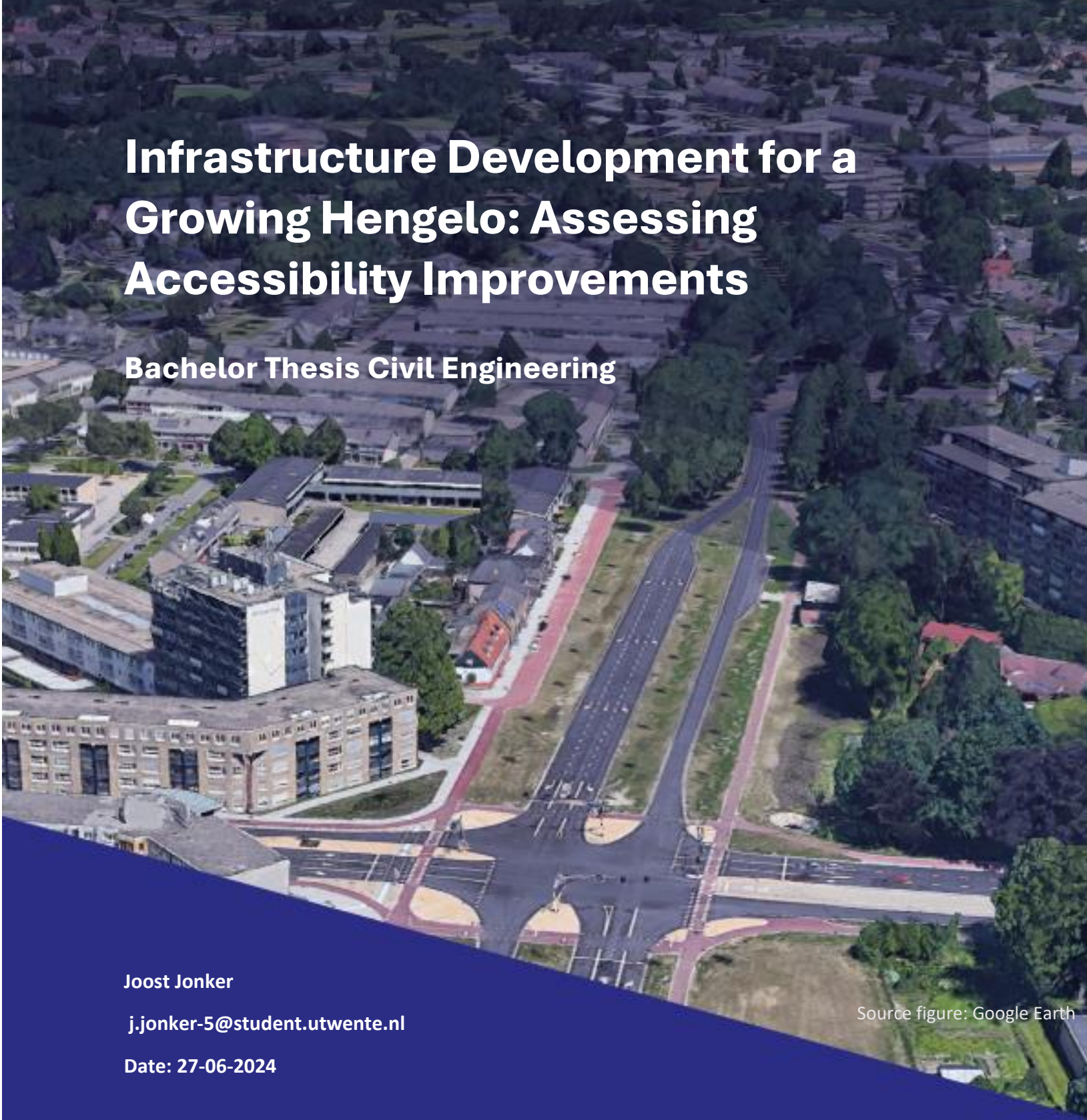
Infrastructure Development for a Growing Hengelo: Assessing Accessibility Improvements

Bachelor Thesis Civil Engineering



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Preface

In this report, I present my Bachelor Thesis assignment “Infrastructure Development for a Growing Hengelo: Assessing Accessibility Improvements”. This research was conducted on behalf of the Municipality of Hengelo. An exploratory study was needed in east Hengelo to improve the connectivity. I have evaluated various possible strategies to enhance traffic flow and reduce congestion in Hengelo. Hopefully, the municipality of Hengelo will benefit from this project. Throughout the graduation period, I gained substantial knowledge in using traffic models and writing this comprehensive report.

I want to thank my internal supervisor, dr. Anna Grigolon, for the guidance through my Bachelor Thesis for Civil Engineering. During meetings, she always made time for me to provide feedback and insightful tips during meetings Apart from that, she motivated me even more for this project. I would like to thank my internal supervisor, ir. Dennis ter Wengel too. He allowed me to develop my own vision but also guided me in the right direction. Next to that, I appreciate the colleagues for my warm welcome at the office in Hengelo. Finally, I want to thank the experts who helped me with my qualitative analysis of the infrastructure in Hengelo.

I hope you enjoy reading my thesis project.

Joost Jonker

Hengelo, 27-06-24

Disclaimer: Dit onderzoek betreft een theoretische opdracht naar het verbeteren van de bereikbaarheid van Hengelo. Hiervoor zijn fictieve alternatieven opgenomen ten behoeve van de studieopdracht.

Summary

The municipality of Hengelo expresses its desire to grow from 80.000 inhabitants to 100.000 inhabitants in 2040, which creates extra pressure on infrastructure in Hengelo. This thesis analyses the current infrastructure in Hengelo East and aims to improve accessibility in Hengelo East. Currently, congestion occurs daily because traffic intensity is higher than traffic capacity on certain road sections.

With the use of expert interviews and traffic data, the current infrastructure is analysed. Subsequently, three alternatives are formulated which are discussed with experts. The first alternative is the extension of the Laan van Driene, which is a plan that was created in the 1960s but never realised. The second alternative is upgrading the Nieuwe Grensweg and Bosweg to manage high traffic flows. The third alternative is the construction of the NOEK, a road that connects the University of Twente with the northern access road of Enschede. To analyse which of these alternatives would maximise the improvements in traffic conditions, traffic models are modelled in mobilityscan of Rijkswaterstaat using intensity data from the Regional Traffic Model of OmniTRANS. A Multi Criteria Decision Analysis (MCDA) was established to compare the three alternatives. The weights and criteria are derived from experts, literature, and model outcomes. This thesis presents an approach to improve accessibility in eastern Hengelo, using traffic data, expert data, and traffic models.

Interviews with specialists in the field of traffic provided qualitative information for the best solutions. The results of the interviews provide a basis for selecting the optimal solution for enhancing accessibility in Hengelo East. Together with quantitative intensity data retrieved from traffic models, the best-ranked solution can be retrieved from the MCDA. The extension of the Laan van Driene has the highest assigned score. Subsequently, the proposed solution is tested in VISSIM. It appeared that the current infrastructure could not cope with the increased intensity as a result of the new intervention. Improving current infrastructure resulted in an average decrease in travel time of 42% in peak hours.

In conclusion, the best strategy to improve accessibility and mobility during rush hours is the extension of the Laan van Driene. This intervention makes the biggest impact on accessibility by shifting traffic from the *wijkring* to the new connection.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Research Motivation

The recently published Mobility Plan of the municipality of Hengelo was the direct motivation for the Thesis Project. In this plan, they re-considered the plan of a direct North-East connection. The possible new connection is displayed in Figure 1.1 with a blue dotted line. For many years this connection has been the topic of discussion in and around Hengelo. Since the 1960s, extending the Laan van Driene was considered. Since then, the space has been reserved for the new connection. The construction of the new road has never been started, but the plan for the new connection was already established. LOS stadomland (2010) did research to suggest the best options for such a major intervention. LOS came with four slightly different alternatives on the extended Laan van Driene. All four options were vehicle-based options, and the options all see the necessity of a tunnel underneath the railway to Oldenzaal. According to the city council, the necessity was not high enough to give a green light to start the construction. These different alternatives and the reason why the construction never happened will be explained in section 1.4.

The municipality of Hengelo proposed an exploratory study for the construction of the extended Laan van Driene to resolve the rising traffic volumes on the road. This thesis aims to evaluate whether the plan formulated in 2010 still aligns with the increased intensity in the future, assumed by the mobility plan of the Municipality of Hengelo. Not only the extended Laan van Driene will be investigated as a possible improvement. Alternatives outside the municipality will also be assessed as possible improvements for eastern Hengelo.

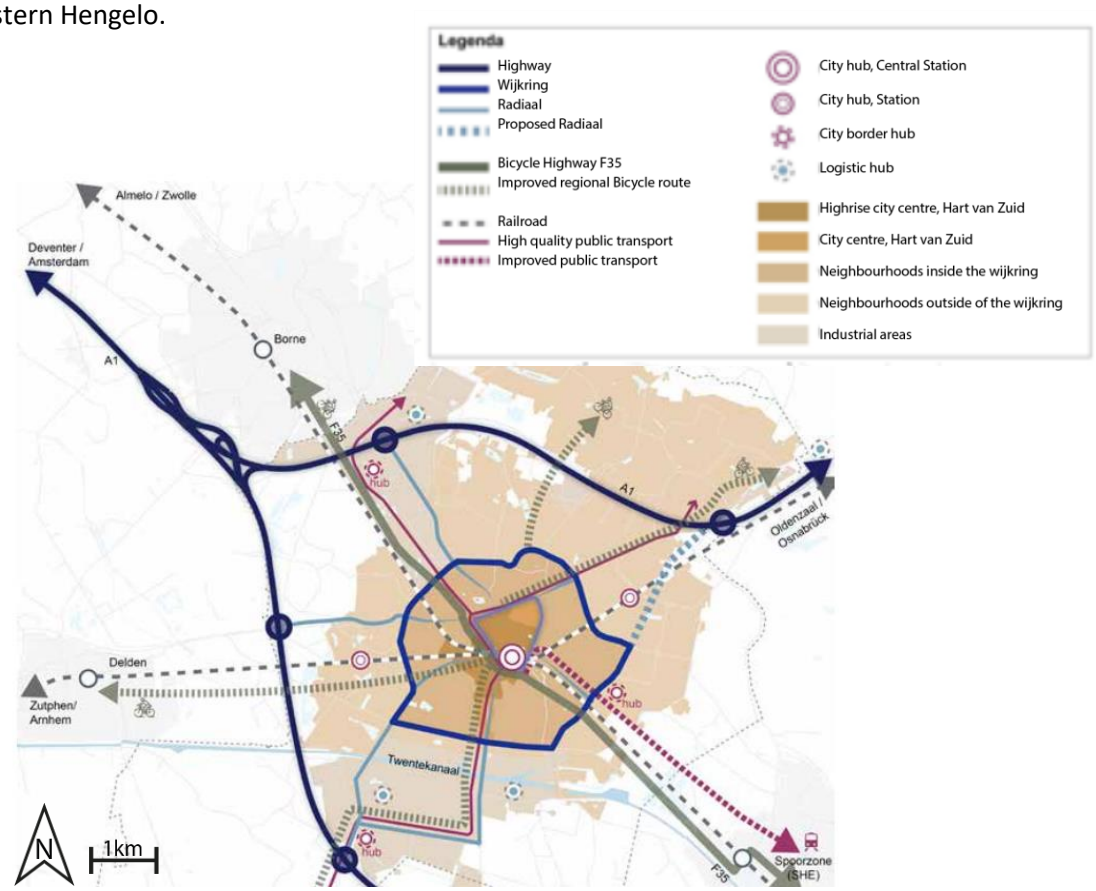

Figure 1.1 Most important roads in Hengelo with the proposed new road (Source: Gemeente Hengelo, 2023)

1.2 Problem context

The municipality of Hengelo aims to grow its population from 80.000 to 100.000 residents. As a result, this increase in population will lead to more movements through the city. The demand for transportation and infrastructure increases, resulting in higher traffic volumes in 2040. The southern area in the city and the area near the railroad between Hengelo and Enschede are allocated for housing. This increase in inhabitants leads to undesirable bottlenecks.

In the current situation, traffic coming from the Oldenzaalsestraat, or the northern neighbourhoods in Hengelo, does not directly connect to the eastern part of Hengelo. They first must head towards the centre, before they can reach the eastern part of the city, and the Enschedesestraat. This results in a high traffic volume on the Beethovenlaan and the Oldenzaalsestraat. This traffic volume then consists of many cars that do not have their origin and destination in the city of Hengelo. In rush hours, this drive-through traffic could be one of the reasons for the long traffic jams on the *wijkringen* and the Oldenzaalsestraat. Safety is consequently a factor at issue when the traffic volume is too high for the capacity of the ring roads. Not only safety for the road users but also for inhabitants of the city. Because of the congestion, emergency services experience hindrances on the Oldenzaalsestraat during rush hours. This means that the travel time for police, ambulance, and fire brigade increases. Which is unfavourable for residents in need of assistance.

In Figure 1.2 the traffic intensities for one day are shown. The clear visualisation of traffic in Hengelo shows that the *radialen* has the highest traffic volume. This is expected since these are the roads that lead traffic from the highways to the city. However, traffic volumes on the Oldenzaalsestraat and Beethovenlaan are high because of the high intensity of through traffic. In Figure 1.3, the destinations of traffic over the Laan van Driene are shown. There is a lot of through traffic on this road section, with destinations beyond the municipality of Hengelo border.

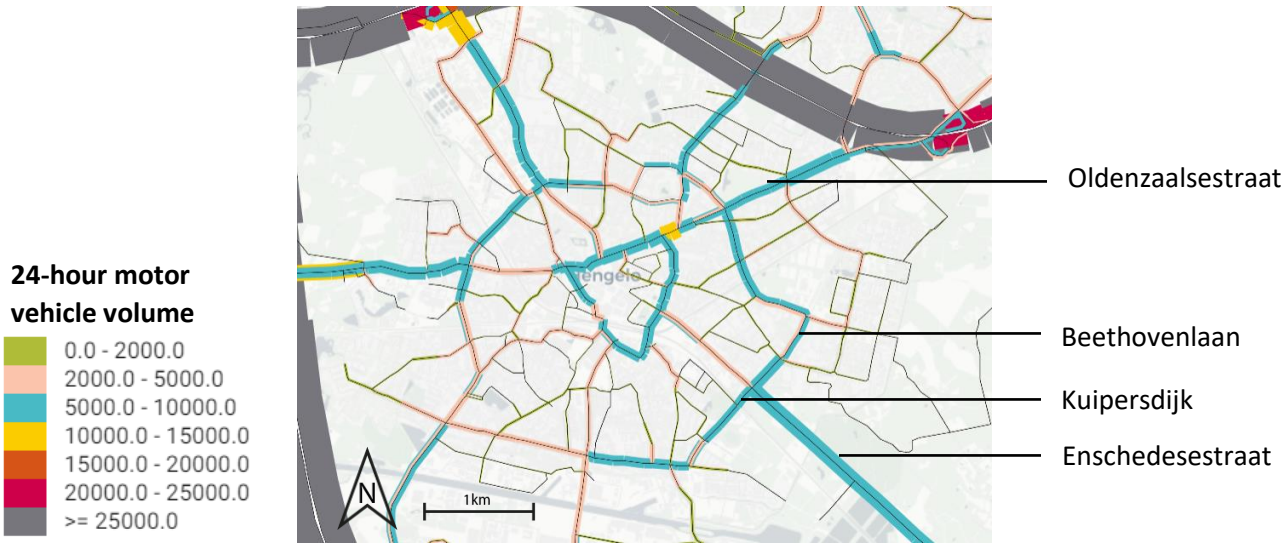

Figure 1.2 Base model 2020, 24-hour traffic intensities in Hengelo (Source: OmniTRANS)

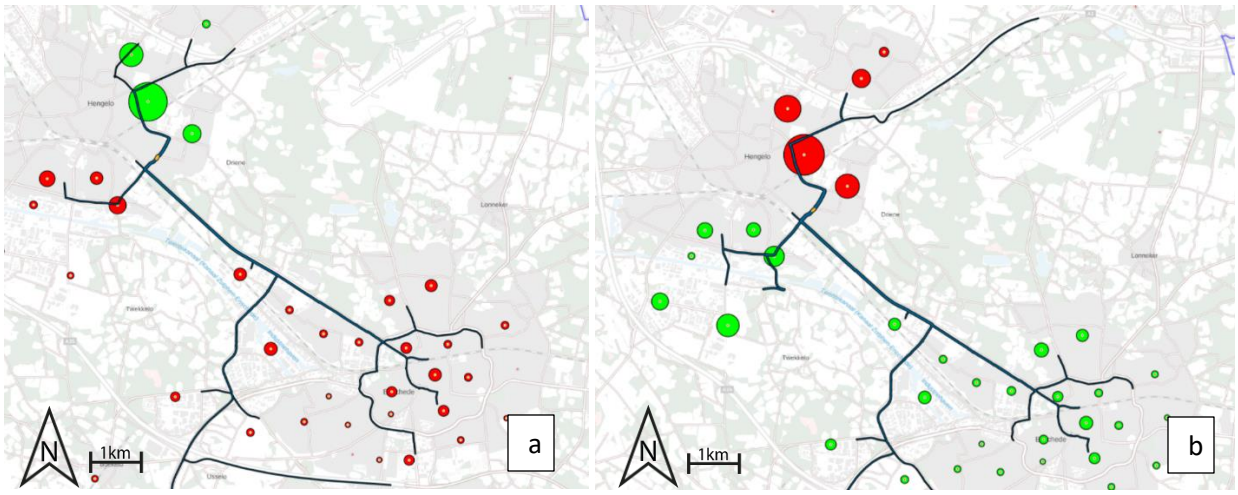

Figure 1.3 Origins (green) and destinations (red) in the morning rush hour (a) and evening rush hour (b). (Source: Mobilityscan)

The problem that could arise when the extended Laan van Driene is realised is that more traffic will make use of the intersection Enschedesestraat/Kuipersdijk. Traffic coming from the eastern part of Enschede could use the newly constructed extended Laan van Driene to reach the A1 highway. This way there is again much drive trough traffic making use of the ring. This increase in extra traffic will be researched as well in the thesis project. When rebuilding the intersection Enschedesestraat/Kuipersdijk in 2016, the municipality took into account the possible traffic volume increase when the extended Laan van Driene would be realised. At the intersection, there is space available for extra turning lanes for higher capacity.

1.3 Involved parties

In this subchapter, the involved parties of this thesis project will be explained.

Municipality of Hengelo

The municipality of Hengelo published their mobility plan for 2040 in which they express their ambitions in terms of mobility. The municipality is the client for this thesis project.

Municipality of Enschede

The neighbouring municipality of Enschede is also identified as a stakeholder. Inhabitants of west Enschede use the eastern part of Hengelo to reach destinations in the western part of Twente, which became clear after the selected link analysis in the above subchapter. Furthermore, the Municipality of Enschede had plans to connect the University of Twente and Kennispark better to the North. This connection was not established due to financial constraints. The establishment of this connection could have an impact on the traffic situation in Hengelo East. However, this plan will not take place.

City Council

The city council is the party with the decision power. In previous years, the extended Laan van Driene has been rejected. The city council decided that the impact on the area was too big in comparison with the

benefits. Furthermore, the project was too expensive. The mobility plan of the municipality is straightforward concerning the mobility in Hengelo. “An exploratory study is needed in east Hengelo, to improve the connectivity.”(Gemeente Hengelo, 2023)

Road car users

The car users in Hengelo East are stakeholders who experience the traffic situation on the road. In the rush hours, congestion occurs often. Car users benefit from the enhancement of the traffic situation in Hengelo. When congestion decreases, car users experience better traffic situations. In this research, trip volumes represent the road car users. Their opinions were not heard in this research, which can be a limitation.

