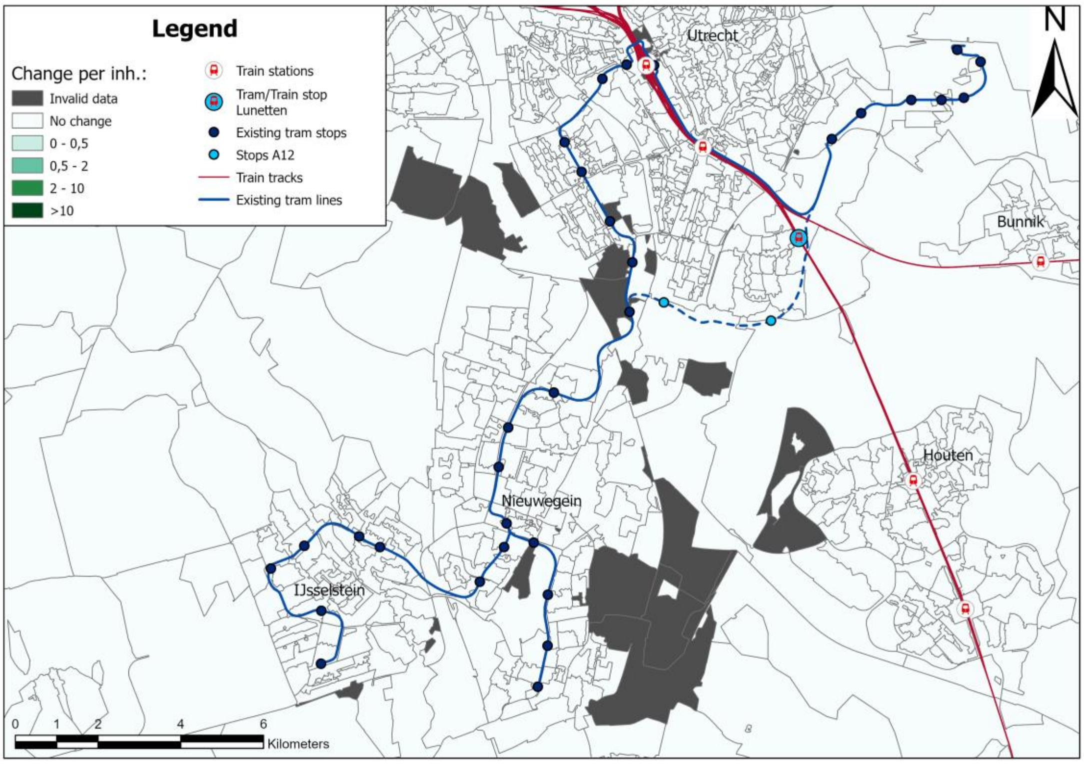

Figure 40: A12_2stops #jobs per inhabitant in the 15 minutes travel time via public transport scenario.

