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Measuring the level of TOD-ness of transit areas around small train stations in Zuidoost-Brabant

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Preface

This report is the result of research that was carried out to finalize my Master Construction Management & Engineering at the Eindhoven University of Technology. In the course of obtaining my Master, I became interested in the field of urban planning and mobility. This led me to choose the topic of my graduation project in this field that fits with my interests.

Starting with a talk with my supervisor Peter van der Waerden a year ago to find a topic in my field of interest, I moved to Taipei, Taiwan, shortly after for an exchange semester. During my semester abroad, I set a goal for myself to find a topic, find a company to collaborate with and write my proposal. It was quite a challenge to arrange this at a distance of over 9500 kilometers from the Netherlands. Luckily, Movares was interested in my background and my suggested research topics, and I was allowed to do a job interview through Skype (what was quite odd at that time). When I was offered an internship, I contacted Ivo Bastiaansen from Movares and my supervisor Peter van der Waerden often through email and telephone calls to specify my research topic. When the topic was set to create a tool to measure the TOD-ness around small stations in the case area of Zuidoost-Brabant, I finished my proposal in Taiwan.

Coming back from my semester abroad in the Netherlands at the end of January, I started my graduation and internship three days after. This required some adaptability. After I had become adjusted to working at the Movares office in Utrecht for just over a month, the COVID-19 pandemic hit the Netherlands. The result was that there was no further possibility to work from the office and all work for the research had to be done from home. Therefore, unfortunately, the connection with colleagues at Movares diminished, but also some proposed ideas for my research could not be developed further.

I think I could say that the period of my thesis was quite a rollercoaster ride. But, due to the good and effective contact with my supervisors, the research has been guided properly and resulted in this final report. Therefore, I would like to thank my supervisors from the TU/e, Peter van der Waerden and Gamze Dane and my supervisor from Movares, Ivo Bastiaansen. They spent a lot of time guiding me, providing critical feedback and helping me to write this thesis. Also, I would like to thank Movares and the colleagues of the department of M&R for welcoming me and providing me information and opportunities within the department. Lastly, I want to thank my parents, my girlfriend and Sven Koch for supporting my throughout the whole process.

Finally, I am happy with my personal development conducting this graduation project and I am delighted to finish my time at university to start a new chapter in my life.

I wish you a pleasant time reading this thesis.

Kind regards,

Steven Wulffraat
Amsterdam, July 2020

Summary

When private cars became more affordable after the Second World War, mobility and urban development changed as accessibility increasingly became an important factor. Suburbanization took place and led to numerous problems such as traffic congestion, loss of open space and increase of pollution. A planning approach that counteracts the urban sprawl and stimulates the use of public transport is Transit-Oriented Development (TOD). Besides a planning approach, the term TOD is also used to define an easily accessible and walkable area around a transit stop, which integrates land use with the transport system to increase access to public transportation, utilizing already serviced land rather than increasing urban sprawl, increasing transit ridership, reducing pollution by vehicular traffic, reducing the consumption of oil and gas and benefits to healthier lifestyles.

The approach of TOD is most often encountered when dealing with dense urban areas or large cities. Here, many facilities and amenities, transit options and inhabitants are present. However, numerous problems such as congestion in large cities originate from the surrounding suburban areas. This is because people that live in these suburban areas, often still work or visit the large cities and are often fervent car users who are not attracted to travelling by public transportation. Therefore, the TOD approach in the suburban areas with lower density, less amenities and transit options is less interesting for policy makers and urban planners compared to TOD's in large cities. However, if a more sustainable society is to be created, trips of people in both high density and low density areas must change by using public transport.

The purpose of this research is to create a tool to measure the level of TOD-ness of transit areas around small train stations. With this tool, a clear overview can be given to see where improvements can be made to increase the TOD-ness and attract more people to make use of the transit area and the public transportation in the area. To formulate the problem, the following research question is defined: *"How can transit areas around small stations be improved to increase the use of public transport by creating a tool to measure the level of TOD-ness?"*

For this research, the case study of Zuidoost-Brabant is used. This area, also seen as the Metropolitan Region of Eindhoven (MRE). This area consists of 21 municipalities with approximately 750,000 inhabitants and about 35,000 workspaces with important locations such as the international airport of Eindhoven, a technological university and the High Tech Campus Eindhoven. The ambition of the area is to maintain and increase their economic position. Accessibility to and between cities is one of the preconditions to achieve this competitive economic position. High quality rail transit and a densification of urban development around the rail network stations through regional planning is required.

To investigate the TOD approach, a theoretical framework is constructed based on a literature review. This state-of-the-art literature review describes the travel behavior, the insights of TOD's and especially TOD's in small cities or villages and the different measurement methods of transit areas. The literature review shows that it is important to focus on new developments around transit stops, but also to integrate with the existing area around these transit stops. Different dimensions, the "5 D's", have to be kept in mind; density, diversity of land-use, design, distance to transit and destination accessibility. Multiple studies are found which evaluate areas around transit nodes, based on the node- and place-values, however the perception of user is ignored while this factor plays an important role in the attractiveness of transit stops. Therefore a sixth D, desirability of facilities, is added to assess and evaluate facilities that influence the perception of users.