Residents Hengelo

The residents of the neighbourhoods in eastern Hengelo will benefit from better accessibility when the increasingly busy situation is solved. When the extended Laan van Driene plan is continued, no housing has to be demolished because the area for this plan has been reserved since 1970. There are some allotment gardens located in the area where a possible extension of the Laan van Driene is planned. The people who have their gardens in these could experience the extension as inconvenient. The residents in eastern neighbourhoods were not heard during this research, which can be a limitation.

1.4 Scope

The scope of the project is the northeastern part of Hengelo. The boundaries are the roads of the *wijkring*, Oldenzaalsestraat, and the neighbourhood Groot Driene. In Figure 1.4, an extensive overview of the most important roads and places can be found to understand the thesis better. This map overview can be helpful to achieve understanding while reading this thesis.

Inhabitants of Groot Driene experience excessive traffic through the neighbourhood because the neighbourhood is used as a shortcut when the *wijkring* is congested. The route through the neighbourhood can be faster when the wijkring is congested. The *wijkring* and Oldenzaalsestraat are roads where accessibility improvement is needed.

The boundaries of the scope are not rigid, the main goal is to improve accessibility in Hengelo East. However, the aims of the mobility plan of the municipality are also taken into consideration. One of the aims is to reduce traffic using the *centrumring*, this is also a factor that is taken into account. Nevertheless, the main goal of the thesis is to improve accessibility in Hengelo East. Several alternatives to reach this goal, lie outside the boundaries. Underneath the overview of the Hengelo map, the proposed plan of the Extended Laan van Driene by LOS stadomland is elaborated with extra background information about infrastructure in the area.

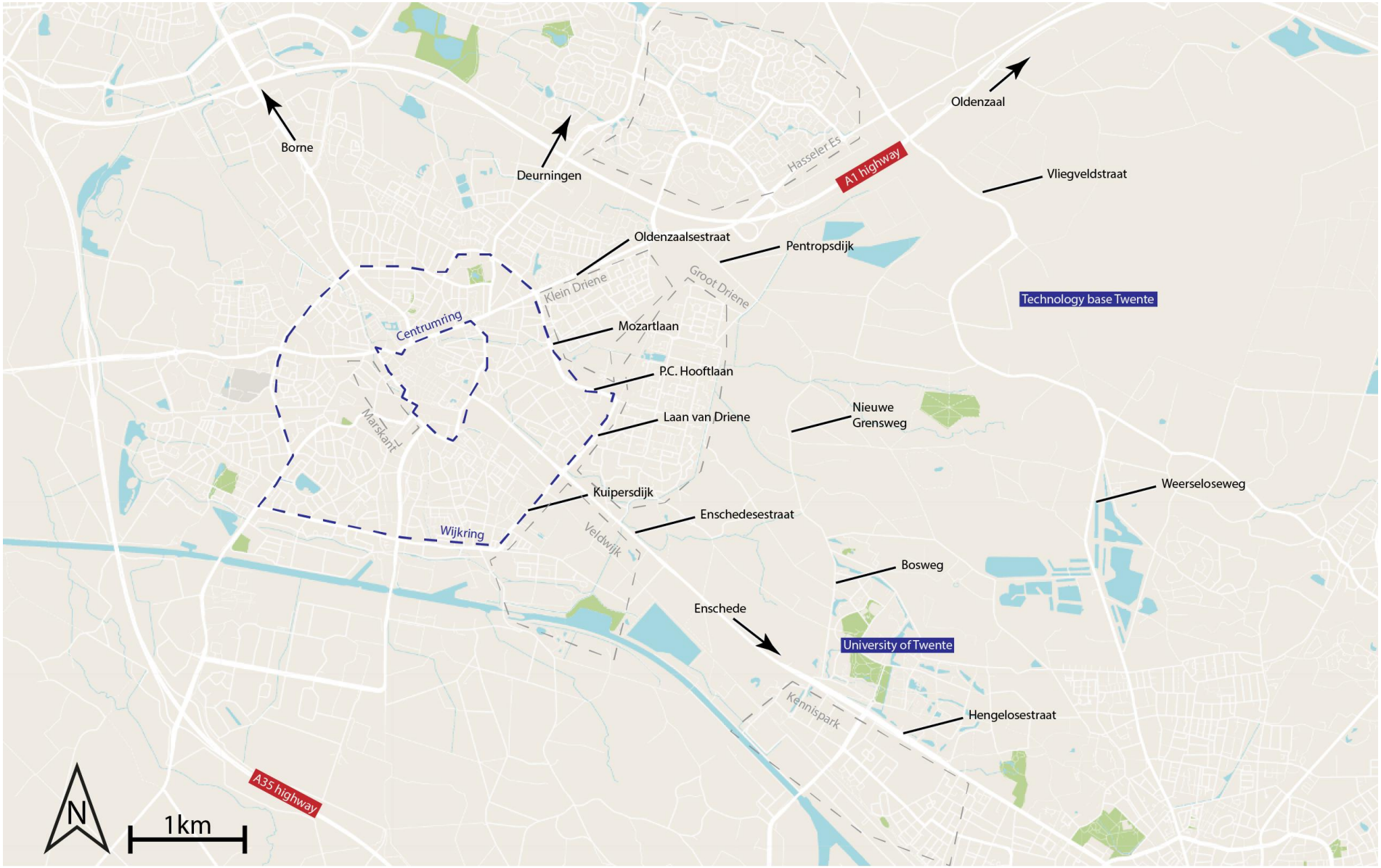

Figure 1.4 Overview Hengelo and parts of Enschede.

Inside the scope, four alternatives were suggested by LOS stadomland in 2008. The options are in essence the same, they propose to extend the Laan van Driene. However, in detail are all four alternatives slightly different from each other.

1. The first option defines the borders of the city, it is stated that this road would be a collector road, which will ensure connectivity with the neighbourhoods on the western side. Subsequently, the eastern side of the road will be the end of the city, the green landscape will be the focus of this side. This option emphasises the completion of the city, it is presumed that there will be no new neighbourhoods on the eastern side of the new road. One of the downsides of this option is that the road crosses the football fields of BWO.
2. The second option that has been proposed, sees the new road as an arterial road. There is no connectivity with neighbourhoods and will directly connect the Oldenzaalsestraat with the Laan van Driene. The road will be sunken, with a partly underground part, which ensures the connectivity between the neighbourhoods themselves.
3. The third option has similarities with the first option, but the connection with the Oldenzaalsestraat is located more eastern. The advantage of this is that football club BWO does not have to relocate.
4. The fourth proposed option focuses on the landscape, the road will follow the meandering landscape, and connects with the neighbourhoods. The advantage of this option is the convenient connection with station Hengelo-Oost.

After determining the four alternatives, a Multi Criteria Decision Analysis (MCDA) has been conducted. The outcome of the decision analysis was that alternatives 1 and 3 are the best options. The preference of the municipality went to the third option which was called “Groene entree – stadspoorten”. The advantage of extending the Laan van Driene is the decrease in traffic in the neighbourhood circles. In the Mobility Plan is mentioned that car traffic will be reduced by 30-40% on the Beethovenlaan and P.C. Hooftlaan if the extended Laan van Driene is realised. (Mobiliteitsplan Hengelo, 2023)

However, the plan was never executed. One of the reasons why the plan was put on hold could be the road vision plan of Regio Twente which was published in 2010. In their vision, the Technology Base Twente should be connected with the northern part of the University of Twente campus. Thereafter, the Technology Base Twente should have a direct connection with the A1. According to this vision of Regio Twente, extending the Laan van Driene is unnecessary. (Regio Twente, 2010)

Another reason why the realisation did not happen was the lack of support from the governing parties. In the coalition agreement of 2010, the coalition parties stated that the study Laan Van Driene is completed with a reservation for the possible extension. They will not propose to the council for this new connection. In this same coalition agreement, there is again focus on the “innovation triangle” (innovatiedriehoek). The main focus in 2010 was on the connectivity between the University of Twente, Technology Base Twente, and the city of Hengelo. (Gemeente Hengelo, 2010)

One segment of the innovation triangle was a connection called the NOEK (Noordelijke Ontsluitingsweg Enschede Kennispark), which connects the Kennispark directly to the Technology base. However, in 2018, the municipality of Enschede decided that the earmarked budget was not sufficient for the connection, and the utility was not high enough to realise the connection (Louwes, 2022).

The success of the development of the Technology Base Twente falls short of expectations. The main requirement for businesses who want to establish on the former Airport is that their main focus is on the research and development of new technologies. There is not much demand for these kinds of companies on the Technology Base. Ordinary production facilities do not get a permit to build on this terrain, since the main focus is developing new technologies (Louwes, 2023).

Because of the low demand for companies at the Technology Base, the direct highway ramp to the A1 highway seems far away. This opens opportunities again for extending the Laan van Driene, to ensure great accessibility to the Oldenzaalsestraat/A1 highway.

2. Literature Review

To understand the meaning of accessibility and mobility El-Geneidy & Levinson (2006) define accessibility as the ease of reaching destinations rather than travelling along the network. In their paper, they state that great mobility does not mean that high levels of accessibility are present. They compare two different cases of travel. When travelling is slow, but there are many opportunities over short distances, the accessibility in general is high because of the high level of opportunities. On the other hand, if road speeds are high, but there are not many opportunities in the area, the accessibility is low because there are few opportunities to reach. This example is simplified in Table 2.1. The study of Geurs and van Wee (2004) indicates that accessibility is the concept of how well land-use- components and transportation systems facilitate users in reaching destinations using a combination of traffic modes. Both papers state that accessibility can be explained as the extent of opportunities that can be reached.

Table 2.1 Differences between mobility and accessibility

Opportunities	Travel speeds	Accessibility
Many	Low	High
Few	High	Low

When improving accessibility is the goal, not only accessibility and mobility are important factors. The congestion over a road should also be measured to evaluate whether interventions did work. Afrin and Yodo (2020) compared different techniques for measuring congestion. First, the cause of congestion must be understood. There are two types of congestion which are recurring congestions and nonrecurring congestions. The causes of the first type of congestion are mainly the concepts of demand being higher than the capacity and converging lanes. This mainly happens during the rush hours. The nonrecurring congestion happens generally due to accidents and weather.

There are many ways to measure the extent of congestion over a road section. The most common measure is the Level of Service approach because of its simplicity. This approach uses the Volume/Capacity ratio to determine the traffic state in different V/C ratios. In Table 2.2, the V/C ratio is displayed with the corresponding traffic state. In chapter 5.1 these states are used to determine road sections in the current network that need improvement.

Table 2.2 V/C ratio with traffic state (Afrin and Yodo, 2020)

V/C ratio	Traffic state
0-0.60	Free flow
0.61-0.70	Stable flow with unaffected speed
0.71-0.80	Stable flow but speed is affected
0.81-0.90	High-density but stable flow
0.91-1.00	Traffic volume near or at capacity level with low speed
>1.00	Breakdown flow

These road intensities also play a role in the safety of roads. The amount of traffic intensity and population density are associated with higher crash risk. It also was found that an increase in truck traffic volume

increases the risk of accidents (Huang et al., 2010). According to SWOV (2024), 30% of all accidents in the Netherlands happened at intersections. A study by Chen et al. (2012) analysed traffic accidents in Australia, they showed that more than half of all accidents happen at intersections without signal control. Furthermore, 75% of fatal accidents happen on these non-signalized intersections whereas only 11% of fatal accidents happen on signalized intersections. Roundabouts, stop signs, and giveway signs are traffic control types with significantly fewer accidents. The age group 25-44 is the group with the highest percentage of accidents both fatal and non-fatal. The age group 16-24 is the group with the second most accidents with a relatively higher fatality.

Petras and Kveton (2022) analysed the impact of new road infrastructure in the Czech Republic. Between 2005 and 2015 many road construction projects were completed. Approximately 1280 kilometres of new road infrastructure has been completed in these 10 years. The researchers studied the change in accessibility to the regional centres in Czechia, together with the change in traffic load on roads through the municipality. The aspects of transport accessibility and traffic load are clearly explained in the paper. The transport accessibility is explained as the transport time between two points. Consequently, the degree of accessibility is related to the degree of connectivity between the points. If two points are closer to each other, the connectivity will increase. The traffic load is meant as the degree of quality of life. The bigger the traffic load, the worse the quality of life is around that road section. This traffic load is determined by number of cars passing per period of time. In this case, the reduction of road traffic means a better quality of life. Modelling was done in GIS with the use of the territorial analysis tool. The situation of 2005 was compared with the situation of 2015, and its impacts are plotted. The increase and decrease of congestion in the municipal centres are shown graphically. Subsequently, travel times between centres are calculated in the old and new situations.

These reviewed studies provide useful insights for the thesis project. Differences between accessibility and mobility are explained with some examples. This gives the framework for the different outcomes that the traffic model could give. The concept of accessibility is needed to understand what should be improved. In this research, accessibility will be measured using the accessibility index. This index compares the average time to reach an opportunity, with the actual trip time. Furthermore, the congestion state can be determined with IC-ratios to determine the flow on road sections, this flow should be as high as possible in order to have high accessibility. Next to high accessibility is safety another factor that plays a role in this thesis. As stated above, safety is proportional to the intensity, in states where traffic intensity is high, the crash risk is also higher. Besides that, the safety on intersections is also considerably lower than on other road sections. The safety is low on intersections without signals. Many fatal accidents happen at these intersections in comparison to signalized intersections. However, the construction of new roads can surely lead to better accessibility despite the higher intensity.

3. Research Aim and Questions

After gathering background information about the study area and reviewing the literature on accessibility, the research aim and questions are formulated.

This research aims to provide recommendations to enhance accessibility in the North-Eastern part of Hengelo. To achieve this aim, two research questions are formulated, together with explanatory sub questions. The methodology used to answer each of the research questions will be explained in Chapter 4.

1. What are the limitations of the current traffic infrastructure in the eastern part of Hengelo, considering the traffic on the wijkring and Oldenzaalsestraat?
    a. What is the current traffic volume on main roads in the eastern part of Hengelo during rush hours?
    b. How do different experts experience accessibility in the eastern part of Hengelo during rush hours?

2. What is the most effective intervention for improving traffic accessibility and safety in the eastern part of Hengelo?
    a. How will the accessibility and intensity change when the proposed extension of the Laan van Driene is implemented?
    b. Which other alternatives provide an increase in accessibility and mobility?

4. Methodology

The different Research methods needed to answer the research questions will be described in the following subsections, together with the data requirements.

4.1 Research Question 1: Analysis of the current infrastructure

To identify the current traffic volumes and bottlenecks that are present in the city, quantitative and qualitative analysis of the infrastructure will be done.

4.1.1 Quantitative analysis

Quantitative analysis will be done using intensities and capacities from the regional OmniTRANS traffic model. From this model, car network characteristics and intensities can be retrieved. The focus of the analysis lies on the morning and evening rush in Hengelo East since these are the busiest periods every working day. The model has the following data which will be used to analyse the network.

- 2-hour morning rush (07:00-09:00) for motor vehicles intensity
- 2-hour evening rush (16:00-18:00) for motor vehicles intensity
- IC ratio morning rush hour
- IC ratio evening rush hour

The intensities during the rush hours give a clear impression of the most used roads in Hengelo. The busiest routes are analysed using these intensities. The IC ratio gives a clear overview of the intensity on roads in comparison with their capacities. Using this ratio, the road sections with a substantial risk of congestion are identified.

Next to the traffic volume, quantitative data about safety is also analysed. The municipality of Hengelo has data about every collision in the city. This data can give a clear overview of the safety concerns in the eastern part of Hengelo. The collision data from the last 5 whole years is used to analyse traffic safety in Hengelo East. The points of interest where the most collisions have happened are analysed separately using the information that is registered.

Table 4.1 Data requirements for quantitative analysis

Data	Source	Year	Secondary/Primary	Availability
2-hour rushes intensity	OmniTRANS model	2020	Secondary	Available
IC-ratio rush hours	OmniTRANS model	2020	Secondary	Available
Collisions in eastern Hengelo	Municipality of Hengelo	2024	Secondary	Available

4.1.2 Qualitative analysis

For the qualitative analysis, different experts are interviewed to discuss limitations in the current traffic network in Hengelo East. Afterwards, various experts in the traffic department can give their views on the best solution for the current problems.

An expert in the traffic department will be interviewed about the current infrastructure in Hengelo East and its limitations. The traffic expert can give more concrete details about the congestion and volume on the road network in Hengelo East. Besides that, the expert indicates points of interest concerning the data from the OmniTRANS model. The real-world scenario is always different from the modelled scenario. It is also essential to analyse why the extended Laan van Driene was never constructed. These reasons can be discovered using expert interviews. Consequently, the view of the expert on different solutions is retrieved.

Furthermore, an Expert is interviewed about the discontinuance of the NOEK. The alternative that upgrades the Bosweg/Nieuwe Grensweg should also be discussed with the municipality of Enschede. The view of Enschede on the extended Laan van Driene is also interesting. Do they think it will improve the connectivity of Enschede to the highway, which only increases drive-through traffic over the Laan van Driene? Or do they think the connection is not as favourable for Enschede as it can be for Hengelo?

Table 4.2 Data requirements for qualitative analysis

Data	Source	Year	Secondary/Primary	Availability
Postponing construction of extended LvD	Expert 1	2024	Secondary	Available after interview
Discontinuance NOEK	Expert 2	2024	Secondary	Available after interview
View limitations	Experts	2024	Primary	Available after interview
Possible solution	Experts	2024	Primary	Available after interview

4.2 Research question 2: Strategies for improving infrastructure

After limitations are identified in Hengelo East, experts will give their views on alternatives for improving infrastructure, the three main alternatives that experts give their opinion on are:

1. The extended Laan van Driene
2. Upgrading the Nieuwe Grensweg
3. The Noordelijke Ontsluiting Enschede Kennispark (NOEK)

After identifying the advantages and disadvantages of the alternatives, the experts are asked to think about an out-of-the-box alternative.