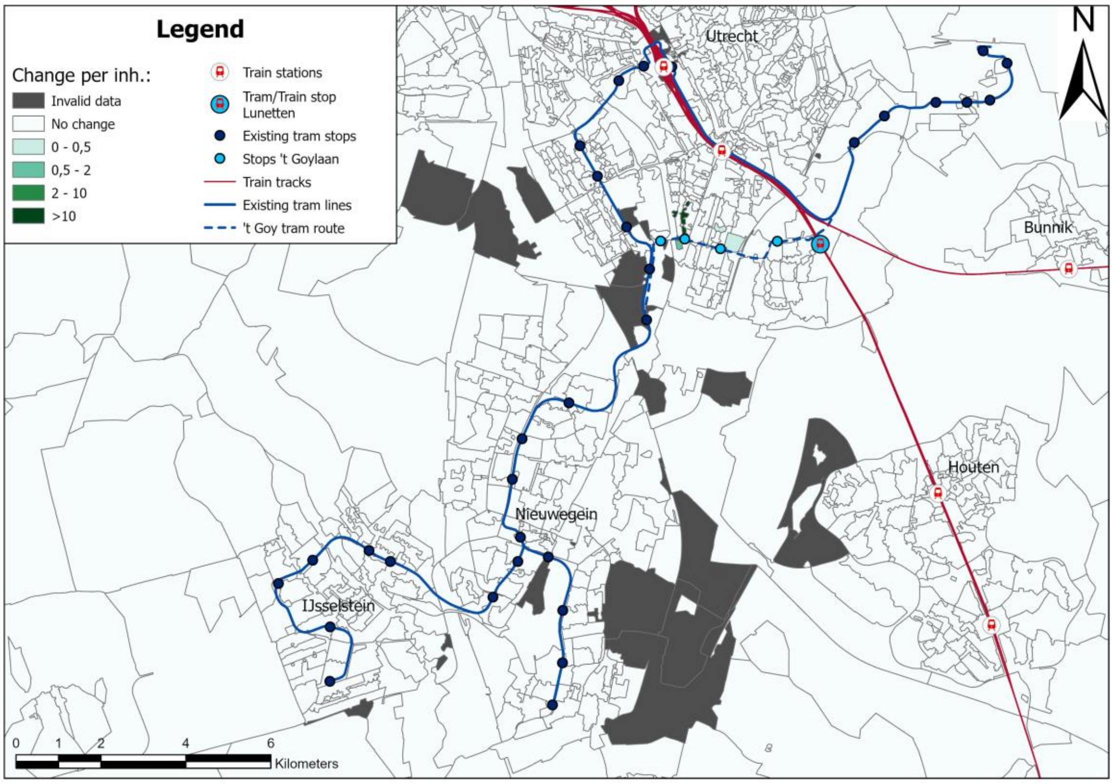

Figure 41: 't Goylaan #jobs per inhabitant in the 15 minutes travel time via public transport scenario.