Also, multiple studies are found that compare different types and sizes of transit areas with each other. This can cause biased results because transit areas of different sizes have different qualities and needs. Few studies are found that only focus on transit areas around small stations. Therefore, it is important to create a measurement tool to evaluate the TOD-ness in transit areas of small cities and villages. The three main values that have to be tested are:

- The place-values to check the accessibility and connectivity within the transit area and with other areas;
- The node-values to see how many and how diverse the activities are that can be performed in a transit area;
- The perception of users which plays an important role for the attractiveness of transit stops and transit areas.

In the case study, 10 stations in the region of Zuidoost-Brabant are selected that are conform the criteria of a small station. These stations are Best, Deurne, Eindhoven Strijp-S, Geldrop, Heeze, Helmond, Helmond Brandevoort, Helmond Brouwhuis, Helmond ’t Hout and Maarheeze.

For the measurement of the transit areas of the stations of the case study, the TOD-Index by Singh et al. (2017) is used as basis and adjusted for the focus on transit areas around small stations. In total, three values (node, place and perception of users) with eight criteria and 24 accompanying indicators are identified. The criteria that are measured are:

- Population density;
- Amenities;
- Land use diversity;
- Walkability/ cyclability;
- Accessibility to and from station;
- Parking supply;
- Capacity of utilization of transit;
- Perception of users.

Data in this research is collected via spatial analyses with GIS in QGIS, using the Verbindingswijzer of Movares, using public data from municipalities, provinces and the NS, using information from earlier studies in this region and by talks with experts.

Using indicators and criteria with different levels of importance, each transit area is evaluated and is given an overall score indicating the level of TOD-ness. Based on the results, it is suggested that a higher level of TOD-ness has a positive influence on the number of daily users of the train stations. Per transit area, area specific recommendations for improvements are given using the overall level of TOD-ness and the scores per criteria.

Overall, this TOD measurement tool aims to fill the scientific gap for evaluating TOD’s around small stations. The TOD measurement tool focuses on transit areas around small stations can be used by for example policy makers for municipalities, provinces and advisory companies to get a clear overview on the level of TOD-ness of certain transit areas. Area specific recommendations can be given to attract people to make use of transit areas and the public transport system. From the user’s perspective, improvements of the transit areas contribute to a more attractive area with high quality transit service, which could lead to a more sustainable mobility and society. A new daily urban system can be created around small train stations that enhances the polycentrism of a region and decreases mobility problems in the city center.

Samenvatting

Sinds de komst van betaalbare privéauto's na de Tweede Wereldoorlog, is de mobiliteit en stedenbouw veranderd doordat de bereikbaarheid verbeterd is. Suburbanisatie vond hierbij plaats en leidde tot verschillende problemen zoals verkeersopstoppingen, verlies van open ruimte en toename van luchtvervuiling. Een planningsaanpak die de stedelijke groei tegengaat en het gebruik van het openbaar vervoer stimuleert, is Transit-Oriented Development (TOD). Naast planningsaanpak, wordt de term TOD ook wel gebruikt voor het aanduiden van een toegankelijk en beloopbaar gebied rondom een halte of station, die de stedenbouw met het vervoerssysteem integreert om de toegang tot het openbaar vervoer te verbeteren. Hierbij wordt gebruik gemaakt van bestaande ruimte binnen het stedelijke gebied in plaats nieuwe gebieden te bouwen aan de rand van de stad. Het openbaar vervoersgebruik wordt vergroot, de vervuiling door het autoverkeer wordt verminderd, het verbruik van olie en gas wordt teruggedrongen en een gezondere levensstijl wordt bevorderd.

De TOD-aanpak is het meest bekend uit dichtbevolkte stedelijke gebieden of grote steden. Hier zijn veel faciliteiten/voorzieningen, vervoersmogelijkheden en bewoners aanwezig. Echter, tal van problemen zoals congestie in grote steden komen voort uit de voorstedelijke gebieden eromheen. Vaak komt dit doordat de mensen die in de voorsteden wonen, nog steeds werken in de grote steden of hier vaak bezoek aan brengen. Vaak zijn deze mensen ook gehecht aan het autogebruik en zijn dan ook minder geïnteresseerd in het reizen met het openbaar vervoer. Daarnaast is de TOD-aanpak in de sub-urbane gebieden met een lagere dichtheid, minder voorzieningen en minder vervoersmogelijkheden minder interessant voor beleidsmakers en stedenbouwkundigen in vergelijking met TOD's in de grote steden. Om een duurzamere samenleving te creëren, moet de verplaatsing van mensen in zowel gebieden met een hoge bevolkingsdichtheid als gebieden met een lage bevolkingsdichtheid verbeteren door meer gebruik te maken van het openbaar vervoer.

Het doel van dit onderzoek is om een instrument te creëren om de TOD-waarde van de vervoersgebieden rond kleine treinstations te meten. Met dit instrument kan een duidelijk overzicht worden gegeven van waar verbeteringen kunnen worden aangebracht om de TOD-waarde te verhogen en meer mensen te stimuleren om gebruik te maken van het vervoersgebied rondom een station en het openbaar vervoer. Om het probleem te formuleren wordt de volgende onderzoeksvraag gedefinieerd: "*Hoe kunnen vervoersgebieden rond kleine stations worden verbeterd, om het gebruik van het openbaar vervoer te vergroten, door een instrument te creëren om het niveau van de TOD-waarde te meten?".*

Voor dit onderzoek wordt de regio Zuidoost-Brabant als case studie gebruikt. Dit gebied wordt ook wel de Metropoolregio Eindhoven (MRE) genoemd. Het is een gebied met 21 gemeenten, ongeveer 750.000 inwoners en ongeveer 35.000 werkplekken met belangrijke locaties als de internationale luchthaven Eindhoven, een technische universiteit en de High Tech Campus Eindhoven. De ambitie van de regio is om de economische positie te behouden en/of te vergroten. Hierbij is de bereikbaarheid van en tussen dorpen en steden een van de belangrijkste voorwaarden. Er is behoefte aan hoogwaardig railvervoer en een verdichting van de stedelijke ontwikkeling rond de stations van het spoorwegnet door middel van regionale planning.