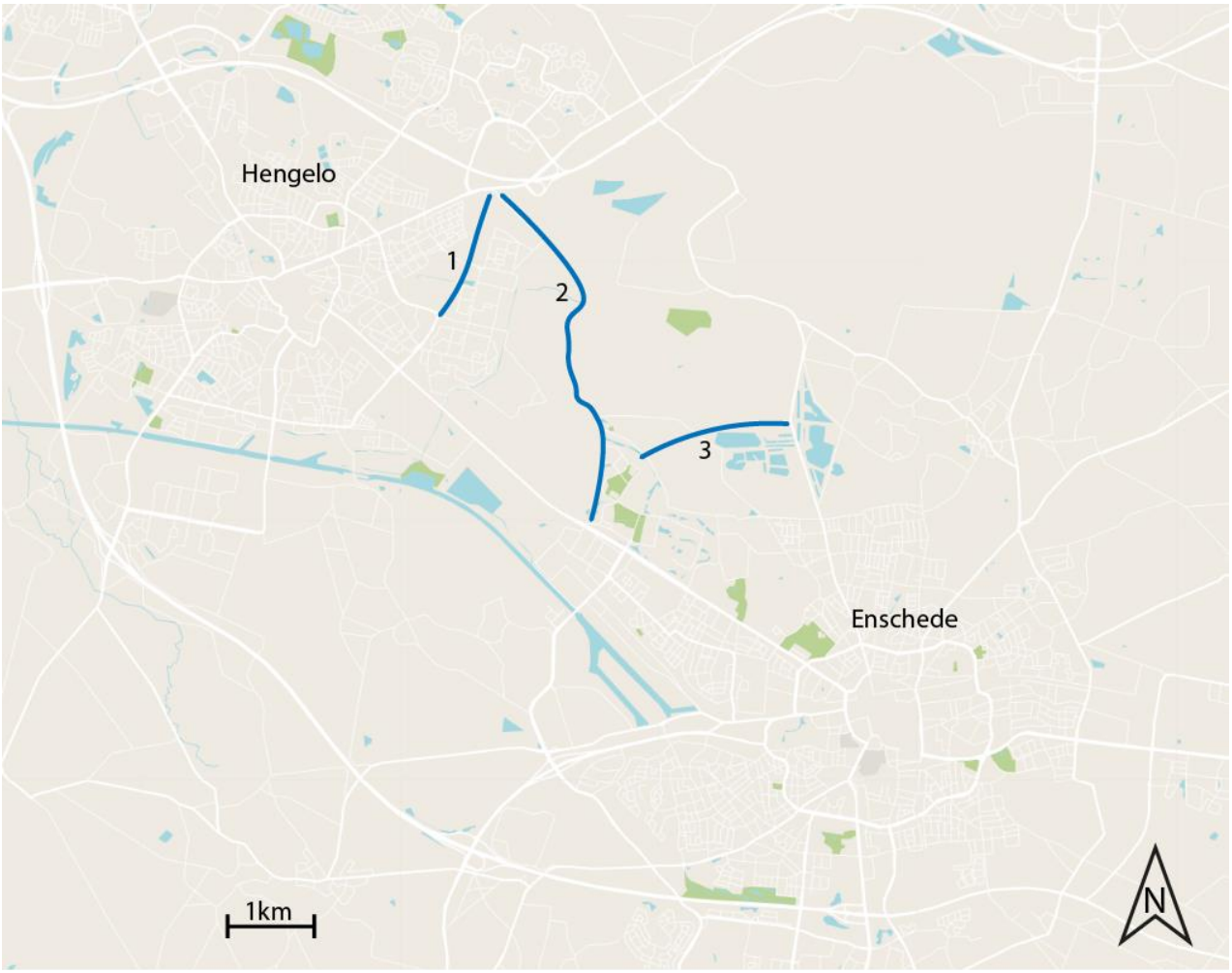

Figure 4.1 Three alternatives to improve accessibility in Hengelo.

When information from experts is gathered, the traffic models will be developed. In Figure 4.2, the framework for this methodology can be found. The municipality of Hengelo uses the regional OmniTRANS model of *Goudappel* to analyse the car traffic in the city. This thesis focuses on the morning and evening rush hours since these situations have the biggest impact on the traffic system of Hengelo. The baseline scenario in OmniTRANS is based on data from 2020. However, the calculation module of OmniTRANS is not available for this thesis project.

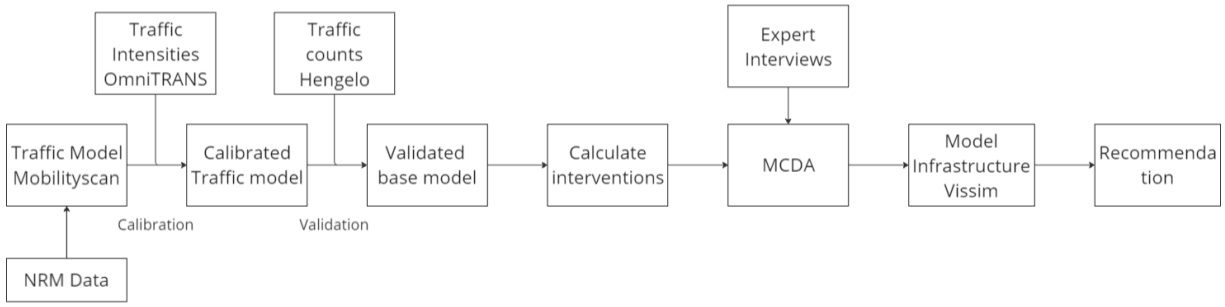

Figure 4.2 Framework from model to recommendation.

As a consequence of the inapplicable calculation module, the calculations of interventions have to be made in another program. This program is the mobilityscan of *Rijkswaterstaat,* which is openly available for students. The scenario builder lets users define capacities and speed limits for roads. The data it uses is Nederlands Regionaal Model (NRM) data (Rijkswaterstaat, 2021). It is possible to make predictions for small road sections using this data. The model allocates arrivals and destinations for each zone in the region. Then, the fastest route is determined between the zone pairs using the Dijkstra algorithm. This algorithm tries to find the shortest path possible to a destination (Medhi & Ramasamy, 2018). The allocation methods are executed only once, thus not iteratively repeated until an equilibrium situation is achieved. The first step for car allocation is determining the route sets. This is determined using a stochastic approach. The second step is determining the travel times. These travel times are directly retrieved from the source model, every road link has a travel time for free flow and a travel time for rush hours. The third step is distributing traffic over the routes. This is done using the C-logit model, which calculates the probability of route choice. Traffic between zones is distributed over the available routes based on these probabilities (Mobiliteitsscan, 2023).

The model is calibrated with relevant intensity data that can be retrieved from the baseline scenario from the OmniTRANS model. Freight and normal vehicles are considered the same in intensity. For the intensity calculations on the roads, freight and small vehicles are combined to make calculations easier. The intensity calculation should be separated for freight because these longer vehicles have a bigger impact on intensity. In both OmniTRANS and mobilityscan, the rush hours are modelled separately which gives a great indication of the traffic intensities at various times of the day.

Besides intensities, capacities are also included in these models. The capacities for the roads in Hengelo are also retrieved from the OmniTRANS model to make valid claims about the intensity-capacity ratio in the mobilityscan model. Furthermore, the intensities of the mobilityscan model are compared with the intensities of the OmniTRANS model. When intensities inside the scope differ from each other, the arrival and destination values between zones are adjusted. The intensities outside the scope are also reviewed to ensure deviations are not too substantial.

Once the intensity values of the mobilityscan approach the OmniTRANS values, the mobilityscan base model will be validated using real traffic counts of 2021 and later. There are 5 locations inside the scope where traffic count data is available (figure 4.3), the data of all these 5 locations will be used to validate the mobilityscan base model.

Figure 4.3 Traffic count locations for validation of the mobilityscan model.

Subsequently, the alternatives and the proposed interventions by experts can be modelled in the mobilityscan model. The mobilityscan user calculates the impact of new road connections. Intensities, IC ratios, and accessibility indices can be retrieved from the mobilityscan. These factors are compared to the calibrated base model. The difference in these factors on road sections is plotted in absolute and relative numbers. The different plots are used to visualize the impact of the new connection. The different interventions are compared using a linear Multi Criteria Decision Analysis (MCDA). The factors which will be used to weigh the alternatives are elaborated with their weights in the next paragraphs. Weights of the different criteria are assumed and thus are limitations for this research project. An MCDA is used for this project because the MCDA allows the inclusion of quantitative and qualitative factors in evaluating the alternatives. Furthermore, the MCDA is a structured and transparent framework, which is convenient to use in this analysis.

- Improvement of accessibility

The weight of this factor is retrieved from the mobilityscan model. The accessibility index can be retrieved for different regions in Hengelo. The accessibility index is calculated by dividing the calculated trip length, by the reference trip length value for the region. The value implies whether the door-to-door duration is longer or shorter than the average same distance in the area. (CBS et al., 2024) The accessibility index of Hengelo East is used since the aim of this thesis is to improve accessibility in this region. Therefore, this criterion gets a score of 2.5.

- Land-use plan

The weight of the land-use plan for different alternatives is retrieved from the expert interviews and information of the municipality. The experts indicate to which extent the proposed alternative is viable in terms of land use. The score will be 2 since the land-use planning can indicate if areas can become the property of the municipality.

- Safety

The safety will weigh 1.5. Safety is an important factor for new road layouts, on the other hand, is safety more a framework than a weighted factor. Every road should comply with the traffic safety norm. Furthermore, it is hard to tell if a planned road in a calculation model will be safe in real life. Therefore, the number of intersections that should be made on the new connections will be assessed for this factor.

- Cost

The cost variable can also be retrieved from the interviews, together with data from the literature. The cost variable is not the most important criterion for this thesis since the aim is improving accessibility. Building stable infrastructure is expensive but is necessary for great accessibility. Thus, the cost criterion will only weigh 1.

- Social Impact

The social impact is the impact of the intervention on the inhabitants. This social impact is assessed with the number of properties that have to be demolished in order to create the alternative. For inhabitants, it is not desirable to lose property to create new infrastructure. Therefore, this will be weighted with a 1.5.

- Incorporation of environmental vision

The incorporation of environmental vision can be retrieved from the plans of the municipality of Hengelo. The vision for the area was published in 2020 regarding leisure in the city. The areas indicated as recreational areas can be found in this document. This long-term vision is part of the law, therefore the weight of 1.5 will be assessed.

The weights and score ranking for the different criteria are shown in Table 4.3. According to this MCDA framework, the different alternatives will be ranked. A sensitivity analysis will determine if the MCDA framework is robust. The method of one-at-a-time will be used for this analysis. This means that one weight is varied with one absolute point in positive and negative magnitude. The other weights are kept constant.

Table 4.3 MCDA framework for ranking the alternatives.

Criterium (weight)		Score
Improvement of Accessibility (2.5)	Worsened impact	0
	No impact	20
	Small impact	40
	Moderate impact	60
	Significant impact	80
	Enormous impact	100
Land use plan (2)	Not viable	0
	Difficult viable	33
	Medium viable	67
	Great viable	100
Safety (1.5)	Many intersections	0
	Several intersections	33
	A few intersections	67
	No intersections	100
Cost (1)	Extremely high	0
	High	25
	Moderate	50
	Low	75
	Very low	100
Social Impact (1.5)	Much demolishing	0
	Moderate demolishing	33
	Minor demolishing	67
	No demolishing	100
Environmental vision (1.5)	Contradictory	0
	In line with	50
	Enhancement	100

The alternative with the best score will be elaborated on in terms of a VISSIM model and is modelled to determine if the current infrastructure can cope with the intervention. First, the current infrastructure is modelled in VISSSIM with the above-retrieved intensities. Then, the already planned roundabout inside the scope is modelled. The municipality of Hengelo intends to complete a new roundabout between the P.C. Hooftlaan and the Laan van Driene in the year 2024. After this, the new intervention can be modelled in VISSIM. Points of interest in the current traffic system are the new roundabout and the intersection Kuipersdijk-Enschedesestraat. After simulating the increase in traffic, it will become apparent whether the current infrastructure can cope with the increased intensity.

If it becomes evident that the infrastructure cannot manage the increased traffic flow, new intersections are modelled. The new intersections will be appended to the recommendation for the intervention that should be made to increase accessibility in the eastern part of Hengelo.

VISSIM is a simulation model based on time steps. In this thesis, the first traffic data is inputted from the OmniTRANS model. The driver behaviour data is unchanged, Wiedemann 74 driver behaviour parameters are not changed in this thesis, this is the standard drive behaviour for urban motorized traffic in the VISSIM

software. For calibrating these parameters, much real-life traffic data on the road sections in Hengelo is needed. The standard parameters can be seen in Figure 4.2.

Table 4.4 Wiedemann 74 parameters

Model parameters	
Average standstill distance:	2,00 m
Additive part of safety distance:	2,00
Multiplic. part of safety distance:	3,00

Using the network tool, and traffic light cycles based on real-world traffic lights, the base network is created. VISSIM can analyse all sorts of traffic data, but for this thesis, the traffic intensities are used to check whether the intensity corresponds to the earlier retrieved data. Subsequently, the travel times are used for indicating bottlenecks after intensity is increased with the data from mobilityscan. If the travel time from the Enschedesestraat to the A1 highway ramp is higher than the base situation, it is indicated that there is a bottleneck in the network since the travel distance is shorter after the intervention.

Table 4.5 Data requirements for strategies for improving infrastructure.

Data	**Source**	**Year**	**Secondary/Primary**	**Availability**
Intensity values traffic	OmniTRANS	2020	Secondary	Available
Capacity values infrastructure	OmniTRANS	2020	Secondary	Available
Traffic data mobilityscan	Nederlands regionaal model			
Traffic count data	Municipality of Hengelo	2021	Secondary	Available
Design Roundabout Laan van Driene	Municipality of Hengelo	2024	Secondary	Available
Traffic light cycles inside the scope	Municipality of Hengelo	2024	Secondary	Available

5. Results & Discussion

5.1 Analysis of the Current Infrastructure

In this section, the current infrastructure in Hengelo East will be analysed. This will be done by comparing intensities on the main network and congestion during rush hours. Furthermore, the view of experts on the current infrastructure will be assessed. This qualitative data is gathered by interviewing experts in the field of traffic analysis. In addition, traffic safety also will be analysed by means of an accident analysis. Different accident types are analysed. The qualitative analysis is done by retrieving data from the expert interviews.

5.1.1 Traffic Intensity

Quantitative analysis

The current traffic system of Hengelo will be visualised with the use of the regional OmniTRANS model of Overijssel. Road intensities of eastern Hengelo during the 2-hour morning and evening rush are shown in Figures 5.1a and 5.1b. The Enschedesestraat is the road with the highest traffic intensity during the morning and evening rush hour. This road section exclusively has an intensity higher than 900 vehicles per hour, excluding the highways. The intersection Kuipersdijk-Enschedesestraat is therefore one of the busiest intersections of Hengelo.

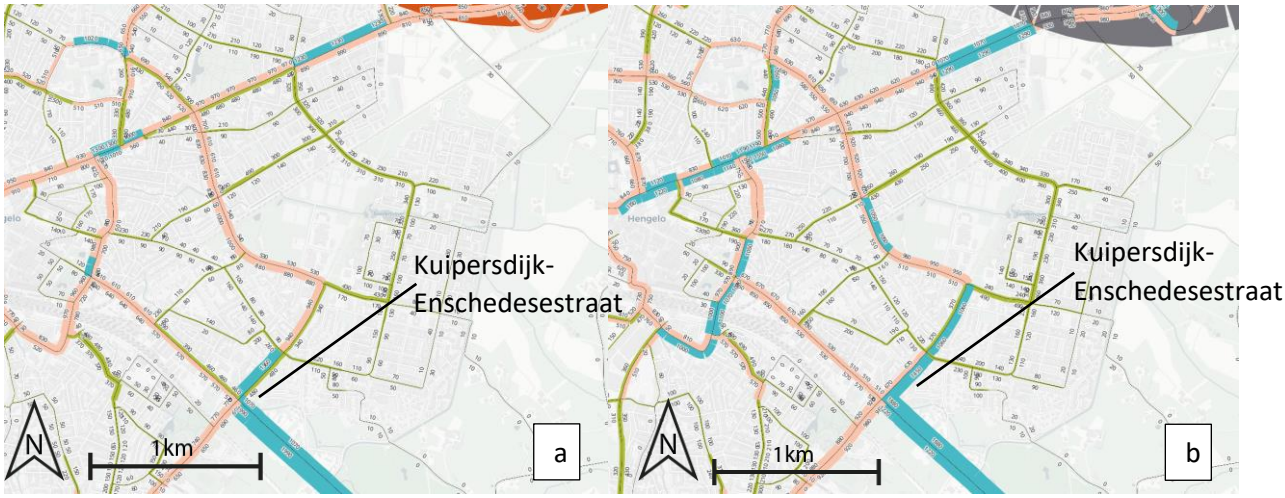

Figure 5.1 Expected traffic 2-hour intensities in Hengelo East during the morning (a) and evening (b) rush hours. (Source: OmniTRANS)

In Table 5.1, the roads with the highest intensities are shown. The visualization of Figure 5.1 is quantified in this Table and divided by two, to show the intensity per hour for the roads with the highest congestion.

Table 5.1 Highest intensities inside scope during morning and evening rush

	Morning Rush hour (veh/h)	Evening rush hour (veh/h)
Laan van Driene, direction North	240	725
Laan van Driene, direction South	680	335
Enschedesestraat, direction Hengelo	530	935
Enschedesestraat, direction Enschede	995	600
Oldenzaalsestraat, direction Hengelo	615	535
Oldenzaalsestraat, direction Oldenzaal	445	645

The intensity-capacity ratio (Figure 5.2) shows approximately the same results. If the IC ratio is too high, congestion occurs. As described in the literature review (section 2), a free flow state happens when the ratio is below 0.6. The higher the IC ratio gets, the more flow will be affected. The Laan van Driene in the direction of the intersection Kuipersdijk has an IC-ratio of 77 in the morning rush. The Enschedesestraat in the direction of Enschede has an IC-ratio of 113 at the intersection with the Kuipersdijk in the Morning rush. Moreover, the Oldenzaalsestraat in the direction of Hengelo has an IC-ratio of 71.

In the evening rush, the IC-ratio is 108 at the Enschedesestraat entering the Kuipersdijk intersection the Laan van Driene leaving the Kuipersdijk intersection has an IC-ratio of 83. The Oldenzaalsestraat leaving Hengelo has an IC ratio of 73. These IC-ratios show indeed that the intensity is on some road sections too high for its capacity.

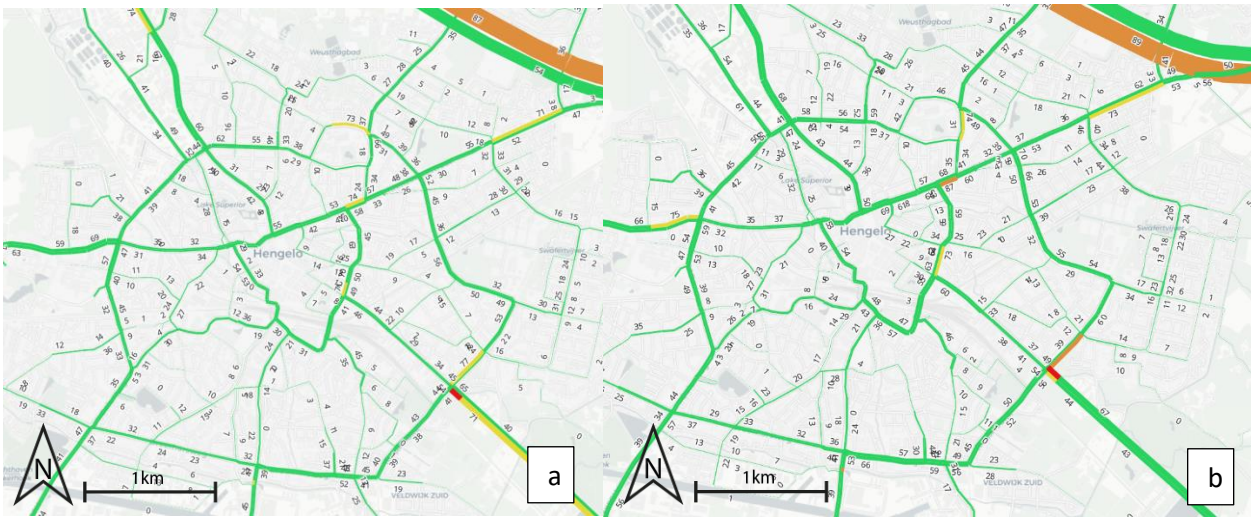

Figure 5.2 IC-ratios during the morning (a) and evening (b) rush hours in Hengelo (Source: OmniTRANS)

In the morning rush hours between 07:00 and 09:00, the access roads and ring roads have the highest intensities, which is the expected situation. Road sections in eastern Hengelo with the highest intensities are the Oldenzaalsestraat in the direction of Hengelo. This intensity is a combination of traffic coming from the A1, traffic from northern neighbourhoods, and traffic from north-eastern towns. Next to this road section, the Laan van Driene and Enschedesestraat have high intensities. The Laan van Driene is mostly used to guide traffic to the Enschedesestraat in the direction of Enschede. A share of the traffic that utilises

this road section is the traffic that also uses the Oldenzaalsestraat. The common route from the A1 to the western part of Enschede is using the *wijkring* and the Enschedesestraat, therefore the intensity is relatively high at these sections.