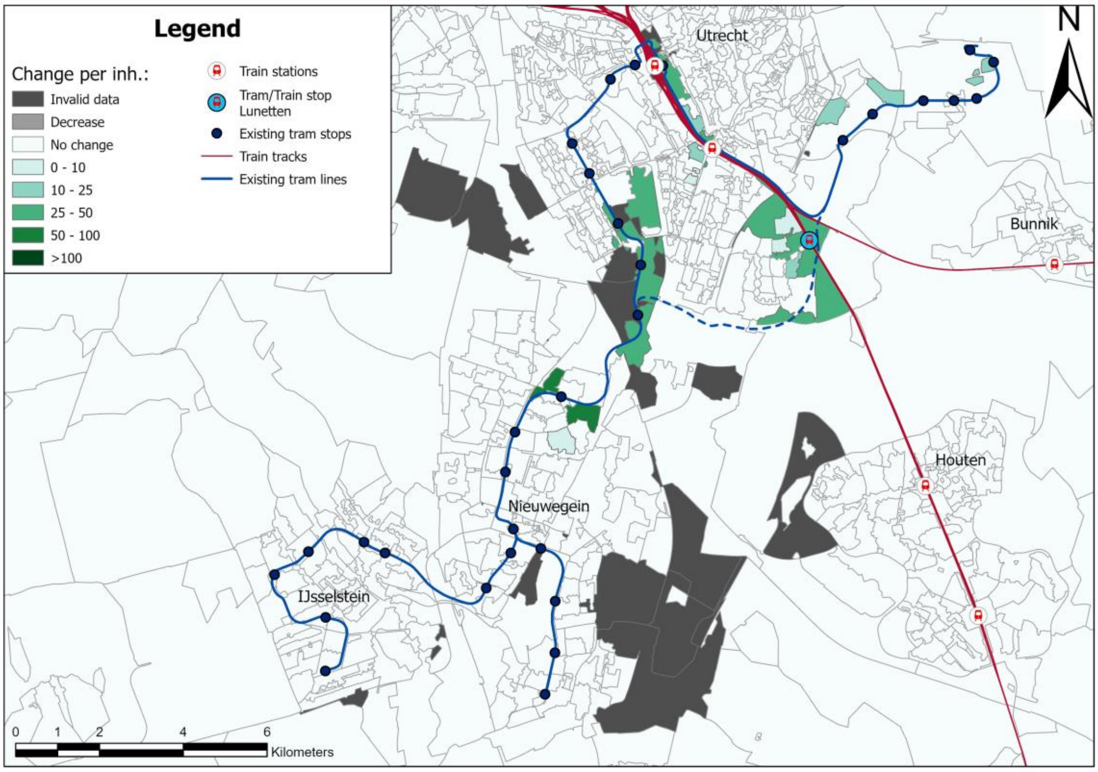

Figure 42: A12_0stops #jobs per inhabitant in the 30 minutes travel time via public transport scenario.

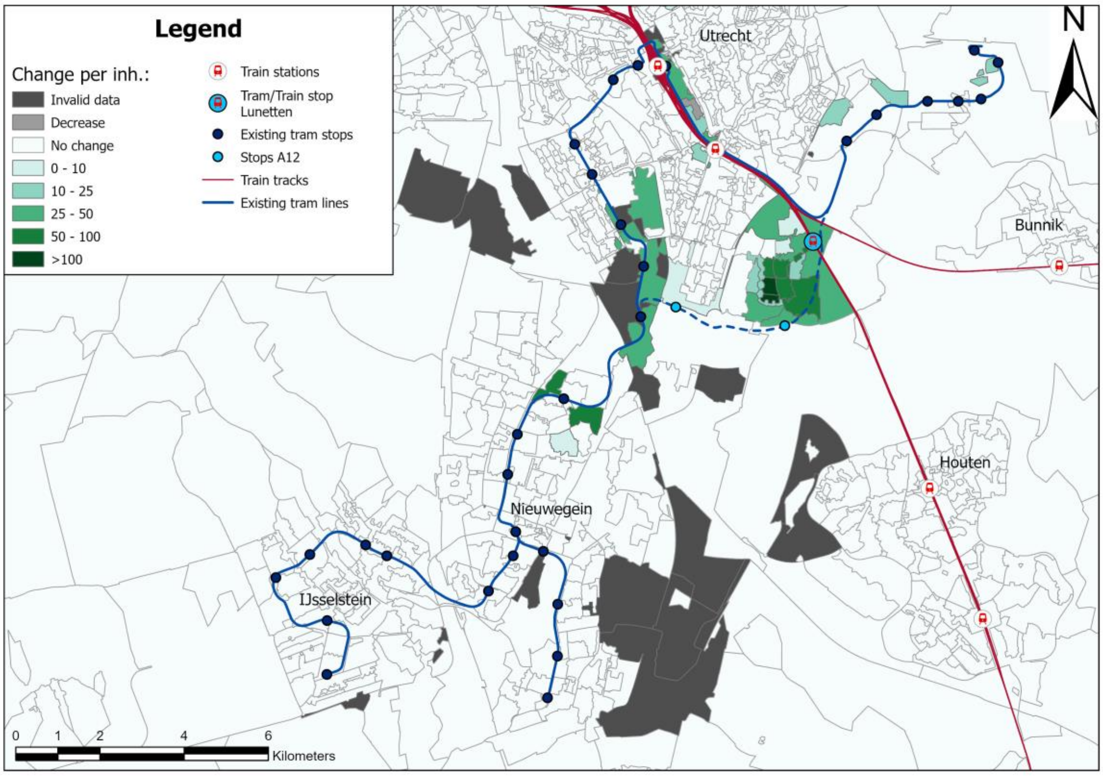

Figure 43: A12_2stops #jobs per inhabitant in the 30 minutes travel time via public transport scenario.