Om de TOD-aanpak te onderzoeken wordt op basis van een literatuurstudie een theoretisch kader geconstrueerd. Dit state-of-the-art literatuuronderzoek beschrijft het reisgedrag, de inzichten van TOD's in zowel grote steden als in kleine steden of dorpen en de verschillende meetmethoden in de vervoersgebieden. Uit literatuuronderzoek blijkt dat het belangrijk is om aan te sturen op nieuwe ontwikkelingen in de vervoersgebieden, maar ook op het integreren van bestaande gebieden rondom deze vervoersgebieden. Hierbij moet rekening gehouden worden met de "5 D's"; dichtheid, diversiteit van het landgebruik, het design, de afstand tot het station en bereikbaarheid van de bestemming (Engels: Density, Diversity of land-use, Design, Distance of travel, Destination accessibility). Er zijn meerdere studies gevonden die vervoersgebieden hebben geëvalueerd, gebaseerd op de knoop- en plaatswaarden, maar niet of nauwelijks gebaseerd op de perceptie van gebruikers terwijl dit wel van invloed kan zijn. Daarom wordt er in deze studie een zesde D, de wenselijkheid van faciliteiten (Engels: desirability of facilities), toegevoegd om voorzieningen die de perceptie van de gebruikers beïnvloeden te beoordelen en te evalueren.

Daarnaast zijn er meerdere studies gevonden die zich richten op verschillende soorten en grootten van vervoersgebieden binnen een grotere regio. Dit kan tot vertekende resultaten leiden omdat deze vervoersgebieden verschillende kwaliteiten en behoeften kunnen hebben. Er zijn weinig studies gevonden die zich alleen richten op vervoersgebieden rond kleine stations. Daarom is het belangrijk om een instrument te creëren om de TOD-waarde in vervoersgebieden van kleine steden en dorpen te evalueren. De drie hoofdaspecten die getest moeten worden zijn:

- De plaatswaarden om de bereikbaarheid en connectiviteit binnen het vervoersgebied en tussen vervoersgebieden te testen;
- De knoopwaarden om de diversiteit van de activiteiten te testen die in een vervoersgebied aanwezig zijn;
- De perceptie van de gebruikers die een belangrijke rol speelt op de aantrekkelijkheid van het station en het vervoersgebied.

In de case studie zijn 10 stations geselecteerd in de regio Zuidoost-Brabant. Deze stations zijn Best, Deurne, Eindhoven Strijp-S, Geldrop, Heeze, Helmond, Helmond Brandevoort, Helmond Brouwhuis, Helmond 't Hout en Maarheeze.

Voor het meten van de vervoersgebieden rondom de stations van de case studie wordt de TOD-Index van Singh et al. (2017) als basis gebruikt en aangepast voor de focus op vervoersgebieden rond kleine stations. In totaal worden drie aspecten (knoopwaarden, plaatswaarden en perceptie van gebruikers) met acht criteria en 24 bijbehorende meetbare indicatoren onderzocht. De criteria die worden onderzocht zijn:

- Bevolkingsdichtheid;
- Voorzieningen;
- Diversiteit in landgebruik;
- Loopbaarheid/ fietsbaarheid;
- Toegankelijkheid van en naar het station;
- Parkeergelegenheid;
- Gebruikscapaciteit van het vervoersmiddel;
- Perceptie van de gebruikers.

De gegevens in dit onderzoek worden verzameld via ruimtelijke analyses met GIS in QGIS, met behulp van de Verbindingswijzer van Movares, met behulp van openbare gegevens van gemeenten, provincies en de NS, met behulp van informatie uit eerdere onderzoeken in deze regio en door gesprekken met experts.

Door de indicatoren en criteria met verschillende wegingen te gebruiken, wordt ieder vervoersgebied geëvalueerd en krijgt het een totaalscore voor de TOD-waarde. Op basis van de resultaten wordt gesuggereerd dat een hogere TOD-waarde een positieve invloed heeft op het aantal dagelijkse gebruikers van de treinstations. Per vervoersgebied worden gebiedsspecifieke aanbevelingen voor verbeteringen gegeven aan de hand van het algemene score van de TOD-waarde en de scores per criterium.

Samenvattend wordt geprobeerd om met dit TOD-meetinstrument het wetenschappelijke hiaat op te vullen om TOD's rond kleine stations te evalueren. Het TOD-meetinstrument gericht op vervoersgebieden rondom kleine stations, kan door bijvoorbeeld beleidsmakers van gemeenten, provincies en adviesbureaus worden gebruikt om een duidelijk overzicht te krijgen van hoe het met het TOD-gehalte van een bepaald vervoersgebied gesteld is. Gebiedsspecifieke aanbevelingen kunnen worden gegeven om mensen te stimuleren om gebruik te maken van de vervoersgebieden en het openbaar vervoer. Vanuit het perspectief van de gebruiker dragen zowel de verbeteringen van de vervoersgebieden als de verbeteringen aan het vervoerssysteem bij aan de aantrekkelijkheid van het gebruik daarvan. Dit kan leiden tot een duurzamer mobiliteitssysteem en een duurzamere samenleving. Een nieuw “daily urban system” kan worden gecreëerd rond kleinere treinstations waardoor het polycentrisme van een regio wordt versterkt en de mobiliteitsproblemen in grotere steden worden verminderd.