For the evening rush between 16:00 and 18:00, the movements are reversed compared to the morning rush. Traffic coming from Enschede East uses the *wijkring* again to reach the highway ramp of the A1. The intersection Kuipersdijk-Enschedesestraat has again the highest intensity. The most significant traffic movements during the morning and evening rush are shown in Figure 5.3.

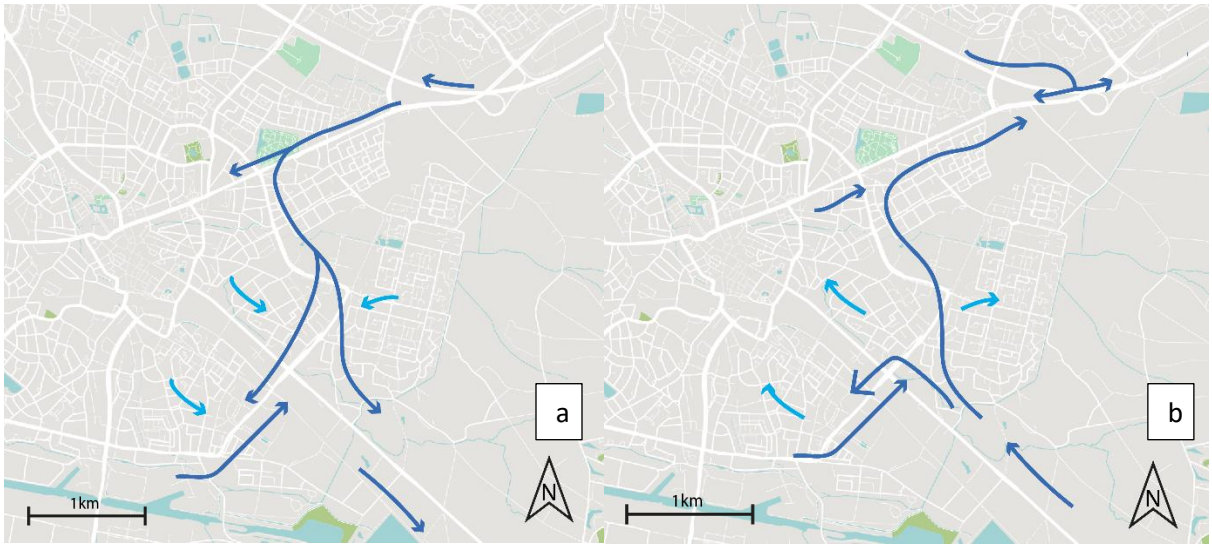

Figure 5.3 Traffic movements in the morning (a) and evening (b) rush hours in Hengelo.

Qualitative analysis

According to Traffic Expert 1, there are currently several bottlenecks in the infrastructure. Firstly, the intersection Kuipersdijk-Enschedesestraat is highly congested during rush hours, which can be confirmed by the quantitative analysis. In the morning rush, traffic intensity in the direction of Enschede is excessive. During the evening rush, this is the other way around. Traffic in the direction of Hengelo is dominant. Secondly, the Oldenzaalsestraat is heavily congested. The traffic lights cannot cope with the traffic numbers anymore. Ideally, the traffic flow on the Oldenzaalsestraat should have priority. However, the traffic from surrounding roads also has to enter the Oldenzaalsestraat. The Beethovenlaan and Josef Haydnlaan are side roads with high intensity that have to enter the Oldenzaalsestraat. The capacity of the Oldenzaalsestraat is reaching its limit. The traffic expert claims that the intensity modelled in the OmniTRANS model is underestimated. When comparing traffic counts to OmniTRANS intensities, there are indeed some road sections that do have a higher traffic count than it is modelled. Thirdly, the traffic intensity on the Staringstraat is high, relatively much heavy traffic uses this route. This street is used as a shortcut from the Oldenzaalsestraat to the Enschedesestraat. This again is not desirable since the street goes through a neighbourhood.

5.1.2 Traffic Safety

Quantitative analysis

Traffic safety in terms of accidents is the second analysis based on quantitative data. In Figure 5.4 – the map of eastern Hengelo – the traffic accident data from 2019 until 2023 is classified into four different categories for this map. The categories are minor damage, injuries, possible injuries, and deaths. It is noticeable that the highest number of accidents happen at intersections along the *wijkring.* Furthermore, a higher number of accidents can be noticed on the access road for the eastern neighbourhood. Over the past 5 years, 3 accidents in Hengelo East have been fatal.

Figure 5.4 Map of accidents by severity level (Source: Municipality of Hengelo using VIA software)

These fatal accidents all happened in the year 2022. The nature of one accident was a head-on collision, while the other two accidents were collisions with a fixed object.

The fatal accident at the Beethovenlaan-Mozartlaan intersection was a head-on collision involving a moped and a car. The collision was fatal for a moped user. The weather circumstances were rainy with a wet road surface. The other two fatal accidents were similar, the car crashed in broad daylight against a tree. The crashes happened at the Enschedesestraat and the P.C. Hooftlaan.

The trend in the number of accidents has remained stable over the past 5 years, which can be seen in Figure 5.5. It is important to note that one accident can involve multiple individuals. In Figure 5.5 the number of accidents is displayed rather than the individuals involved in accidents. An average of 59 accidents per year occurred over the past five years.

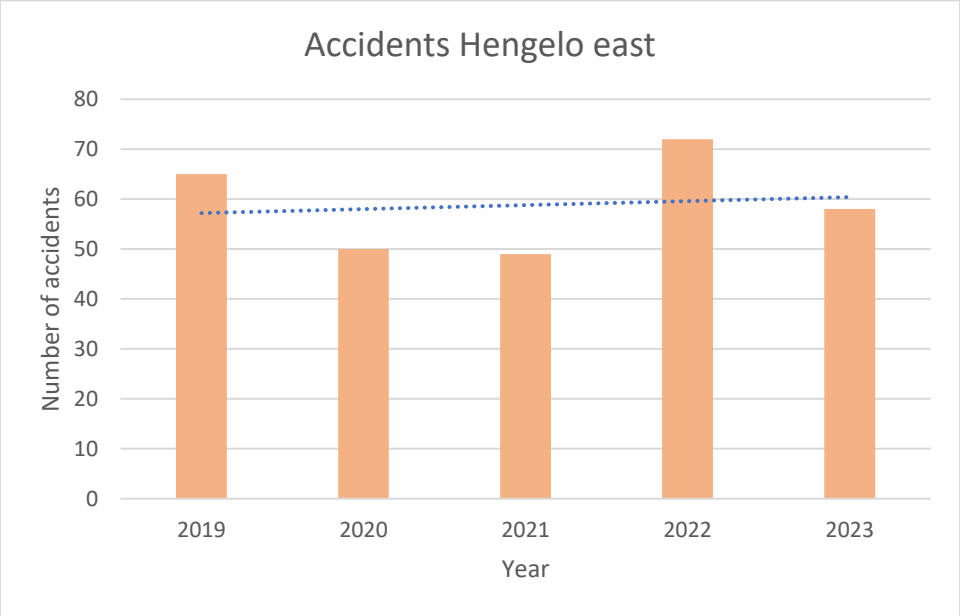

Figure 5.5 Total number of accidents in Hengelo East over the past 5 years.

The number of individuals in accidents per age class is displayed in Figure 5.6. The age class 25 until 39 has the highest number of individuals involved in an accident. The distribution of classes is a bit skewed since this age class involves the most ages. The same applies to the 70+ age class, which has no upper bound. The choice for the age classes is made by the accident monitoring software. The reason behind the dimensions of these classes is the fact that the software makes a difference between the novice driver and the experienced driver. The first five to seven years after earning a driver's license, someone is a novice driver in the Netherlands. Therefore, the age class 18-24 is chosen by the software. After five to seven years, drivers are more experienced. This age class is then 25-39. After this age class, the ages are classified per 10 years.

A noticeable fact about these statistics is that the relative value of victims (sum injuries and deaths), in contrast, is one of the lowest values for the 25-39 age class. The relative number of victims is higher in the younger and older age classes.

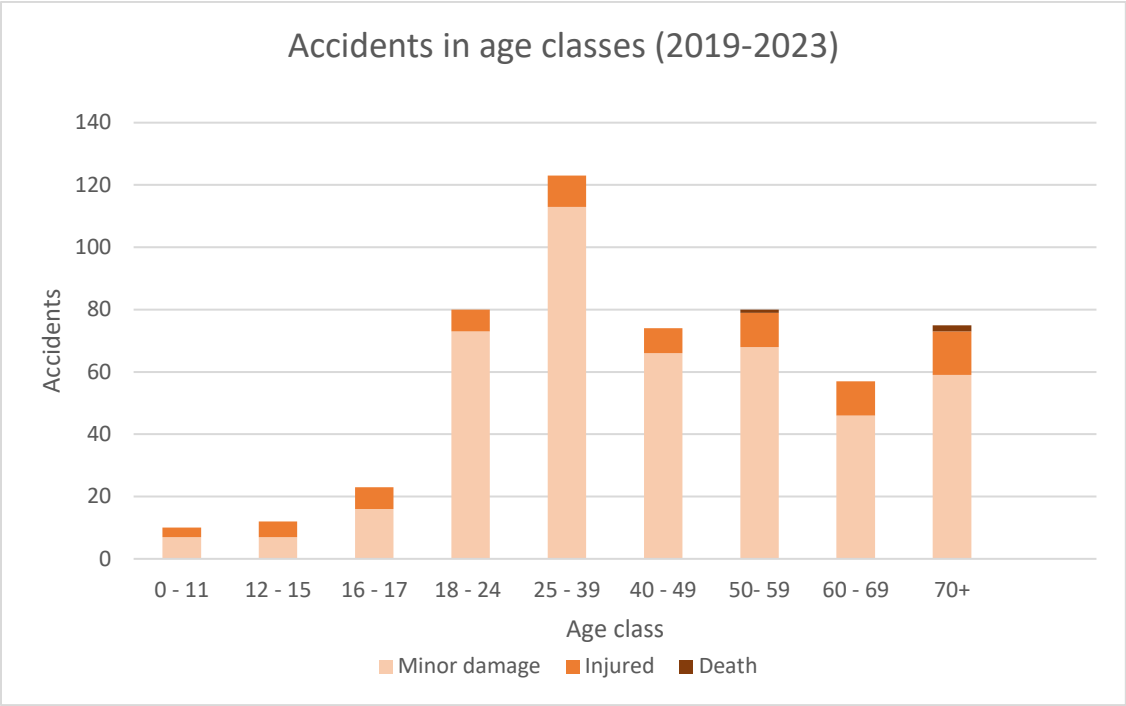

Figure 5.6 Number of accidents in Hengelo East per age class.

In Figure 5.7, the graph with individuals involved in accidents per transportation mode is displayed. Significantly, most individuals were in a car. The modes after that are the bicycle and the moped. The number of victims (injuries and deaths) using a car is relatively low in comparison with the bicycle and moped.

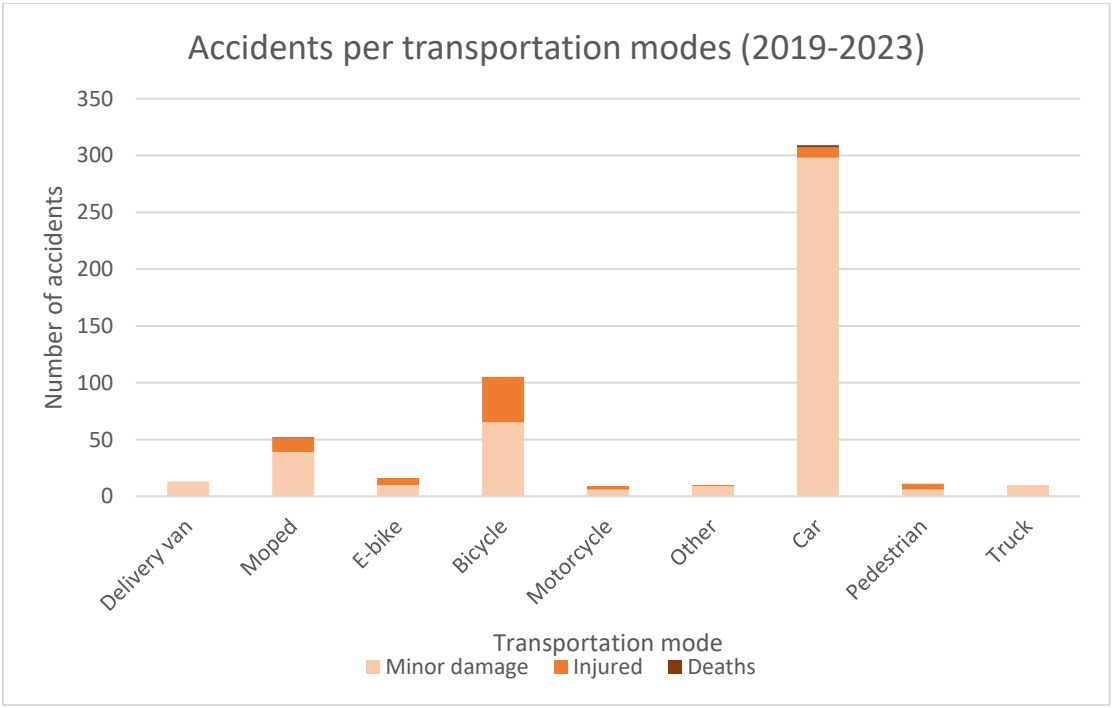

Figure 5.7 Number of accidents in Hengelo East per transportation mode.

Qualitative analysis

In a sense, safety is coherent with the traffic intensity, safety worsens when the intensity increases as described in theory. There is a primary school located in the neighbourhood of Groot Driene, therefore it is not desirable to have much traffic along this street. Besides that, only bike lanes are present on this street, whereas it would be preferable to have separate bike paths for schoolchildren. Expert 1 emphasized that this section is subjective unsafe, in his opinion this street feels unsafe. However, the number of accidents on this road does not indicate the unsafe nature of this road.

The intersection P.C. Hooftlaan is more objectively unsafe. Quantitative data shows that the number of accidents is high. Many accidents happen there, especially with bicyclists. The bicycle crossing is not safe enough, this is the reason why this intersection will be replaced with a roundabout at the end of this year. The unsafe nature of this intersection has a relation with the unusual priority situation in this turn. The cars turning have priority over the straight-ahead traffic, car users therefore enter this turn at high speeds.

5.2 Strategies for Improving Infrastructure

In this section, the strategies for improving the infrastructure in Hengelo East are identified. Firstly, the expert interviews are used to determine the advantages and disadvantages of the different alternatives. Secondly, the traffic model for intervention calculations will be calibrated and validated. The calibrated model is subsequently used to retrieve traffic intensities after interventions. The three alternatives are then ranked with the use of a Multi-Criteria Decision Analysis. The highest-ranked alternative is modelled in VISSIM to evaluate intersection flow, the flow of these intersections is subsequently enhanced by the new designs of the intersections.

5.2.1 Input from Interviews

Alternative 1: Extended Laan van Driene

According to traffic expert 1, alternative 1 is a great way to relieve the current bottlenecks in eastern Hengelo. However, the expert emphasized that new bottlenecks would occur. The traffic intensity on the Oldenzaalsestraat, Beethovenlaan, and P.C. Hooftlaan will decrease when the extended Laan van Driene is realised because of the faster connection that is established. The new bottlenecks are the intersection Kuipersdijk-Enschedesestraat, the Laan van Driene, and the roundabout that will be finished at the end of this year. The capacity of these three elements is too low for the increased traffic intensities. Furthermore, the non-signalized intersections on the current Laan van Driene will have adverse effects on traffic coming from the neighbourhood since the priority traffic is increased.

The extended Laan van Driene alleviates the traffic load in different parts of the city. The *centrumring* could be modified to a one-way traffic configuration. However, extensive research should be done on the effects of this intervention. There is a possibility that the traffic intensity on the *wijkring* will increase extensively. Moreover, expert 1 mentioned that the traffic in Hengelo East cannot be solved regarding the modal shift. The municipality aims to encourage residents to utilize bicycles, public transportation, and shared mobility options. However, traffic numbers on the *wijkring* and *radialen* will rise if the city expands to 100.000 inhabitants. Therefore, hard measures by means of new infrastructure are needed to improve accessibility. This intervention is needed for the future, the current infrastructure is inadequate for the population growth of 20.000 inhabitants which is desired by the city.

The increase in traffic coming from Enschede is a side effect of this alternative. However, this should be accepted since mobility should be interpreted as transboundary between Hengelo and Enschede, according to Traffic Expert 1.

Traffic expert 2 also thinks that the construction of the extended Laan van Driene should be considered with both Hengelo and Enschede as interested parties. The traffic load in Hengelo will be increased because of the faster connection to the A1 for inhabitants of Enschede. However, expert 2 thinks that the hard measures should be postponed for several reasons. Firstly, the solution should be found in the modal shift from car to bicycle, PT, and shared mobility. A park-and-ride facility on the municipal border with a direct PT connection to the centre would be more ideal. Secondly, the effects of the high-tech sector which is planned at the railroad zone between Hengelo and Enschede are not known yet. Therefore, the construction should be re-considered after these developments. Thirdly, traffic expert 2 says that the goal for the connection should be the decrease of inner-city traffic. Will the intervention only result in more through traffic, the intervention misses its purpose.

Alternative 2: Upgrading the Nieuwe Grensweg and Bosweg

The second alternative is the upgrade of the Nieuwe Grensweg and the Bosweg. This upgrades the currently closed road to an access road. Both experts share the same view. These roads are currently not intended for excessive amounts of traffic. The purpose of these roads is recreational use, it is used for walking, cycling, and running through green areas. Furthermore, many green spaces along the road are protected areas. The area between the highway and the Nieuwe Grensweg even is a Natura 2000 green space. Therefore, the construction of the road is highly challenging. Natura 2000 is a network of protected areas to preserve biodiversity in Europe. The emissions of both construction and usage may be a threat to the biodiversity in this area. Thus, the viability of this road is minimal.

Alternative 3: NOEK (Noordelijke Ontsluiting Enschede Kennispark)

According to traffic expert 2, the NOEK is a substitute for the extended Laan van Driene. Both roads function as an access road to the North, and the A1 highway. Therefore, building both roads should not be taken into consideration. The realisation of the NOEK shifts traffic intensity from Hengelo to Enschede. The same applies conversely to the extended Laan van Driene. The city that invests in new infrastructure will see more traffic coming from the neighbouring city. Expert 2 states that the location where the NOEK will connect with the current access road to the north has an impact on the users of the NOEK. The more to the North the road will connect with the Weerseloseweg, the more users from Hengelo it will attract. The further south the connection is located, the more people from Enschede will make use of the road.

However, the NOEK has not necessarily had as much impact on Hengelo, as the extended Laan van Driene has on Enschede. The main reason for this is the A1 highway ramp that is located at the end of the proposed extension. Next to this, the costs of the intervention were not in line with the benefits. The calculated impact of the NOEK was not as big as desired, decrease on the ring road did not meet expectations. Furthermore, the Nanolab located at the University of Twente could experience hindrances. The University is worried that vibrations interfere with research that is done in the Nanolab. Although vibration research showed that the Nanolab would not have an impact, the Municipality of Enschede wants to maintain the relationship with the University. Besides that, the proposed road cuts through an area with much greenery. From a more ecological view, the NOEK is not favourable.

Alternative 4: Public Transport and modal shift

Better accessibility using public transport and modal shift is something that cannot be neglected in the 21st century. The expert 2 states that before hard infrastructure can be built, all other facilities should first be optimized. He describes that a park-and-ride facility in combination with a shared bicycle facility also should be considered in eastern Hengelo. Additionally, this facility can also function as a hub for the University.