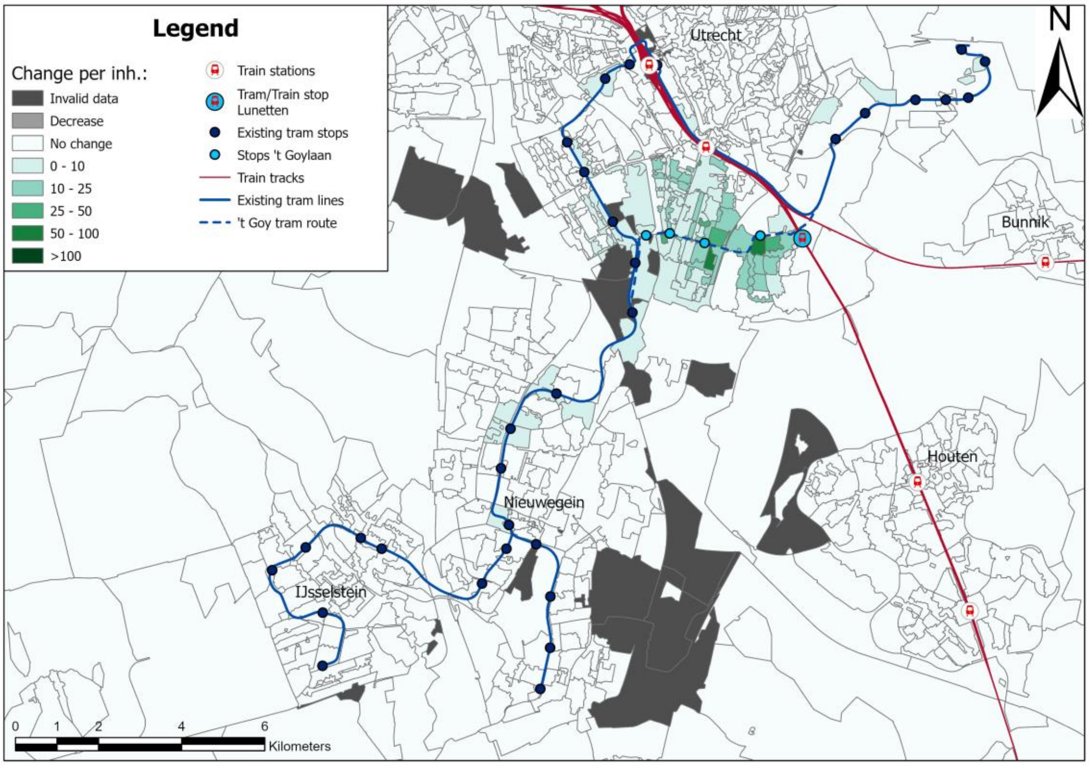

Figure 44: 't Goylaan #jobs per inhabitant in the 30 minutes travel time via public transport scenario.