Abstract

Transit-Oriented Development (TOD) is a planning approach that counteracts urban sprawl and stimulates the use of public transport. It is an easily accessible and walkable area around a transit stop, which integrates land use with the transport system to increase access to public transportation, utilizing already serviced land rather than increasing urban sprawl, increasing transit ridership, reducing pollution by vehicular traffic, reducing the consumption of oil and gas and offering benefits such as healthier lifestyles. TOD is best known from dense urban areas or large cities, while numerous problems in city centers originate from suburban areas around it. This is because people from suburban areas, often still work or visit the big cities and are high users of personal cars. Besides that, the TOD approach in the suburban areas with lower density, less amenities and transit options is less interesting for policy makers and urban planners compared to TOD's in large cities. To create a more sustainable society, trips of people in both high density and low density areas must change.

To evaluate the TOD-ness of transit areas around small train stations, a tool is created that gives an overview of where improvements can be made. This tool measures the node values, place values and the perception of users with eight criteria and 24 measurable indicators at a total of 10 transit areas around small stations in the case study of Zuidoost-Brabant. Area specific recommendations are given based on eight criteria and the final TOD score.

This tool aims to fill the scientific gap for measuring TOD's around small stations and can be used by municipalities, provinces and advisory companies to get a clear overview on the level of TOD-ness is of a certain transit area. From the user's perspective, improvements of the transit areas contributes to a more attractive area with high quality transit service, which could lead to a more sustainable mobility and society. A new daily urban system can be created around small train stations that enhances the polycentrism of a region and decreases mobility problems in the city center.

Keywords: Transit-Oriented Development; Urban sprawl; Land use; Sustainable mobility; Mobility problems; TOD measurement tool; Polycentrism; Zuidoost-Brabant; MCA;

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List of abbreviations

BREVER-law	=	Law of conservation of travel time and displacement (Dutch: Wet van Behoud van REistijd en VERplaatsingen)
CBS	=	Statistics Netherlands (Dutch: Centraal Bureau voor de Statistiek)
CPBR	=	Cafes/Pubs/Bars/Restaurants
DUS	=	Daily Urban System
GIS	=	Geographic Information System
IC	=	Intercity train
IPCA	=	Impedance Pedestrian Catchment Area
MCA	=	Multi-Criteria Analysis
MRE	=	Metropolitan Region of Eindhoven
NS	=	Dutch Railways (Dutch: Nationale Spoorwegen)
OSM	=	OpenStreetMap
OV	=	Public Transport (Dutch: Openbaar Vervoer)
QGIS	=	Quantum-GIS
TASS	=	Transit Areas around Small Stations
TOD	=	Transit-Oriented Development

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1. Introduction

1.1 History of land use and transport

Until the Industrial Revolution, cities were built on a relatively small scale. At that time, almost the only way to travel for people was on foot and therefore the cities were limited by transport technology. Services were concentrated in the center of the cities with a radius of approximately 2.5 kilometer (Marchetti, 1994). Inhabitants worked and lived at almost the same location. The long distance public transport was on roads with stage wagons or horse-drawn barge transport over water to other locations. During the Industrial Revolution steam engines were introduced and with that, railways were constructed which also changed the spatial planning of urbanization. Later, after the Second World War, private cars became affordable which contributed to mobility and landscape change. Accessibility increased and therefore became the most important factor in landscape change (Antrop, 2004). People moved out of cities to the suburbs. This urban sprawl will continue and it is estimated to triple in the next 40 years (The Guardian, 2016). This process of suburbanization led and will lead to several problems such as traffic congestion, loss of open space, and increased pollution (Sutton, 2003).

1.2 Transit-oriented development

One of the planning approaches to counteract urban sprawl and stimulate the use of public transport is Transit-Oriented Development (TOD). This approach is a relatively recent development model which gained interest in the United States and later in Europe since the 1990s. Besides the planning approach, a TOD can also be defined as an urban environment with high densities, mixed and diverse land use that is located within an easy accessible and walkable area around a transit stop (Calthorpe, 1993). It integrates the land use and transport system to increase access to public transportation, utilizing already serviced land rather than increasing urban sprawl, increasing transit ridership, reducing pollution by vehicular traffic, reducing the consumption of oil and gas and benefitting healthier lifestyles (Singh et al., 2017). It is focused on using existing land and its existing infrastructure network for better utilization instead of focusing on future value of development. Other benefits of TOD are, for example, linking sparsely populated areas of the province to jobs and amenities of the larger cities through public transport and responding to socio-economic trends such as teleworking and face-to-face contacts in the economic sectors where easily accessible locations are important (Provincie Noord-Holland & Vereniging Deltametropool, 2013). This means that a TOD is not just only a development near public transit, but also has to include: “location efficiency”, that people can use their bike or walk to access or egress public transit; a boost of transit ridership and minimize the impacts of traffic; a rich mix of housing, jobs, shopping and recreational choices and value for the public and private sectors, and for both new and existing residents, a sense of community and of place (Center for Transit-Oriented Development, 2009).