Expert 1 is on the other hand not an advocate of the park-and-ride facilities. He gives an example using the park and rides next to the station Hengelo Central. The P+R is much of the time almost empty. People should be encouraged to use their bicycles to reach their destinations. The municipality of Hengelo emphasizes the aim to shift to more PT and active modes of usage. On the other hand, it is not realistic to rely on the modal shift to solve limitations in Hengelo East since the aim is to attract residents in the near future. However, when new infrastructure is built, the attractiveness of PT will increase since more direct PT routes are available.

Conclusion

Both experts think that the extension of the Laan van Driene is the most favourable in comparison with the other two alternatives in terms of hard infrastructure. The land utilization for the extended Laan van Driene has big advantages. The space is already reserved for the construction of the new connection. Construction of the NOEK and upgrading the Nieuwe Grensweg means that much greenery will be destroyed for asphalt. To some extent, the same applies to the construction of the extended Laan van Driene since allotment gardens are located in the already reserved area. However, the ecological impact would be much less. Besides this, the A1 highway ramp is located near the proposed extension of the Laan van Driene. The impact of the extended Laan van Driene is therefore considerably higher than the NOEK. The NOEK can only be favourable if the A1 highway ramp shifts to the Vliegveldstraat. A new additional highway ramp is considered unrealistic since the highway ramp Hengelo-Noord is located only one kilometre further. Nevertheless, the solution cannot only be found in enhancing PT and encouraging modal shift. New infrastructure is needed to increase accessibility, when the aim is to attract 20.000 more inhabitants.

In the next sections is shown whether the traffic model – which considers traffic intensities – also shows the same preference.

5.2.2 Model calibration

In this subsection, the mobilityscan model will be calibrated with data from the OmniTRANS. The goal is to match the intensities on road sections. The first step will be defining the correct capacities for the roads in the city. Consequently, the scenarios in mobilityscan are optimized by closing road sections that are not available for traffic. After that, the calibration of the model is divided into the morning rush and evening rush base scenarios.

The capacities used by OmniTRANS are adopted in the mobilityscan model. It is assumed that these capacities are the right road capacities for the infrastructure in Hengelo. The road capacities for the different roads in the city are shown in Figure 5.8.

A discussion point for these OmniTRANS intensities is that these are based on traffic counts from different municipalities. These traffic counts are most certainly counts from only a few weeks per year. Therefore, this data can deviate from the real-world traffic intensities. Furthermore, the base model in OmniTRANS is based on the year 2020. The traffic movements could have changed in the past years.

Figure 5.8 Road capacities in Hengelo (Source: OmniTRANS).

The OmniTRANS model defines the following capacities for roads in the city.

- 600 vehicles per hour for neighbourhood streets.
- 800 vehicles per hour for minor ring roads.
- 1000 vehicles per hour for major ring roads.
- 1600 vehicles per hour for roads connecting to different cities.

After the correct capacities are configured, the network in the mobilityscan model is analysed on road errors. The most significant error in this model was the Nieuwe Grensweg. The model wrongly indicated that the road was open for traffic. The scenario with the correct capacities and road availability is indicated as scenario 0. Subsequently, the intensities of scenario 0 are compared with the intensities of the OmniTRANS model. In the eastern part of the city, the mobilityscan model underpredicted traffic

intensities during the morning rush. However, in the northwestern part of the city, the model over-predicted traffic intensities. The under and over predictions of the mobilityscan model, during the morning rush, are shown in Figure 5.9.

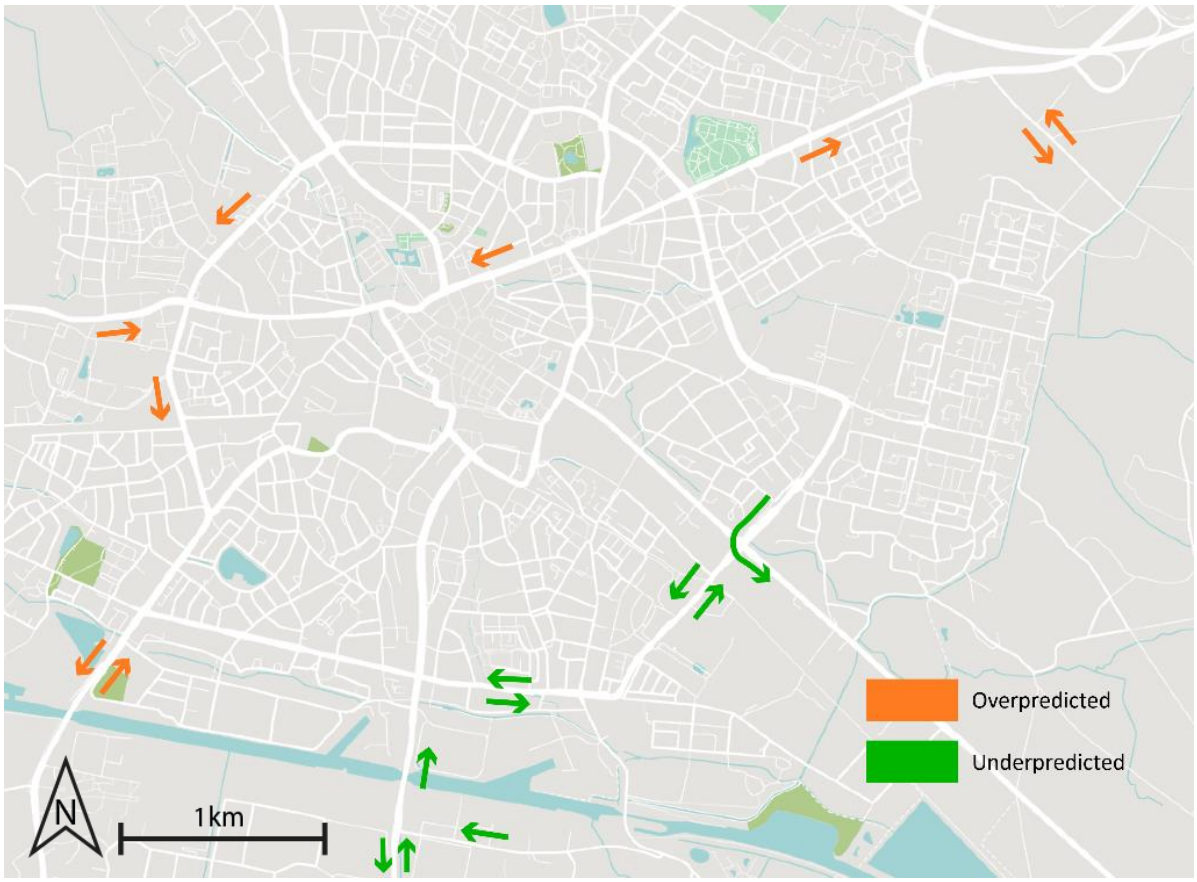

Figure 5.9 Over and underpredictions during the morning rush by the mobilityscan start model.

To ensure that the model is as close to the OmniTRANS model intensities, the number of origins and destinations of various zones are modified in the mobilityscan model. The focus for enhancing the predicted intensity is aimed at the roads that lie inside the scope. In addition, the intensity of roads connecting the scope is also optimised.

The underpredicted areas are solved by increasing the destinations in zone Kennispark. By doing so, the underpredicted road areas on the Laan van Driene and the Enschedesestraat are refined. Furthermore, to correct the underpredicted values of traffic on the Kuipersdijk, the origin and destination traffic for Veldwijk is substantially increased.

On the other hand, there are some overpredicted intensities on the Oldenzaalsestraat. This intensity is decreased by minimizing the destination traffic to Oldenzaal. A side effect of this is that the intensity on the A1 highway also decreases. This can be neglected since the capacity of the highway is far from reached. The intensity/capacity ratio changed from 0.52 to 0.46. This change in the I/C ratio does not change the route choice behaviour of traffic since the intensity was never too high to not choose the highway over a substitute road. In addition, the traffic arriving in Hasseler Es is also reduced to decrease traffic intensity

on the Oldenzaalsestraat. Another part of the Oldenzaalsestraat that has overpredicted values is part of the *centrumring*. The original scenario of the mobilityscan model had the speed limit parameter of this section wrong. Exclusively this road section had a higher speed limit than the rest of the roads in the city. On top of that is also the arriving traffic in Marskant reduced to lower traffic intensity on the *centrumring.* After reducing the speed limit and arrivals, the intensities on the *centrumring* are much closer to the regional OmniTRANS model.

The arrival and departure modifications for the different zones to refine traffic intensity values inside the scope can be found in Table 5.2. The reason for the seemingly random numbers is the fact that after increasing the arrivals in a certain zone, departures must increase from other zones.

Table 5.2 Modifications to different zones during the morning rush to calibrate the mobilityscan model.

Zone	**Arrivals in zone**			**Departures from zone**		
	Before	**After**	**Difference**	**Before**	**After**	**Difference**
Veldwijk	132	724	448%	174	446	156%
Marskant	561	302	-46%	245	231	-6%
Oldenzaal (Hulsbeek + Hooiland + Scholtenhoek)	834	94	-89%	828	598	-28%
Groot Driene	297	100	-66%	471	500	6%
Kennispark	444	909	105%	24	22	-8%
Deurningen	139	15	-89%	296	262	-11%
Klein Driene / Noork	190	102	-46%	456	143	-69%
Hasseler Es	530	52	-90%	900	833	-7%

After these modifications, the base morning rush model is calibrated to meet the traffic intensities of the OmniTRANS model. In Table 5.3, the deviations of the mobilityscan model in comparison to the OmniTRANS model can be found. The deviations smaller than 10% are considered to be significant. Bigger deviations are not preferable but were at some road sections unavoidable. Especially on road sections where the intensity is relatively low. A small absolute difference can lead to big relative differences in these road sections. Therefore, at some road sections, bigger relative deviations are accepted for the mobilityscan model.

The roads with the highest deviations are marked blue in Figure 5.10. These deviations can be considered as outliers. The deviations at the Nieuwe Grensweg are this high since the OmniTRANS model does not allocate any traffic to the Nieuwe Grensweg. This road is closed for through traffic, but destination traffic can still enter this road. On the other hand, is the predicted traffic by the mobilityscan model too high because the Nieuwe Grensweg is part of a zone where cars arrive and depart. Thus, the model sees this road as a route for arrivals and departures.

The deviation inside the scope is an overprediction of the Laan van Driene. This overprediction was unavoidable since the traffic entering the Kuipersdijk intersection had to be increased. A consequence of this is the increase in the road leading up to the intersection. It is strange to see that only this small section has a significant deviation. The sections before and after are close to the OmniTRANS data. Therefore, this section is also considered an outlier.

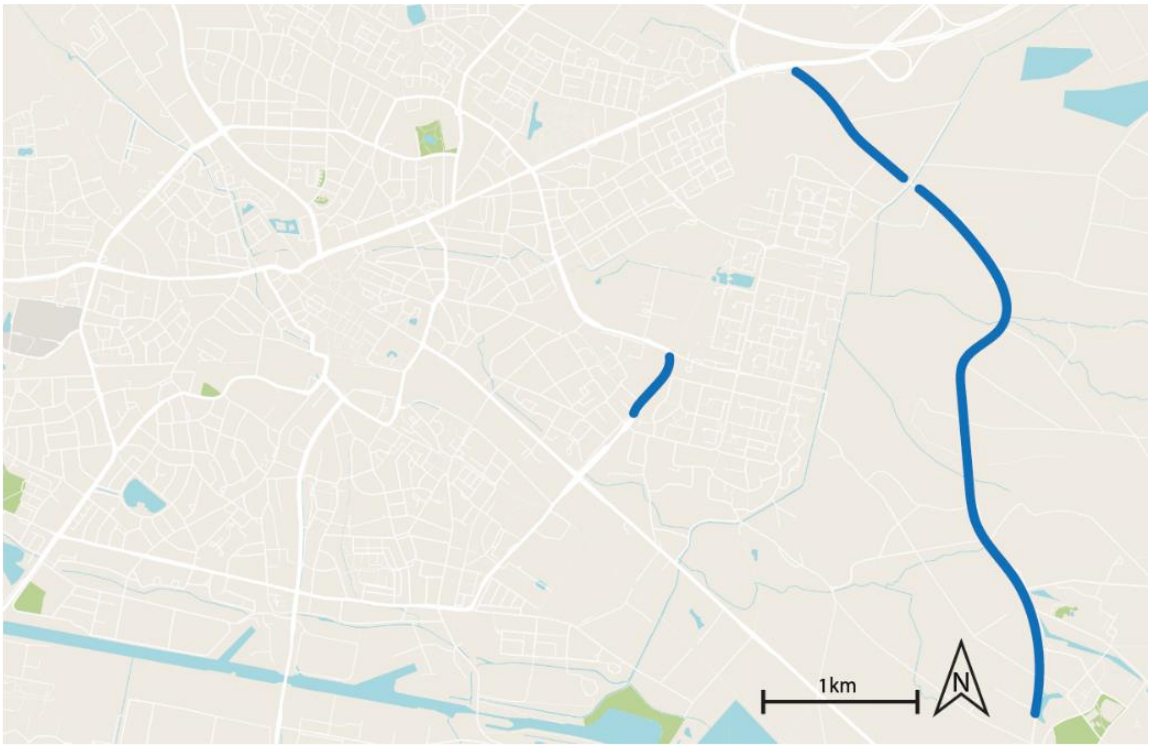

Figure 5.10 Roads with deviation after calibration.

Table 5.3 Overview traffic intensities with deviations in comparison with the OmniTRANS model during the morning rush.

Roadsection	Base Model before changes	Base Model after changes	Regional OmniTRANS model (1hour)	deviation mobilityscan model (rel)
Enschedesestraat/Hengelosestraat (Section Kuipersdijk-Capitool)	665	919	995	-8%
Enschedesestraat/Hengelosestraat (Section Capitool-Kuipersdijk)	457	490	530	-8%
Enschedesestraat (Section Kuipersdijk-Grundellaan)	339	285	230	24%
Enschedesestraat (Section Grundellaan-Kuipersdijk)	395	304	285	7%
Kuipersdijk (Section Enschedesestraat-Artemisstraat)	180	348	370	-6%
Kuipersdijk (Section Artemisstraat-Enschedesestraat)	190	296	325	-9%
Laan van Driene (Enschedesestraat-Reviusstraat)	214	271	240	13%
Laan van Driene (Reviusstraat-Enschedesestraat)	355	738	680	9%
Laan van Driene (Reviusstraat-P.C.Hooftlaan)	219	257	170	51%
Laan van Driene (P.C.Hooftlaan-Reviusstraat)	364	723	470	54%
P.C.Hooftlaan (Laan van Driene-Grundellaan)	217	252	265	-5%
P.C.Hooftlaan (Grundellaan-Laan van Driene)	251	480	440	9%
Beethovenlaan (Grundellaan-Mozartlaan)	259	298	270	10%
Beethovenlaan (Mozartlaan-Grundellaan)	305	544	500	9%
Beethovenlaan (Mozartlaan-Oldenzaalsestraat)	329	357	350	2%
Beethovenlaan (Oldenzaalsestraat-Mozartlaan)	242	419	415	1%
Oldenzaalsestraat (Beethovenlaan-Castorweg)	359	259	240	8%
Oldenzaalsestraat (Castorweg-Beethovenlaan)	347	421	485	-13%
Oldenzaalsestraat (Beethovenlaan-Deurningerstraat)	592	495	500	-1%
Oldenzaalsestraat (Deurningerstraat-Beethovenlaan)	373	311	280	11%
Oldenzaalsestraat (Castorweg-Hasselerbaan)	672	606	445	36%
Oldenzaalsestraat (Hasselerbaan-Castorweg)	584	646	615	5%
Pentropsdijk-Nieuwe Grensweg	814	133	15	787%
Nieuwe Grensweg-Pentropsdijk	467	233	10	2230%
Nieuwe Grensweg (Zwavertsweg-Morshoeksweg)	816	133	0	
Nieuwe Grensweg (Morshoeksweg-Zwavertsweg)	368	65	0	
Bosweg (Langenkampweg-Hengelosestraat)	453	386	275	40%
Bosweg (Hengelosestraat-Langenkampweg)	213	179	125	43%

In Figure 5.11, the overpredicted and underpredicted road sections of the mobilityscan model during the evening rush are shown. The inaccurate predictions of intensity look similar to the inaccuracies in the morning rush model. However, the magnitude of the inaccuracy changes. For example, the Enschedesestraat and Laan van Driene its intensities were underpredicted towards Enschede in the morning rush model. In this evening rush model, the intensities of these roads are underpredicted in the direction of Hengelo. This outcome is logical, since the traffic that leaves the city in the morning for work, will return in the evening.

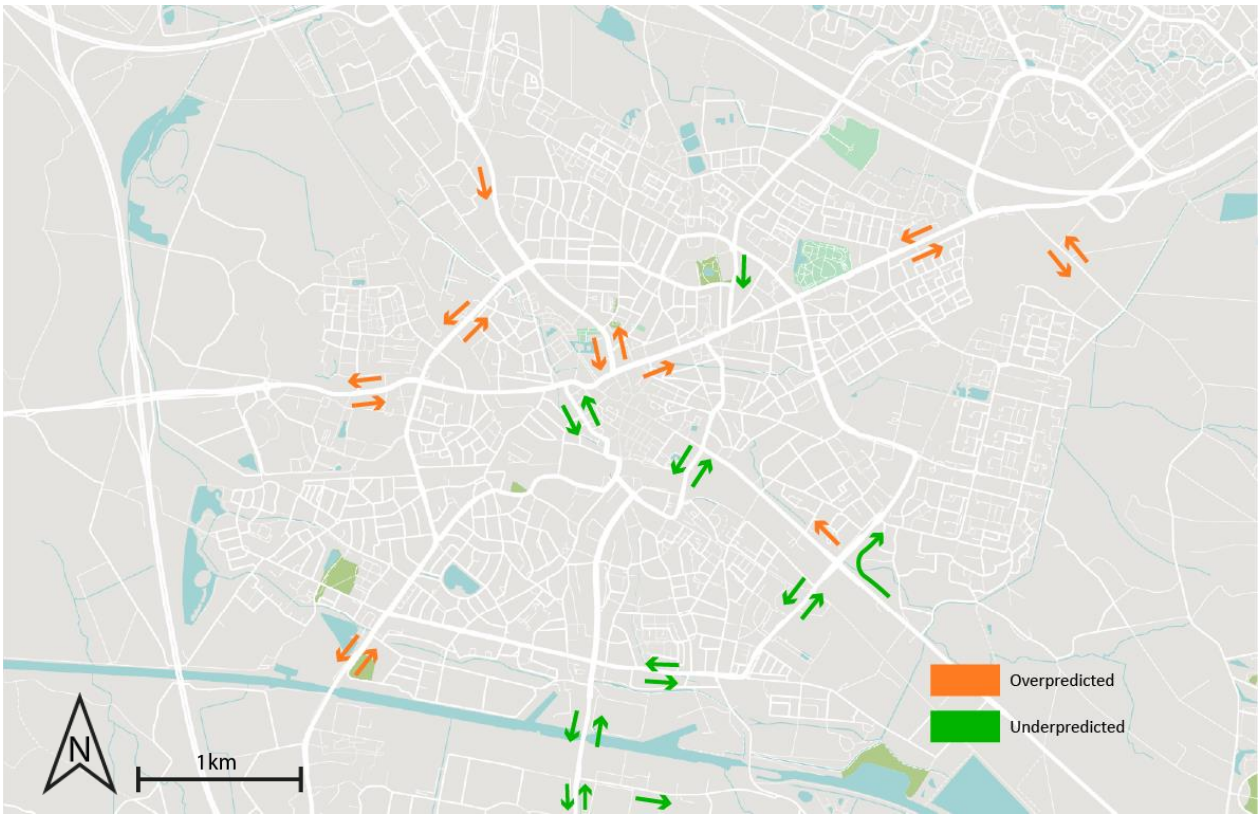

Figure 5.11 Overpredicted and underpredicted roads during the evening rush in mobilityscan before calibration.