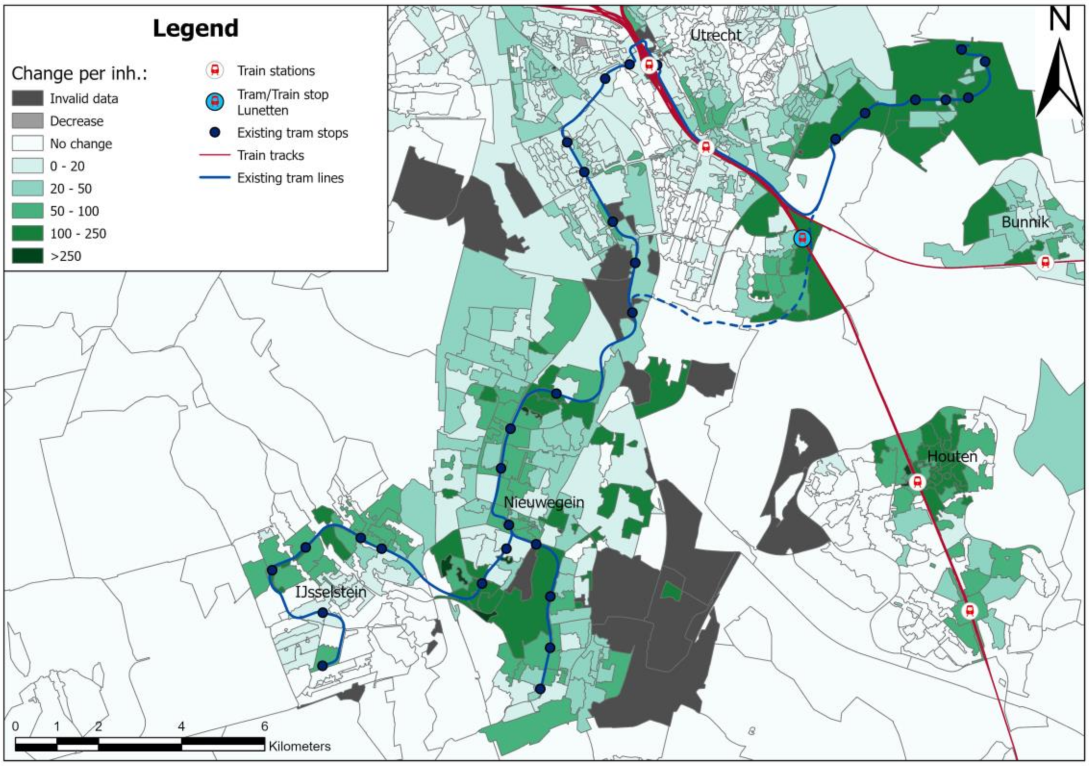

Figure 45: A12_0stops #jobs per inhabitant in the 60 minutes travel time via public transport scenario.