1.3 Small cities and villages

There are numerous reasons for people to live in surrounding areas of a large city. In general, the prices of houses are lower, there is more space, it is more quiet, etc. But, the problem that often occurs is that people are still working in the big city and therefore have to commute over some distance. The urban structure and attitude, as stated before, is important for the mode choice of people. When neighborhoods are not well connected to public transport nodes or the distances are too big, there is a high possibility that inhabitants will prefer to use their private vehicles. This is in line with the fact that multimodality mostly occurs between cores of urban areas (Ministerie van Infrastructuur en Waterstaat, 2019b). For a more sustainable mobility in a metropolitan area, trips of people in high density plus low density areas have to change. Only changing the urban structure in areas with lower density, will not certainly lead to more public transport users. It could also be a specific choice to live in more sub-urban regions with low-density. These people could be fervent car users who might not be interested in travelling by public transportation at all, even though a high accessibility has been created after adapting the urban structure of the area (De Vos et al., 2014). Focusing on transit areas in small cities or villages, it could be interesting to see where improvements can be made and how it will help to attract people from the surrounding area to make use of stations and transit areas.

In this research, transit areas around small stations (TASS) will be measured on TOD-ness (the level of TOD value). A small station is classified as a station that is categorized by NS as a station type 4, 5 or 6; respectively a station in the center of a small city or village, a suburban station without node function, or a station in an outlying area near a small city or village. Furthermore, the type of station has to be categorized by ProRail as a “Basis” or “Stop” station; respectively with <10.000 and <1.000 passengers per day.

Looking at the built environment situation of small cities and villages, there are several differences to acknowledge compared to the situation in large cities. In table 1 differences between small cities/ villages and city centers are presented.

Table 1: Differences of characteristics between small city/ village and a city center

Small city/ village	***City center***
Density	
Low-density of residents	High-density of residents
Low density of amenities	High density of amenities
Public transport options	
Few public transport options	Multiple public transport options
Low frequency of public transport	High frequency of public transport
Small and unattractive station	Attractive station with lots of facilities
Infrastructure	
Mixed roads for cars and bicycles	Often separated bicycle lane from main roads
Mode preferences	
Often fervent car using residents	Residents used to use slow modes or public transport

As shown in table 1, the characteristics of small cities and villages are low population and amenities density, few public transport options with low frequency of public transport, unattractive stations with few facilities, mixed roads for cars and bicycles, and often with fervent car using residents.

1.4 Case study: Zuidoost-Brabant

1.4.1 About Zuidoost-Brabant

The region Zuidoost-Brabant, also seen as the Metropolitan Region of Eindhoven (MRE), is the third metropolitan region in the Netherlands after Amsterdam metropolitan area and Rotterdam- The Hague metropolitan area. The area consists of 21 municipalities with approximately 750,000 inhabitants and about 35,000 workspaces with important locations such as the international airport of Eindhoven, a technological university and the High Tech Campus Eindhoven (see figure 1). It is a top economic region with focus on technology, innovation and sustainability (Metropoolregio Eindhoven, 2016).

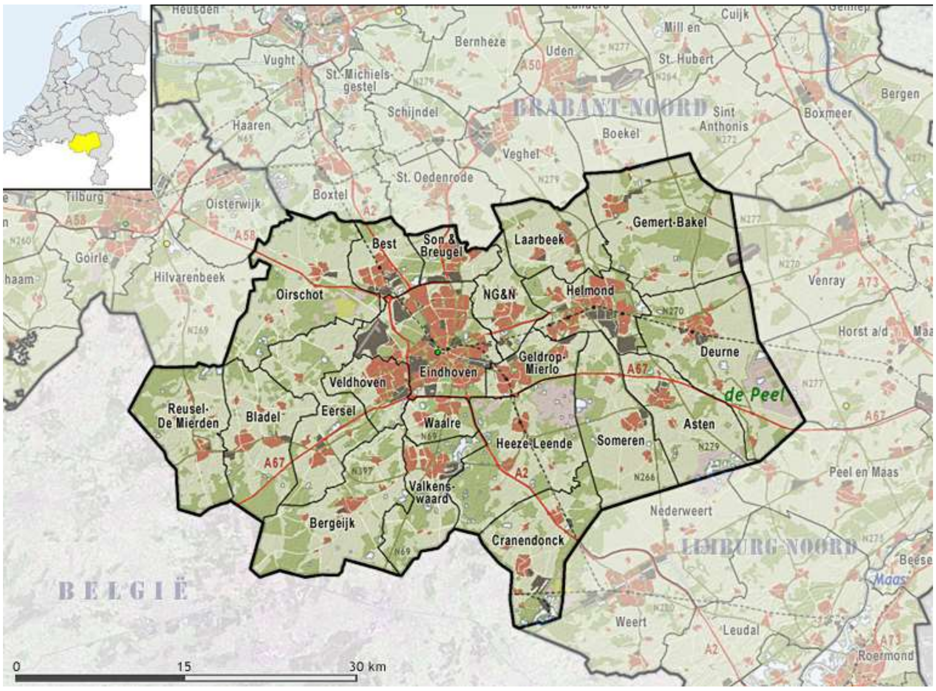


Figure 1: Zuidoost-Brabant (van Aalst, 2010)

1.4.2 The ambition of Zuidoost-Brabant

In the Zuidoost-Brabant region, there is an ambition to maintain/ increase the competitive economic position. Accessibility to and between cities is one of the preconditions to achieve this competitive economic position (Movares Nederland B.V., 2019b). High quality rail transit and a densification of urban development around rail network stations through a regional planning is needed to increase the competitive economic position. The region sets six specific challenges for mobility (Metropoolregio Eindhoven, 2020a);

- International connectivity with the economic centers in the area;
- Connectivity in the daily surroundings through multiple transport flows to each part of the region;
- Livability, traffic safety and sustainability;
- Stimulate smart mobility in the region;
- Connecting mobility with other regional themes such as economy, energy transition and rural transition;
- Logistics to bring economic opportunities.