To again ensure that the model is as close as possible to the OmniTRANS model, the arrivals and departures of various zones are enhanced. The changes that are implemented are in many zones the opposite of the changes in the morning rush model. Arrivals and departures are added in Veldwijk to increase intensity on the Kuipersdijk. The mobilityscan model underpredicted the traffic on this road section significantly. Departures are increased in the Kennispark area, to get higher intensity values on the Enschedesestraat towards Hengelo.

The arrival and departure modifications for the different zones to refine traffic intensity values inside the scope can be found in Table 5.4.

Table 5.4 Modifications to different zones during the evening rush to calibrate the mobilityscan model.

Zone	Arrivals in zone			Departures from zone		
	Before	After	Difference	Before	After	Difference
Veldwijk	201	682	239%	166	485	192%
Marskant	427	98	-77%	831	853	3%
Groot Driene	551	472	-14%	392	197	-50%
Kennispark	46	44	-4%	421	725	72%
Klein Driene / Noork	555	540	-3%	316	219	-31%
Hasseler Es	1083	738	-32%	802	137	-83%

The same roads as in the morning rush hours show the biggest deviations. These roads can be seen in Figure 5.10. These deviations are again considered to be outliers. The overview Table which compares OmniTRANS data with the calibrated data from mobilityscan can be found in Table 5.5. The deviations with the OmniTRANS intensities are a point of discussion. Some noticeable deviations could not be avoided. These deviations do make the model less accurate. Nevertheless, a is traffic model always an indication of traffic flows through a city. There are always some variances in the traffic model. The deviations of the scenario zero model are points of discussion in this thesis. Next to that is the mobilityscan model of Rijkswaterstaat originally developed for the main roads in the Netherlands. In this thesis, the model is used to evaluate traffic flows through the city. The reason why this can be justified is the amount of calibration that is done before any calculation is done.

Table 5.5 Overview traffic intensities with deviations in comparison with the OmniTRANS model during the evening rush.

Roadsection	Base Model before changes	Base Model after changes	Regional OmniTRANS model (1hour)	deviation mobilityscan model (rel)
Enschedesestraat/Hengelosestraat (Section Kuipersdijk-Capitool)	524	546	600	-9%
Enschedesestraat/Hengelosestraat (Section Capitool-Kuipersdijk)	588	748	935	-20%
Enschedesestraat (Section Kuipersdijk-Grundellaan)	357	271	265	2%
Enschedesestraat (Section Grundellaan-Kuipersdijk)	426	355	285	25%
Kuipersdijk (Section Enschedesestraat-Artemisstraat)	204	381	440	-13%
Kuipersdijk (Section Artemisstraat-Enschedesestraat)	312	434	460	-6%
Laan van Driene (Enschedesestraat-Reviusstraat)	462	714	725	-2%
Laan van Driene (Reviusstraat-Enschedesestraat)	221	369	335	10%
Laan van Driene (Reviusstraat-P.C.Hooftlaan)	474	673	530	27%
Laan van Driene (P.C.Hooftlaan-Reviusstraat)	228	318	185	72%
P.C.Hooftlaan (Laan van Driene-Grundellaan)	338	439	475	-8%
P.C.Hooftlaan (Grundellaan-Laan van Driene)	228	270	255	6%
Beethovenlaan (Grundellaan-Mozartlaan)	408	511	525	-3%
Beethovenlaan (Mozartlaan-Grundellaan)	265	310	275	13%
Beethovenlaan (Mozartlaan-Oldenzaalsestraat)	389	483	485	0%
Beethovenlaan (Oldenzaalsestraat-Mozartlaan)	359	416	415	0%
Oldenzaalsestraat (Beethovenlaan-Castorweg)	462	407	470	-13%
Oldenzaalsestraat (Castorweg-Beethovenlaan)	372	291	310	-6%
Oldenzaalsestraat (Beethovenlaan-Deurningerstraat)	502	357	355	1%
Oldenzaalsestraat (Deurningerstraat-Beethovenlaan)	697	552	540	2%
Oldenzaalsestraat (Castorweg-Hasselerbaan)	773	617	645	-4%
Oldenzaalsestraat (Hasselerbaan-Castorweg)	791	710	535	33%
Pentropsdijk-Nieuwe Grensweg	463	194	25	676%
Nieuwe Grensweg-Pentropsdijk	776	402	35	1049%
Nieuwe Grensweg (Zwavertsweg-Morshoeksweg)	396	77	0	
Nieuwe Grensweg (Morshoeksweg-Zwavertsweg)	735	75	0	
Bosweg (Langenkampweg-Hengelosestraat)	338	226	155	46%
Bosweg (Hengelosestraat-Langenkampweg)	479	326	295	11%

5.2.3 Model validation

In this chapter, the validation of the mobilityscan model will be executed. The municipality of Hengelo conducted many traffic counts in the last years. The data present in the system is from the years 2010 until 2024. To create the OmniTRANS base model 2020, data until 2019 is used. Therefore, this data cannot be used to validate the mobilityscan model, this data is indirectly already used for the calibration of the model. Newer traffic count data is used for the validation, obtained from 2021 onwards. The locations of the traffic count data are shown in Figure 5.12. The traffic count data at locations 1 and 2 are from Nationwide Data Collection. The other traffic counts are conducted by the Municipality. The traffic count system counts vehicles for at least one week including the weekend. For this validation, only the rush hour intensities on working days are included.

The validity of the counts can be discussed. These traffic counts include only a few weeks per year. The weather or the time of year can influence the traffic count seriously. Next to that are there several traffic counts from the coronavirus pandemic years. In these years, traffic movements were lower than in the years before. The traffic counts used to validate the mobilityscan model are all from 2021 and later, in this period the traffic movements are considered to be on the common level again.

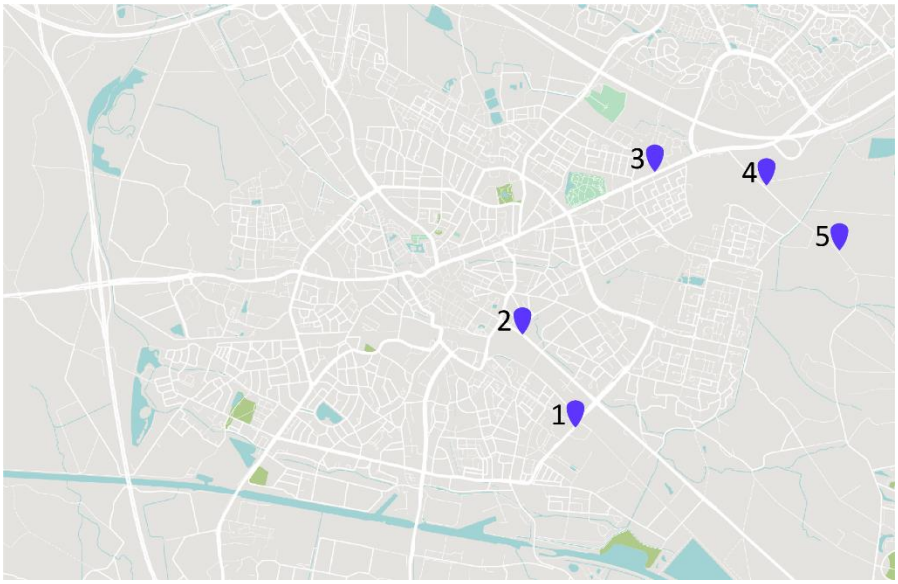

Figure 5.12 Traffic count locations for validation of the mobilityscan model.

The validation is considered successful if the deviation is +- 10% or smaller. These traffic counts in comparison with the mobilityscan scenario zero can be found in Table 5.6 for the morning rush, and Table 5.7 for the evening rush. In this case, the validation is accepted at traffic counts 1 and 2 during the morning rush. The evening rush has higher average intensities according to the traffic counts, which gives a higher deviation than 10%. The intensity counted at location 3 can validate only one direction during the morning rush. The traffic travelling to the west at location 3 has a deviation of 4%. The other direction has a bigger deviation. The traffic count values of the evening rush are close to the calculated values of the mobilityscan scenario 0.

Traffic count locations 4 and 5 are more controversial. The road on which traffic count 4 is placed is used as a shortcut to travel to the Enschedesestraat through the neighbourhood. The road adjacent to count location 4 is the road with count location 5. This road is prohibited from traffic since this road is too small for the high intensity of traffic that uses this road as a shortcut to the Kennispark. Only destination traffic is permitted on this road. The intensity on road section 4 seemed to be majorly insignificant after comparing it to the OmniTRANS model. However, the insignificance is much smaller than the deviation Table 5.4 and Table 5.5 showed. The deviation on the road with traffic count 5 was in the first instance not calculated. The reason for this is the absence of traffic on this road in the OmniTRANS model. The deviation would otherwise approach infinity since dividing by zero is not possible. The big deviation can be explained since the road has much destination traffic according to the model. Even after completely closing the road for traffic, the intensity holds. The model allocated some destinations and origins along the road. This traffic has to use the closed-down road. The destination and origins of the area cannot be changed since the area is too big. Changing the origins and destinations of the area means that the intensity on other roads decreases too much. Therefore, this intensity will be accepted on the road which only accepts destination traffic.

Table 5.6 Deviations of the base model with traffic counts during morning rush hour.

Road Sections	Scenario 0	Traffic counts	Relative difference
1. Enschedesestraat (Section Kuipersdijk-Grundellaan)	285	283.5	1%
1. Enschedesestraat (Section Grundellaan-Kuipersdijk)	304	286.5	6%
2. Kuipersdijk (Section Enschedesestraat-Artemisstraat)	348	387.5	-10%
2. Kuipersdijk (Section Artemisstraat-Enschedesestraat)	296	322	-8%
3. Oldenzaalsestraat (Castorweg-Hasselerbaan)	606	461.3	31%
3. Oldenzaalsestraat (Hasselerbaan-Castorweg)	646	622.7	4%
4. Pentropsdijk-Nieuwe Grensweg	133	165.15	-19%
4. Nieuwe Grensweg-Pentropsdijk	233	111.35	109%
5. Nieuwe Grensweg (Zwavertsweg-Morshoeksweg)	133	141.15	-6%
5. Nieuwe Grensweg (Morshoeksweg-Zwavertsweg)	65	12.65	414%

Table 5.7 Deviations of the base model with traffic counts during evening rush hour.

Road Sections	Scenario 0	Traffic counts	Relative difference
1. Enschedesestraat (Section Kuipersdijk-Grundellaan)	271	336.5	-19%
1. Enschedesestraat (Section Grundellaan-Kuipersdijk)	355	456	-22%
2. Kuipersdijk (Section Enschedesestraat-Artemisstraat)	381	432	-12%
2. Kuipersdijk (Section Artemisstraat-Enschedesestraat)	434	485	-11%
3. Oldenzaalsestraat (Castorweg-Hasselerbaan)	617	664	-7%
3. Oldenzaalsestraat (Hasselerbaan-Castorweg)	710	682.1	4%
4. Pentropsdijk-Nieuwe Grensweg	194	138.8	40%
4. Nieuwe Grensweg-Pentropsdijk	402	202.8	98%
5. Nieuwe Grensweg (Zwavertsweg-Morshoeksweg)	77	44.7	72%
5. Nieuwe Grensweg (Morshoeksweg-Zwavertsweg)	75	29.1	158%

5.2.4 Calculating interventions

The results of the mobilityscan traffic model are elaborated in this section. The intensities of the morning and evening rush hour are compared with the current traffic situation in Hengelo. The intensities after the interventions are shown in absolute vehicles increase or decrease. Furthermore, the accessibility index is plotted for the different alternatives. The index indicates the improvement in accessibility per direction after interventions are calculated.

Alternative 1: Extended Laan van Driene

The extension of the Laan van Driene is modelled as follows: The road connects with the intersection of P.C. Hooftlaan and the existing Laan van Driene. The intersection is not further specified in the mobilityscan model. The model sees a road as a connection between two nodes. The northern connection of the extended Laan van Driene intersects with the Oldenzaalsestraat at the level of the Pentropsdijk. This connection is not realistic since the intervention requires more infrastructural modifications. However, this is not modelled in the mobilityscan model since the model does not offer the complexity of redesigning intersections. The model gives a prediction of roads which will be used by the traffic to get from their origin to their destination. In Figure 5.13 the difference in intensity is visualized for the road sections that experience effects from the intervention in the morning rush. The most significant increases and decreases are shown in absolute values in Table 5.6. The capacity and rush hour speed of the extension is adopted from the Laan van Driene, which is 1000 vehicles per hour and 40 km/h for the rush hour speed.

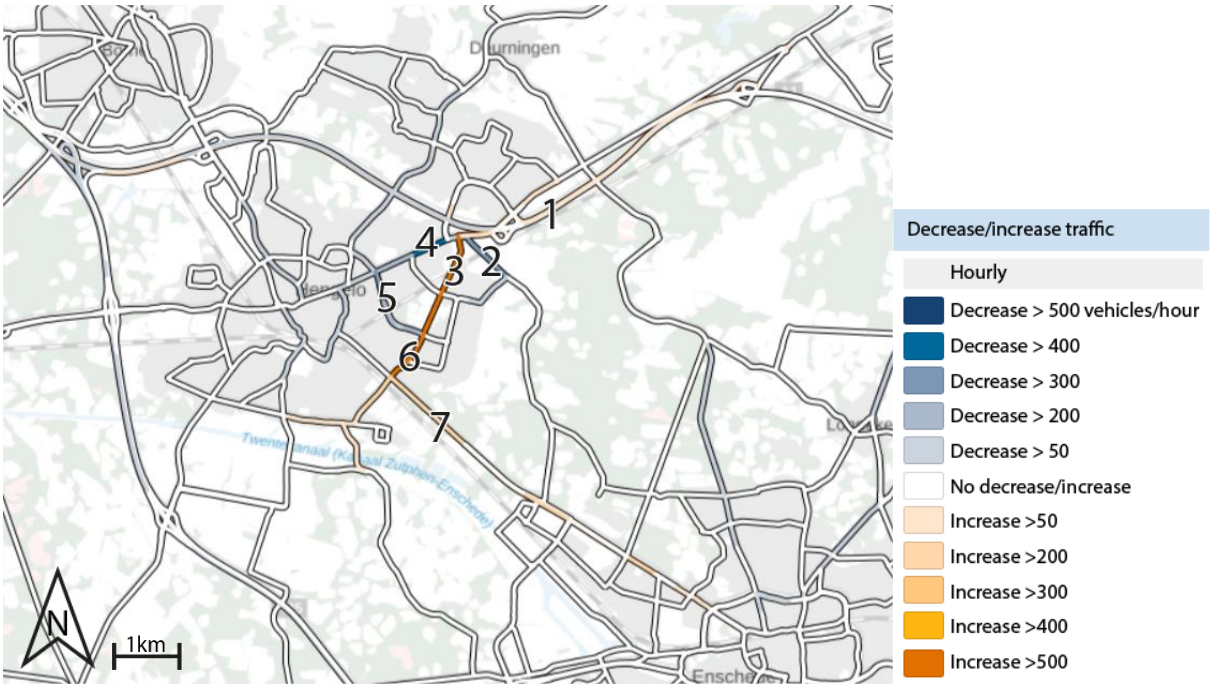

Figure 5.13 Model intensities of the extended Laan van Driene compared with the base model during morning rush hour. (Source: Mobilityscan)

Table 5.8 Intensities before and after intervention during morning rush hour.

Road with direction	Situation 0	After intervention
1. A1 towards Hengelo	2754	2836
2. Pentropsdijk (direction south)	418	133
3. Extension Laan van Driene (direction south)	0	846
4. Oldenzaalsestraat towards Hengelo	652	369
5. Beethovenlaan (direction south)	428	211
6. Laan van Driene (direction south)	738	1247
7. Enschedesestraat towards Enschede	919	1192

In Figure 5.14, the visualization of the intensity differences in the evening rush hour can be seen. The decrease and increase look very similar to the morning rush plot. Which is a sign that both models are consistent. In Table 5.7 these decreases and increases are quantified.

Figure 5.14 Model intensities of the extended Laan van Driene compared with the base model during evening rush hour. (Source: Mobilityscan)

Table 5.9 Intensities before and after intervention during evening rush hour.

Road with direction	Situation 0	After intervention
1. A1 towards Oldenzaal	2849	2866
2. Pentropsdijk (direction North)	402	208
3. Extension Laan van Driene (direction North)	0	589
4. Oldenzaalsestraat towards Oldenzaal	617	456
5. Beethovenlaan (direction North)	477	331
6. Laan van Driene (direction North)	714	890
7. Enschedesestraat towards Hengelo	748	825

At many road sections in Hengelo, a decrease in traffic volume is predicted in the morning and evening rush hours. There are obviously also roads where an increase in traffic intensity happens.

1. The *centrumring* experiences a decrease in volume. The reason for this could be that usage of the extended Laan van Driene and the A1 is now the faster route to get from north-west (Borne) to south-east (Enschede) and vice versa.
2. The Oldenzaalsestraat and the Beethovenlaan experience a significant decrease in traffic volume. This was the aim of the research project. The decrease in traffic volume means a better quality of life in these areas. With this decrease of approximately 200 vehicles per hour in the morning rush, and 150 vehicles per hour in the evening rush, the intensity does meet the capacity of the Oldenzaalsestraat and the Beethovenlaan. This means the congestion on these roads will be less, and thus accessibility will be greater.
3. The original Laan van Driene is getting busier than before. The intensity increased from 919 to 1192 in the morning rush after the new connection. This means that the traffic will experience significant congestion. Consequently, the extended Laan van Driene also has an increase in volume since there was no volume at this road section before.
4. The Hengelosestraat in Enschede experiences a slight increase in intensity. On the other hand, the northern connection from and to Enschede experiences a decrease in intensity.
5. The highways also experience intensity differences. The A35 south of Hengelo experiences a slight decrease in volume. The reason for this could be that inhabitants of West Enschede will use the highway ramp to the A1 in Hengelo. This is a result of the extended Laan van Driene, as the travel time from the Enschedesestraat to the highway ramp “Hengelo-Noord” is decreased. The intensity on the A1 highway coming from the east increased after the intervention. The reason for this is probably the new route to get from Oldenzaal to the Kennispark. This route is now used rather than the northern Enschede connection.
6. Lastly, the traffic that uses the neighbourhood of Groot Driene as a shortcut to reach the Kuipersdijk-Enschedesestraat intersection is decreased. The extension of the Laan van Driene offers a faster safer option. The safety increases since the traffic does not use the neighbourhood with primary school anymore.

The accessibility index of Hengelo East is compared with the accessibility index before the intervention. In Figure 5.15, the accessibility index is shown in a radar chart. It clearly can be seen that the accessibility towards the north has improved. This is expected since the extended Laan van Driene connects the eastern neighbourhoods with roads located to the north. The smallest circle indicates the distances until 7,5 km. The second circle indicates distances between 7,5 and 30 km. The biggest circle indicates distances greater than 30 km. It is noticeable that the accessibility for trips smaller than 30 km heading southwest decreases after the intervention. The reason for this is the congestion on the Laan van Driene since more vehicles will use this route. Trips further than 30 km southwest probably use the highway A1, which again can be reached faster with the new connection.