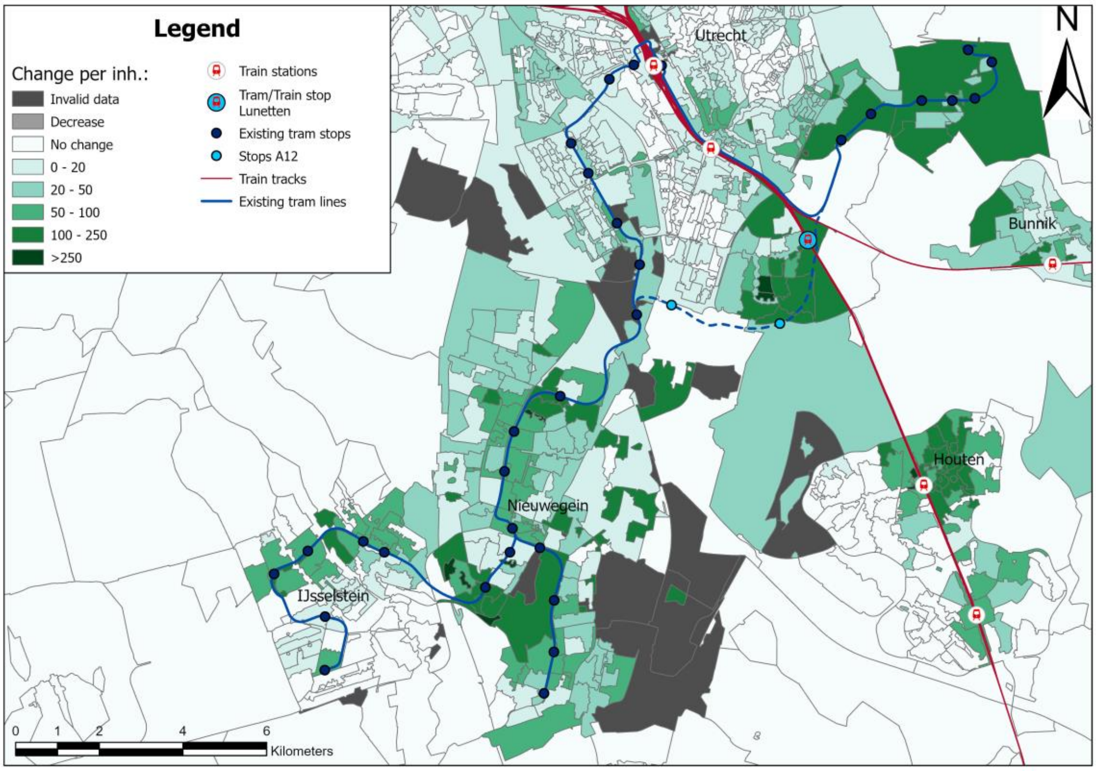

Figure 46: A12_2stops #jobs per inhabitant in the 60 minutes travel time via public transport scenario.

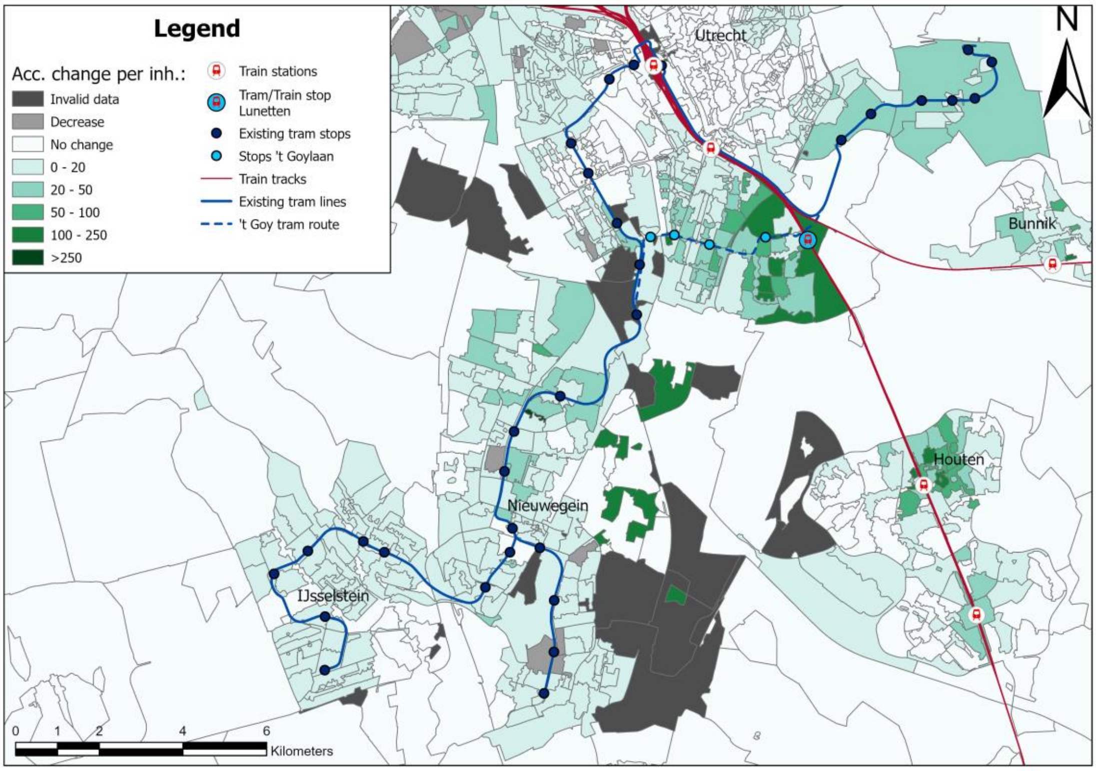

Figure 47: 't Goylaan #jobs per inhabitant in the 60 minutes travel time via public transport scenario.