An example of the ambition of Zuidoost-Brabant to maintain/ increase their competitive economic position, is that the province of Noord-Brabant and the NS want to increase the frequency of trains in 2030 and 2040; 6 intercity (IC) trains per hour between Eindhoven and Amsterdam, 4 IC trains per hour between Eindhoven – Breda – Rotterdam – Den Haag and a Sprinter train frequency of 2 to 4 per hour in the province of Noord-Brabant (Ministerie van Infrastructuur en Waterstaat, 2019a; Provincie Noord-Brabant, 2012). But using the approach of only increasing the frequency of trains in the area is not enough to attract more people to make use of public transport. To create an attractive public transport product in the area of Zuidoost-Brabant with trains, a more integrated approach is needed with urban development to increase the use of trains in the area and to compete with the car system (Movares Nederland B.V., 2019b). As a solution, the TOD approach could be an interesting way to enhance these transit areas.

2. Research approach

2.1 Problem statement

As previously mentioned, changing a society to be more sustainable by making use of public transportation is important. The focus to change to a sustainable society is mostly done in urban areas or in cities. The TOD approach is one of the solutions to stimulate public transport and to create a smaller Daily Urban System (DUS); an area around a city where daily commuting takes place. But, congestion problems in city centers often originate from regions around cities with lower density and a more car-friendly environment. To formulate the research problem properly; Many problems in cities regarding congestion and a lack of use of public transport often originate from low density areas around it. In order to create a more sustainable mobility in a metropolitan area, trips of people from the suburbs have to be considered. Therefore, this research focusses on measuring the TOD-ness of TASS.

2.2 Research gap

The TOD approach is well known in literature, but is mostly applied in dense urban areas. Also a lot of research has been done to measure transit areas around train stations, metro stations, bus station etc. But, these measurement tools mostly apply to evaluate transit areas of different types and sizes. This can give biased results, because incorrect comparisons are made between different types and sizes of train stations where different qualities and needs apply. A measurement tool that focusses only on transit areas around small train stations is rarely found.

2.3 Research objective

The aim of this research project is to create a tool to measure TOD-ness of small stations. By using the case study Zuidoost-Brabant, project-specific conclusions will be drawn which could apply for other TOD cases for small cities or villages. Recommendations will be given to the researched transit areas.

2.4 Research questions

The main question that arises from research gap is:

“How can transit areas around small stations be improved to increase the use of public transport by creating a tool to measure the level of TOD-ness?”

To answer the main question, the following sub-questions are formulated:

1. How can a TOD be a stimulator for the use of public transport in small cities and villages?
2. How can the level of TOD-ness of transit areas around small stations be measured?
3. What does the TOD measurement tool include to evaluate transit areas around small stations?
4. What is the state of the transit areas around small stations in the case study of Zuidoost-Brabant?
5. What could be changed to increase the level of TOD-ness of the transit areas around small stations in the case study of Zuidoost-Brabant?

2.5 Scope

The scope of the research is on the transit areas around small train stations in the Zuidoost-Brabant region. A measurement tool is created to evaluate these areas on built environment characteristics, infrastructure planning characteristics and characteristics that influence the perception of users. The stations that will be researched in the Zuidoost-Brabant region are:

- Best;
- Deurne;
- Eindhoven Strijp-S;
- Geldrop;
- Heeze;
- Helmond;
- Helmond 't hout;
- Helmond Brandevoort;
- Helmond Brouwhuis;
- Maarheeze.

An overview of the Zuidoost-Brabant region including the stations within the scope are shown in figure 2.