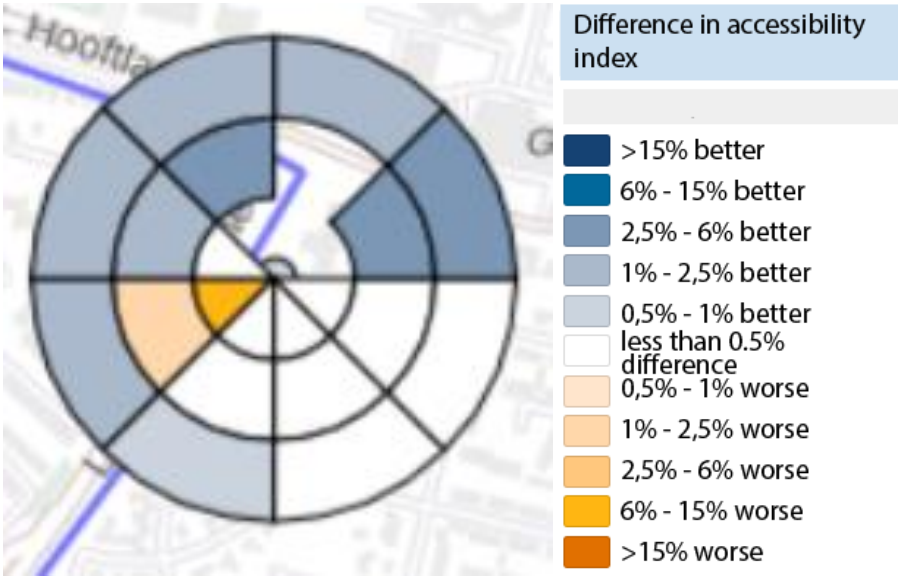

Figure 5.15 Accessibility index in Hengelo East after constructing the extended Laan van Driene. (Source: Mobilityscan)

Alternative 2: Upgrading the Nieuwe Grensweg and Bosweg

The upgrade of the Nieuwe Grensweg and Bosweg is modelled by upgrading the capacity and the speed limit. The speed limit is based on the rush hour speed of the Hengelosestraat. This rush hour speed is determined by the model to be 54 km/h. The same speed is copied to the Nieuwe Grensweg and Bosweg. The capacity of this road is again adopted from the Hengelosestraat, which is 1600 vehicles per hour. The visualisation of the intervention during the morning rush can be seen in Figure 5.16. In Table 5.8, the decreases and increases are shown in quantities.

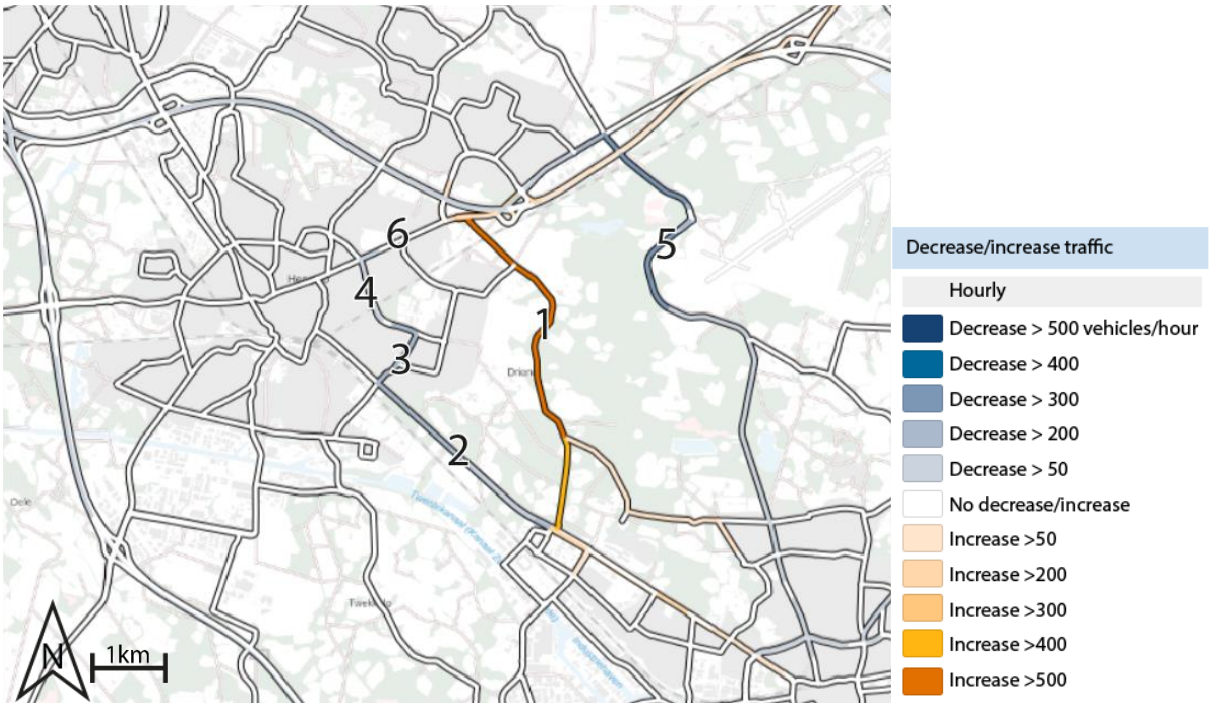

Figure 5.16 Model intensities of the upgrade of the Bosweg/Nieuwe Grensweg compared with the base model during morning rush hour.

Table 5.10 Intensities before and after intervention during morning rush hour.

Road with direction	Situation 0	After intervention
1. Nieuwe Grensweg towards Enschede	133	1346
2. Enschedesestraat towards Enschede	919	687
3. Laan van Driene (direction south)	738	524
4. Beethovenlaan (direction south)	428	289
5. Vliegveldstraat towards Enschede	975	717
6. Oldenzaalsestraat towards Hengelo	652	577

The visualisation of the intervention during the morning rush can be seen in Figure 5.17. The decreases and increases in quantities are shown in Table 5.9. Underneath this information, the reasons for these changes in intensities are explained.

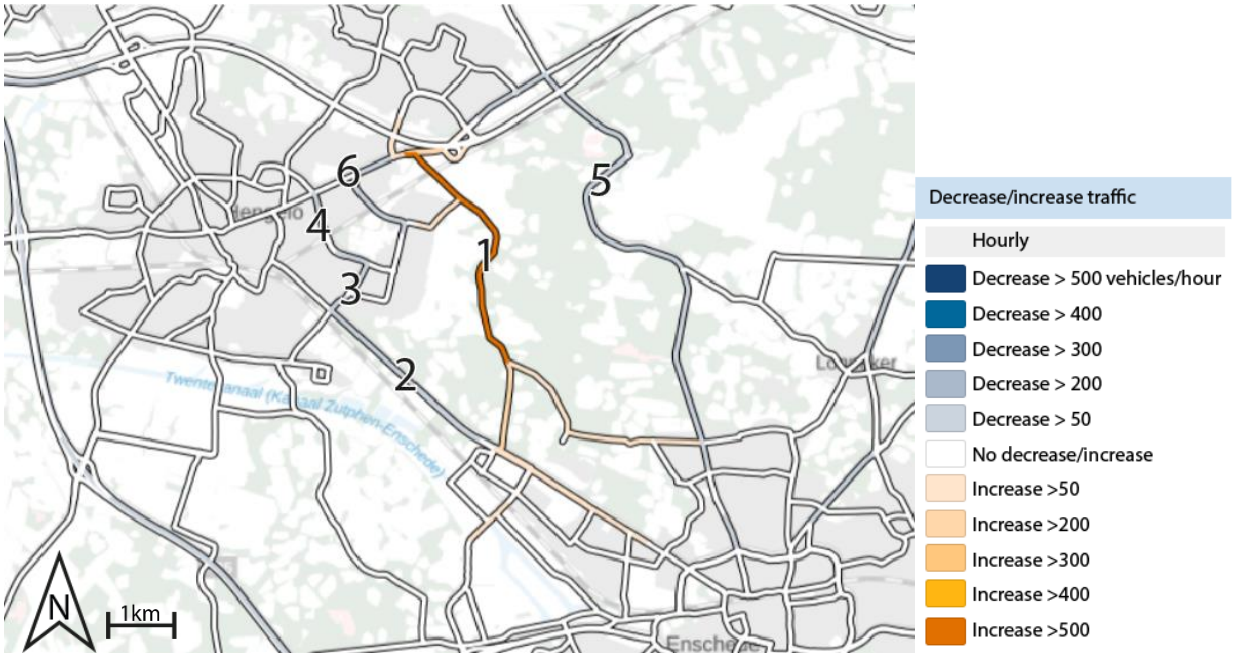

Figure 5.17 Model intensities of the upgrade of the Bosweg/Nieuwe Grensweg compared with the base model during evening rush hour.

Table 5.11 Intensities before and after intervention during evening rush hour.

Road with direction	Situation 0	After intervention
1. Nieuwe Grensweg towards Hengelo	75	865
2. Enschedesestraat towards Hengelo	748	604
3. Laan van Driene (direction North)	714	578
4. Beethovenlaan (direction North)	511	384
5. Vliegveldstraat (direction North)	711	591
6. Oldenzaalsestraat towards Oldenzaal	617	568

The increase on the Nieuwe Grensweg is significant after the upgrade since the road was not accessible before. The decrease in traffic volume in Hengelo is however not that significant.

1. The *centrumring* in Hengelo does not experience any benefits. The traffic intensity does not change according to the model.
2. The *wijkring* in Hengelo does experience a decrease in intensity during the morning and evening rush hours. The intensity on the Beethovenlaan decreases with approximately 150 vehicles per hour.
3. The Oldenzaalsestraat section heading towards the centre experiences a slight decrease in traffic volume since the Nieuwe Grensweg offers a faster option to reach Enschede.
4. The Laan van Driene does experience a decrease in traffic volume after the Bosweg is made accessible for traffic. The upgrade of the Bosweg relieves the Kuipersdijk/Enschedesestraat intersection. The same applies to the Enschedesestraat and the Vliegveldstraat. The reason for this is the extra choice to reach Kennispark.
5. This connection can also become an important route to the University of Twente. Currently, there is only one entrance to reach the University.

The Bosweg/Nieuwe Grensweg upgrade does relieve the infrastructure in Hengelo at the *wijkring.* It shifts the traffic that previously used the *wijkring* to get to the A1 highway ramp, to the Bosweg. This alternative only favours the eastern part of Hengelo, without contributing benefits to the rest of Hengelo. For this thesis project, this was not an issue as the scope of the project was improving the traffic situation in eastern Hengelo. The intervention also relieves the Kuipersdijk-Enschedesestraat intersection significantly, which is great since the intersection is near its capacity. The upgrade of the Bosweg has primarily influenced the Weerseloseweg since it decreased traffic volume there. This road is outside the scope of this project because it is an access road for the northern part of Enschede.

The accessibility index in Hengelo East of this intervention shows fewer results than the extension of the Laan van Driene. The index can be seen in Figure 5.18. Accessibility for trips between 7,5 and 30 km towards the north and northeast is increased. The other directions show no differences after the Nieuwe Grensweg intervention.

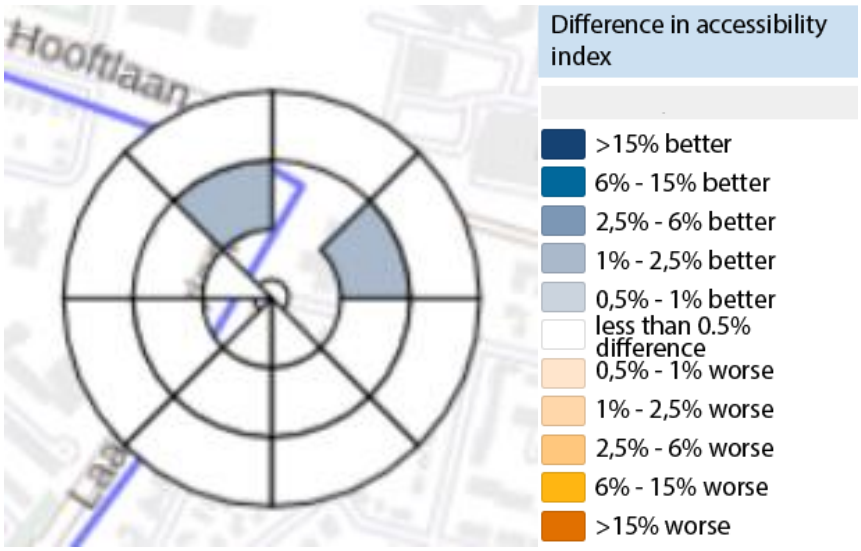

Figure 5.18 Accessibility index in Hengelo East after upgrading the Nieuwe Grensweg and Bosweg.

Alternative 3: NOEK (Noordelijke Ontsluiting Enschede Kennispark)

The route of the NOEK is based on the Ontwikkelagenda Netwerkstad Twente (Provincie Overijssel, 2013). In this document, ambitions for the future are expressed. The accessibility plan shows the NOEK approximately the same as the modelled intervention. Furthermore, expert 2 claimed that the more to the north the NOEK will be connected to the Weerseloseweg, the more benefit car users from Hengelo will experience from the new connection. Therefore, the NOEK is modelled as shown in Figure 5.19. The capacity and rush hour speed are adopted from the Hengelosestraat, which are 1000 vehicles per hour, and 35km/h. The most significant increases and decreases are shown in Table 5.10, together with important roads in Hengelo East.

Figure 5.19 Model intensities of the NOEK compared with the base model during morning rush hour.

Table 5.12 Intensities before and after intervention during morning rush hour.

Road with direction	Situation 0	After intervention
1. NOEK towards Enschede	0	354
2. Weerseloseweg towards Enschede	683	605
3. Vliegveldstraat towards Enschede	975	1096
4. Enschedesestraat towards Enschede	919	869
5. Laan van Driene (direction south)	738	686
6. Beethovenlaan (direction south)	428	391
7. Oldenzaalsestraat towards Hengelo	652	617

In Figure x, the intensities on road sections in the evening rush are displayed, subsequently, Table x quantifies these intensity values.

Figure 5.20 Model intensities of the NOEK compared with the base model during evening rush hour.

Table 5.13 Intensities before and after intervention during evening rush hour.

Road with direction	Situation 0	After intervention
1. NOEK (direction North)	0	410
2. Weerseloseweg (direction North)	616	519
3. Vliegveldstraat (direction North)	711	794
4. Enschedesestraat towards Hengelo	748	744
5. Laan van Driene (direction North)	714	698
6. Beethovenlaan (direction North)	511	482
7. Oldenzaalsestraat towards Oldenzaal	617	587

This intervention has not had a significant influence on the intensities in Hengelo. This already was expected after the expert interviews. The mobilityscan model shows the same outcome.

1. The Enschedesestraat and Laan van Driene experience a small decrease in intensity. However, the intensity decrease is minimal.
2. The intervention has mainly influenced the roads in Enschede. The road can be seen as an extra entrance road for Enschede. Therefore, the other entrance roads are relieved.
3. The Oldenzaalsestraat experiences a minor decrease, this happens because of the faster connection from Oldenzaal to the Kennispark area.

The NOEK can become a substantial connection for Enschede, on the other hand, this connection is disappointing for Hengelo. According to the model, the intensities in Hengelo do not decrease. substantially. As predicted by expert 2, the NOEK can only be a meaningful connection when there is a connection with the A1 highway in line with the NOEK.

The accessibility index of Hengelo East shows no difference after this intervention is modelled. This means that according to the model, the accessibility index in Hengelo East does not improve after constructing the NOEK.

5.2.5. Multi-criteria decision analysis

The MCDA framework with scores and outcomes are shown in Table 5.14. The explanation for the allocated scores can be found on the next page.

Table 5.14 MCDA framework with the outcome

Criterium		**Score**	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Weight**	**Alt. 1**	**Alt. 2**	**Alt. 3**
Improvement of Accessibility	Worsened impact	0	80	60	20	2.5	200	150	50
	No impact	20							
	Small impact	40							
	Moderate impact	60							
	Significant impact	80							
	Enormous impact	100							
Land use plan	Not viable	0	100	33	67	2	200	66	134
	Difficult viable	33							
	Medium viable	67							
	Great viable	100							
Safety	Many intersections	0	67	33	67	1.5	101	50	101
	Several intersections	33							
	A few intersections	67							
	No intersections	100							
Cost	Extremely high	0	25	75	75	1	25	75	75
	High	25							
	Moderate	50							
	Low	75							
	Very low	100							
Social Impact	Much demolishing	0	33	33	67	1.5	50	50	101
	Moderate demolishing	33							
	Minor demolishing	67							
	No demolishing	100							
Environmental vision	Contradictory	0	50	0	50	1.5	75	0	75
	In line with	50							
	Enhancement	100							
Total score							650	390	535

Improvement of accessibility

The first criterion is retrieved from the accessibility index and car users the new road attracts. The extended Laan van Driene makes big improvements in terms of accessibility. Accessibility in nearly every direction has increased after the construction of the Laan van Driene. Therefore, a score of 80 is allocated for this alternative, the reason why this alternative does not get the highest score is the direct decrease in accessibility in the southern direction, which is explained by the extra traffic that uses the road. The road gets more congested than before, so accessibility along the road decreases. The upgrade of the Bosweg does increase the accessibility in eastern Hengelo less than the extended Laan van Driene. However, it does attract extra users from Enschede to use this road to get to the A1, so accessibility increases in Hengelo East since the intensity on the Laan van Driene decreases. Therefore, a score of 60 is allocated. On the other hand, the NOEK has no direct impact on the accessibility in Hengelo East. The NOEK can be a substantial connection for the traffic in western Enschede. However, the impact on Hengelo is very minimal. Decreases in accessibility are small, faster routes are also not present. Therefore, the score allocated is 20.

Land-use plan

The second criterion is retrieved from the land-use plans. In these land-use plans, the purpose of the area is determined. The area for the extended Laan van Driene is reserved for the implementation of the new connection. Therefore, a score of 100 is allocated for this criterion. The upgrade of the Nieuwe Grensweg and Bosweg is difficult to perform since the area is publicly owned, next to that is the road close to a Natura 2000 area. This protected area hinders the possible construction of this road. The score is therefore 33. The NOEK also crosses publicly owned land but cannot be stopped because of the protected Natura 2000 area. A score of 67 is allocated.

Safety

Safety can be broadly interpreted, so to simplify this, the number of intersections is considered. In the literature section, it is made clear that accidents happen more at intersections than at all other road sections. The extension of the Laan van Driene will encounter one intersection along the new road section. Therefore a score of 67 will be given. The Bosweg has many houses and side streets, therefore in this context, the safety will be lower. For this reason, the score allocated is only 33. It is difficult to decide the number of intersections for the NOEK, the exact road plans are not available. Therefore, an estimation of 2 intersections along the road is made. The score for this alternative will also be 67.

Cost of infrastructure

Cost-wise is the extended Laan van Driene substantially more expensive than the other two options. This alternative requires a tunnel underneath the rail tracks. The construction of a tunnel is a big investment in comparison with the other two alternatives. On the other hand, the distance that must be paved is bigger at the other two alternatives. However, the construction costs of a tunnel are much higher than the extra distance of pavement costs. Therefore, the extended Laan van Driene does get a score of 25, the other two alternatives get a score of 75.

Social impact

The weights of the social impact are based on the properties that must be demolished in order to create the intervention. The area of the extended Laan van Driene now accommodates gardens. Inhabitants of Hengelo can grow their crops and plants over there. The demolition does not include any buildings if executed the right way. However, there is a football pitch located on the span of the road. A score of 33 is allocated for this alternative. For the Nieuwe Grensweg and Bosweg upgrade, some extra space is needed. There is a possibility that houses directly near the current road must be demolished. Therefore, the social impact score for this alternative is also 33. The NOEK is a road with not much information about its route. Therefore, it is hard to make statements about what could be demolished. After a small area overview, it can be assumed that the possibility of demolishing houses is not remarkably high. In this area, there are mainly grasslands and trees. The score given is therefore 67.

Environmental vision

The scores for this criterion are retrieved from the environmental vision plan of the municipality of Hengelo. The most important factor that is retrieved is the vision for the rural area where the Nieuwe Grensweg is located. It is clearly stated that this area is intended for recreational use. Bicyclists and hikers should feel the connection with nature in these parts of Hengelo. (Gemeente Hengelo, 2020) Therefore the Nieuwe Grensweg and Bosweg alternative will get a score of 0. The other two alternatives receive a score of 50.

The MCDA gives a clear outcome. The extended Laan van Driene has the highest score, thus is the intervention that in general is the best solution for enhancing the accessibility in Hengelo East. In short is an extension of the Laan van Driene the most viable alternative. The Nieuwe Grensweg and Bosweg is a difficult alternative since the location is not optimal regarding the protected nature and the environmental vision. The impact of the NOEK on Hengelo East is too minimal. For this reason, the extended Laan van Driene outscores the NOEK. In terms of viability land-use and cost, this option outscores the extended Laan van Driene.

The sensitivity of the MCDA is assessed using the one-at-a-time analysis. In Appendix A, the graphs of the analysis can be seen. The MCDA can be considered robust. Small changes do not change the outcome of the MCDA. In every situation, the result with the highest score is still alternative 1.

5.2.6. Model infrastructure in VISSIM

In this section, the best intervention – according to the MCDA – will be modelled in VISSIM. Firstly, the current infrastructure including the proposed roundabout is modelled in VISSIM. Secondly, the extended Laan van Driene is modelled. Thirdly, existing intersections are enhanced to accommodate extra traffic. Lastly, travel time results will be elaborated for the morning and evening rush.

Model current infrastructure

The intersection Kuipersdijk-Enschedesestraat is already a bottleneck in the infrastructure according to expert 1. During the morning rush, the intensity of traffic from Hengelo to Enschede is substantially high. In the evening rush, this movement is reversed, meaning traffic from Enschede to Hengelo experiences congestion.

In order to recreate the real-world scenarios, real-world traffic light data is adopted in the model. The traffic light controllers are simplified for the VISSIM model since the real traffic light data is too complex. The green times and traffic cycles are retrieved from hard data. The involvement of detectors is excluded in the model, as well as public transit and bicycles. However, the bicycle traffic light cycle is pseudo-modelled. During green times for straight-through traffic, bicycles in the same direction can cross the intersection because cars will not turn.

The proposed roundabout at the P.C. Hooftlaan and Laan van Driene is also modelled since this intervention will be done by the end of 2024. This roundabout will be constructed to improve safety, mainly because the crossing traffic experiences unsafety. It is hard to cross the road for bicyclists, subsequently, during rush hours, cars coming from the neighbourhood can hardly enter the *Wijkring.* (Waanders, 2024)

To create the morning and evening rush models, the traffic intensity data from OmniTRANS is used. At every start link, the intensity of the OmniTRANS model is applied. Then, static routing decisions are used to lead the cars through the infrastructure system, ensuring the right intensities on various road sections. The base model (Figure 5.21) including a new roundabout is created to capture travel times through the system. The average travel time is measured from the Enschedesestraat to the first A1 highway ramp. This distance in the base model is 4000 meters.

Model extended Laan van Driene

The extension of the Laan van Driene shortens the path by approximately 1200 meters. This means that the described route only is 2800 meters. The extended Laan van Driene has one intersection along the route, this intersection is pseudo-modelled with a reduced speed area in the link. The extended Laan van Driene ends with a roundabout. The roundabout can be compared with the proposed plan of LOS stadomland (2010). The pseudo-modelling of an intersection is a point of discussion. The static speed reduction may insufficiently emulate the congestion caused by an intersection.

The extended Laan van Driene attracts extra traffic, which means that intensities on the road sections will increase. These increases will be retrieved from the mobilityscan model. During the morning rush hour, the traffic going from the A1 and Hengelo to Enschede increases. During the evening rush hour, traffic coming from Enschede to Hengelo and the A1 increases.

The traffic input on the Oldenzaalsestraat during the morning rush will be increased to 1079 vehicles per hour. The static vehicle route is adjusted to meet the expected intensity on the extended Laan van Driene.

Model enhancements of current infrastructure

After the increased intensity in the morning rush, a new bottleneck occurs. The roundabout which will be completed at the end of 2024 does not have the capacity for the increased intensity. The vehicles experience extreme congestion on the extended Laan van Driene. To solve this problem, the roundabout will be replaced with a signalized intersection. The intersection can be seen in Figure 5.21. The roads with the highest intensities have a dedicated turning lane for each direction. The road which connects the neighbourhood with the *wijkring* only has 2 turning lanes since the intensity is far from the capacity.

Figure 5.21 Redesign of intersection P.C. Hooftlaan-Laan van Driene.

The bottleneck at the intersection with the extended Laan van Driene is solved. However, the problem shifts to the Kuipersdijk-Enschedesestraat intersection which already reaches its capacity nowadays. The congestion after increased intensity is enormous. The Kuipersdijk-Enschedesestraat intersection is improved next. During the morning rush hour, traffic movements from Hengelo to Enschede are extreme. An extra turning lane is designed to accommodate the extra traffic that wants to turn left to the Enschedesestraat. On the other hand, the traffic flows mainly to Hengelo during the evening rush. This traffic experiences congestion mainly at the right turn. Vehicles back up to the start of the turning lane, which means that left turning, and straight-through vehicles also experience congestion. Therefore, an extra turning lane to the right is added to increase traffic flow to the Laan van Driene. The new intersection design with double turning lanes can be seen in Figure 5.22.

Figure 5.22 New intersection design Kuipersdijk-Enschedesestraat

Analysis of travel times

To summarise, three big interventions are designed to improve accessibility in eastern Hengelo. The first intervention is the construction of the extended Laan van Driene. The extended road has one intersection before entering the tunnel which leads underneath the train tracks. When the road ascends again after the tunnel, it connects with the Oldenzaalsestraat. LOS stadomland (2010) proposed a roundabout for the connection with the Oldenzaalsestraat. The capacity of roundabouts is heavily dependent on the size, traffic intensity, and number of vehicles that make a left turn. (Tan, 2001) However, during both morning and evening rush hours, the direction with the highest intensity is the straight-ahead direction. Therefore, a roundabout can be a viable design for this part of the extended Laan van Driene.

The second intervention that is needed is the redesign of the P.C. Hooftlaan and Laan van Driene intersection. When traffic intensity increased because of the extended Laan van Driene, the capacity of the roundabout that will be constructed at the end of 2024 is not sufficient. The roundabout should be replaced with a signalized intersection. The layout of this signalized intersection can be seen in Figure 5.22. This signalized intersection has a higher capacity than the small roundabout.

The third intervention to accommodate the extra traffic is the extra turning lanes at the Kuipersdijk-Enschedesestraat intersection. Traffic in the morning rush hour benefits from an extra turning lane at the Enschedesestraat in the Laan van Driene direction since this is the direction with the highest intensity. Subsequently, these two turning lanes have to merge again after the intersection. Conversely, during the

evening rush hour, the traffic benefits from an extra turning lane at the Laan van Driene in the direction of the Enschedesestraat. This means that the intersection will include 2x4 turning lanes and 2x3 turning lanes after the intervention. After these interventions, an average decrease in travel time of 42% occurs measured from the A1 highway to the Enschedesestraat and vice versa. The sum of all travel times of the base scenario is compared with the sum of the intervention scenario. The base and intervention scenarios are shown in Figure 5.23 including the locations of the travel time counters. In Table 5.15, the travel times in different directions at the rush hours are shown.

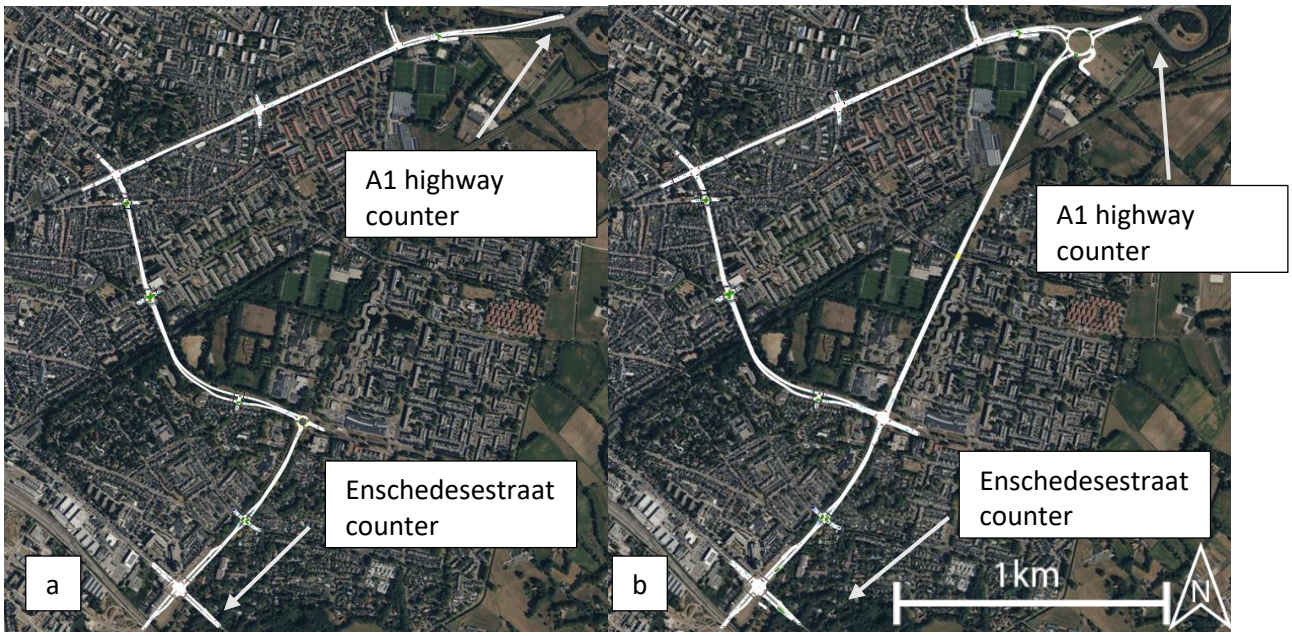

Figure 5.23 Infrastructure base (a) and intervention (b) scenario, including locations of travel time measurements.

Table 5.15 Travel times before and after interventions

Model Scenario	Road section	Time morning rush hour (s)	Time evening rush hour (s)
Base scenario (Figure 5.23a)	Enschedesestraat- A1 ramp	405.67	437.00
	A1 ramp - Enschedesestraat	526.86	415.95
Extended LvD with double left and right (Figure 5.23b)	Enschedesestraat- A1 ramp	246.61	252.66
	A1 ramp - Enschedesestraat	272.21	256.43

Although these interventions are beneficial for the municipality of Hengelo, Enschede could experience an increase in congestion. As stated by Expert 1, mobility and accessibility are transboundary concepts. The bottlenecks regarding congestion could shift to the municipality of Enschede, which means that the accessibility to Enschede would not improve as much as desired. Therefore, the increase in traffic volume on the Enschedesestraat in the direction of Enschede should be considered when further research is done.

6. Conclusions

The aim of this thesis was to analyse the current traffic intensities and analyse the effects of an intervention to alleviate congestion during rush hours in Hengelo East. The research questions are:

1. What are the limitations of the current traffic infrastructure in the eastern part of Hengelo, considering the traffic on the wijkring and Oldenzaalsestraat?
2. What is the most effective intervention for improving traffic accessibility and safety in the eastern part of Hengelo?

Based on expert interviews and quantitative analysis of traffic flows and safety, it can be concluded that the bottlenecks in Hengelo East occur in several intersections. The best strategy to improve accessibility and safety during rush hours was analysed with traffic models and expert interviews. An MCDA analysis concluded that the extension of the Laan van Driene makes the biggest impact on accessibility by shifting traffic from the *wijkring* to the new connection. An average travel time reduction of 42% is measured after the construction of the extended Laan van Driene and the improvement of existing infrastructure.

In conclusion, this research applied a mixed method approach, which provided a comprehensive understanding of the bottlenecks by combining the view of experts and quantitative analysis. This strategy was chosen to capture not only objective traffic data but also the subjective opinions of traffic experts.

While there are some limitations, such as bias in the MCDA scores and model simplifications, the findings of this thesis are valuable recommendations for the municipality of Hengelo. Another limitation that lies outside the scope of this project is the modal shift in the future. This thesis is based on car-related infrastructure measures, the decreased intensity as a result of modal shift is not considered. However, the insights of this thesis are setting a strong foundation for future research and planning efforts.

7. Recommendations for further research

This thesis was an exploratory study for the improvement of accessibility. The rough outlines for the best solution are developed in this thesis. Further research should prove that the traffic intensity through the Laan van Driene does not improve disproportionally. Next to that is deeper research into the intersections along the current Laan van Driene needed. It can become apparent that the other intersections along the Laan van Driene also need signalized intersections when intensities are higher than calculated. The roundabout that LOS stadomland (2010) proposed needs also further research. The capacity of roundabouts where high intensities come together performs worse than signalized intersections. On the other hand, we should be careful that the number of signalized intersections on one road is not getting out of hand. In short, the elaboration of the best alternative requires further research.

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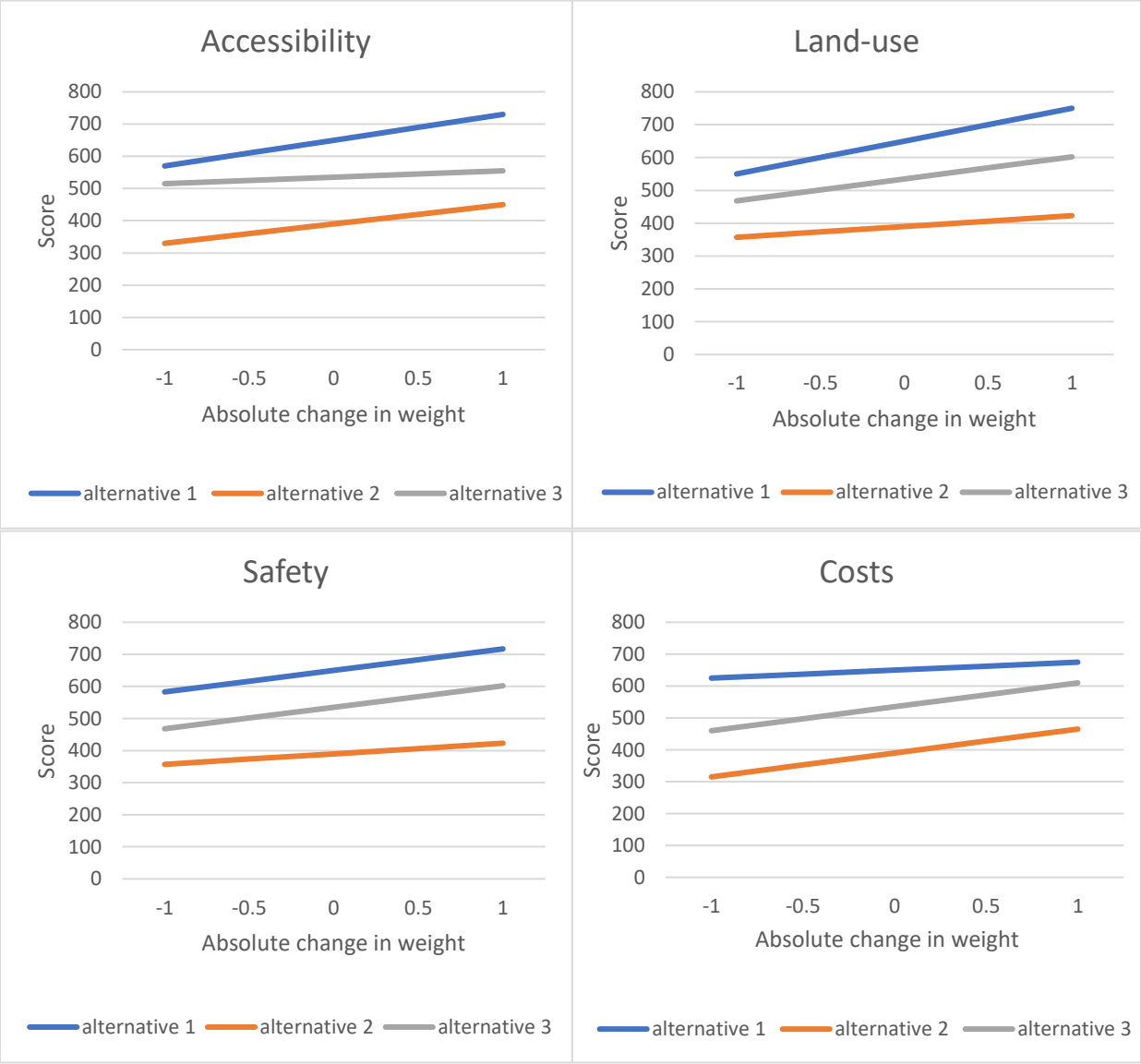
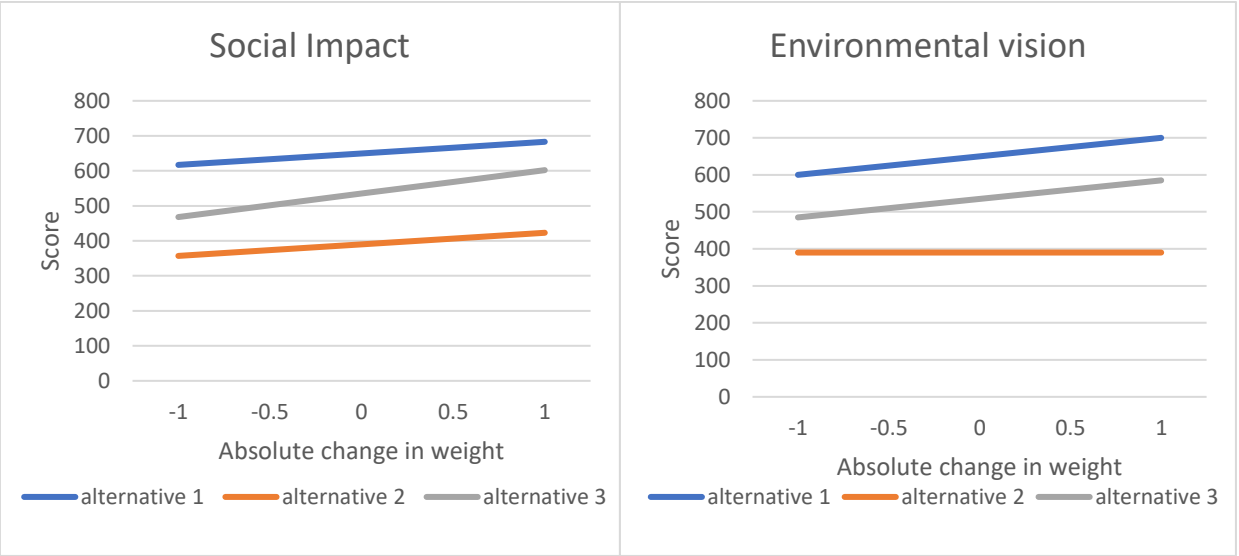
9. Appendix

Appendix A: Graphs Sensitivity Analysis MCDA




Social Impact
800
700
600
500
400
300
200
100
0
Score
-1
-0.5
0
0.5
1
Absolute change in weight
alternative 1
alternative 2
alternative 3
Environmental vision
800
700
600
500
400
300
200
100
0
Score
-1
-0.5
0
0.5
1
Absolute change in weight
alternative 1
alternative 2
alternative 3