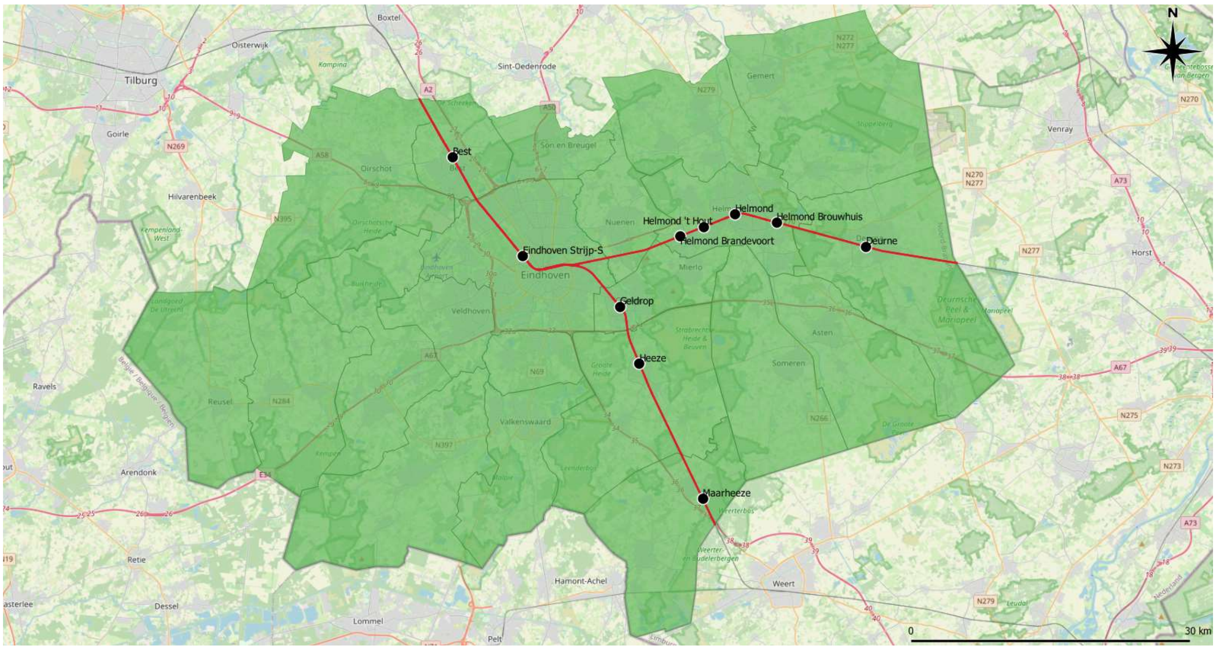


Figure 2: Overview of the Zuidoost-Brabant region

2.6 Scientific Relevance

Since the start of the TOD approach in the 90s, a lot of research has been done in the field of measuring transit areas and what attracts people to make use of transit areas. Although there are many tools to measure transit areas on the level of TOD-ness, no tool exists that focuses only on measuring TASS. This research aims to create a complete tool to measure the TOD-ness of TASS and adds an application to the literature.

2.7 Social relevance

As the examples mentioned before state, residents of small cities and villages in areas with lower density around cities can benefit from attractive transit areas. By increasing the TOD-ness of the transit areas, the public transportation and the transit areas themselves become more attractive which causes an increase of the use of these areas and a decrease in car use. This is also beneficial for the main city in a metropolitan area and the public transport companies in a specific region.

2.8 Research design

To give answer to the main research question, the research is done in several stages. The first stage of the research is a literature review, presented in Chapter 3. In this chapter, the literature is studied to determine what is known about TOD's, why people undertake a trip, what is known about small stations and the situation in the surrounding areas and what could stimulate people to make use of public transport. Also, the literature review gives answer to which measurement methods are used to evaluate transit areas. After the literature, the next stage is to create a conceptual model to test the transit areas of small train stations. This stage gathers information for which criteria and indicators have to be measured. This is presented in Chapter 4. In Chapter 5, the case study of Zuidoost-Brabant is introduced. Here, the transit areas around small stations are selected. In Chapter 6 Methodology, the data from the TOD areas is collected and the measurable indicators are calculated. Also, the weights of the criteria and indicators are determined which finalizes the tool. When the tool is finalized, the results of the level of TOD-ness of the selected transit areas are evaluated and the model is checked on its robustness. Lastly, recommendations are given to the transit areas where improvements could be made to increase the level of TOD-ness. Finally, in Chapter 7, the main research questions with the accompanying sub-questions are answered in the conclusions and the discussion addresses the scientific relevance, the social relevance, the research limitations and recommendations for future research are given. An overview of the research design is shown in figure 3.

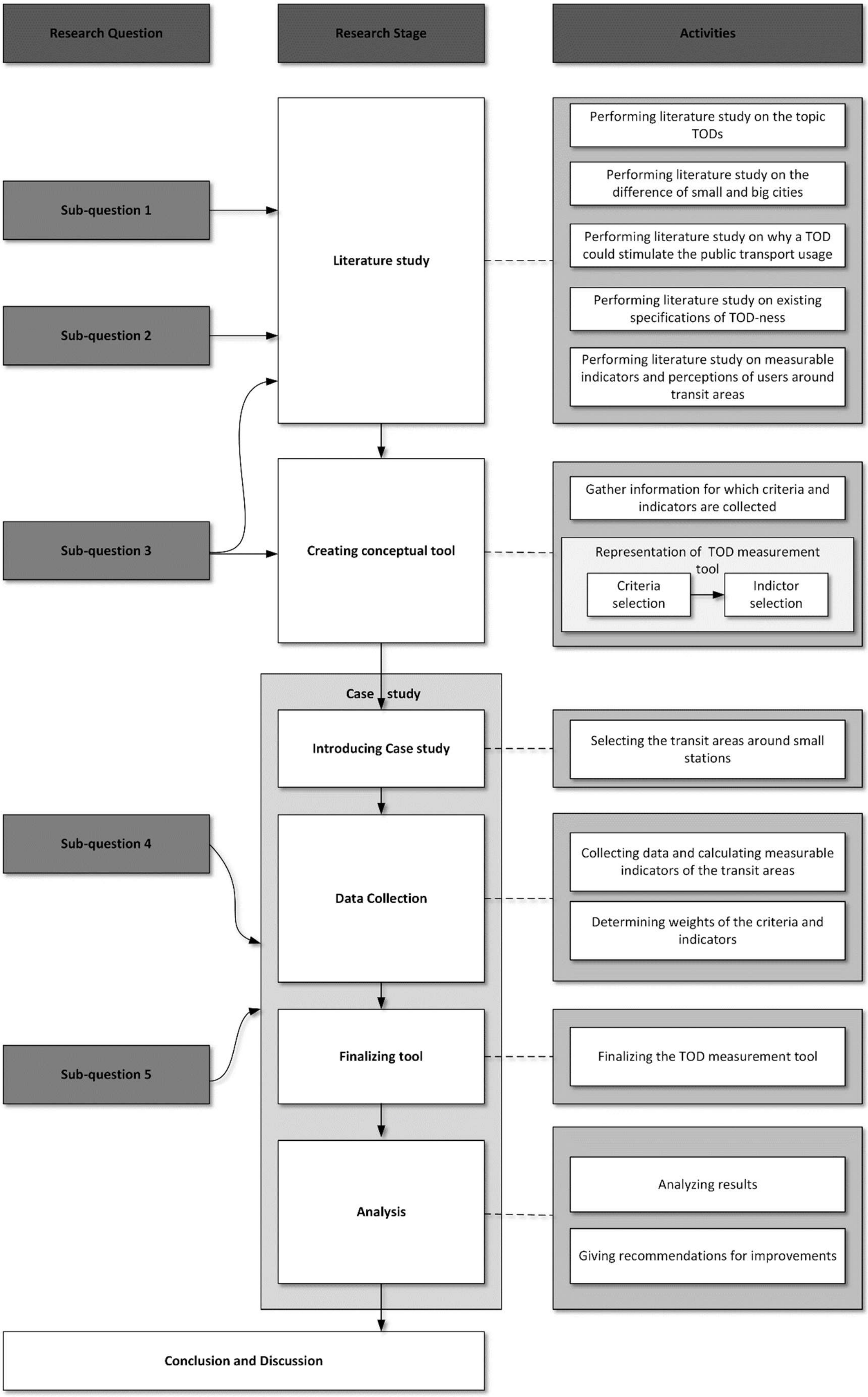


Figure 3: Research design

3. Literature review

In this chapter, an in-depth literature review on the subject is done. Existing research is used to find answers to different sub-questions.

3.1 Travel behavior

To understand why TOD is useful and why constructing near transit stops is a useful planning approach, travel behavior of people has to be explained. This section explains why and how people are traveling and what makes them choose between different transportation modes. With that, the aspects that make travel sustainable are explained and what has to be taken into account to attract people to make use of sustainable modes.

3.1.1 Choosing transportation modes

Almost every day people are travelling to certain places. This could be for example to work, shops and the gym. For these trips, people can choose between different kinds of transport modes or even a combination of them. But, travelling is not an activity that people usually like, because it is seen as stressful, costly and time consuming (Ory et al., 2004). Therefore, people mostly choose the mode that provides the highest utility, but also the mode that is easiest to use. This is selected by considering, for example, the shortest travel time or the lowest travel costs, but is also related to the socio economic and demographic characteristics (Schwanen & Mokhtarian, 2005). Besides that, status, comfort, autonomy and personal security play a role in the choice of transport mode (Filarski, 2004).

Because of the high utility and the status, comfort, autonomy and personal security, it can be assumed that car use is popular. By car, people can go almost from door to door from their origin to their destination over a relative long distance in a short period of time and without making a transfer. This is in line with the mode choice in the Netherlands and the distance traveled by mode in the Netherlands. In figure 4, the mode choice in the Netherlands is shown, where blue stands for car driver, orange for car passenger, green for bicycles, light green for walking, yellow for train, light blue for bus/tram/metro and purple for other transport modes. In figure 5, the organization of the distance traveled per mode is shown, where blue stands for car driver, orange for car passenger, green for walking, yellow for public transport, light blue for bicycles and light green for other. In total, 75% of the distance traveled in the Netherlands is by car and the mode choice of the car is 42% compared to 10% of travel distance by train and 2% for choosing the train as travel mode (Kennisinstituut voor Mobiliteit, 2019).

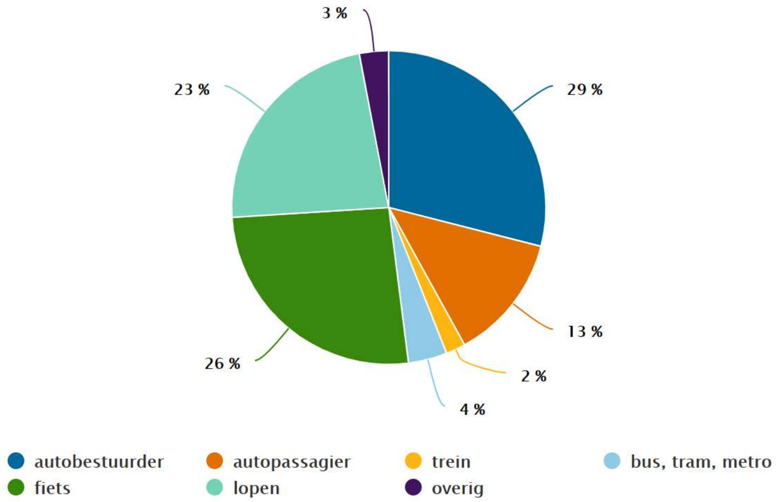


Figure 4: Organization of travel behavior in the Netherlands (Kennisinstituut voor Mobiliteit, 2019)

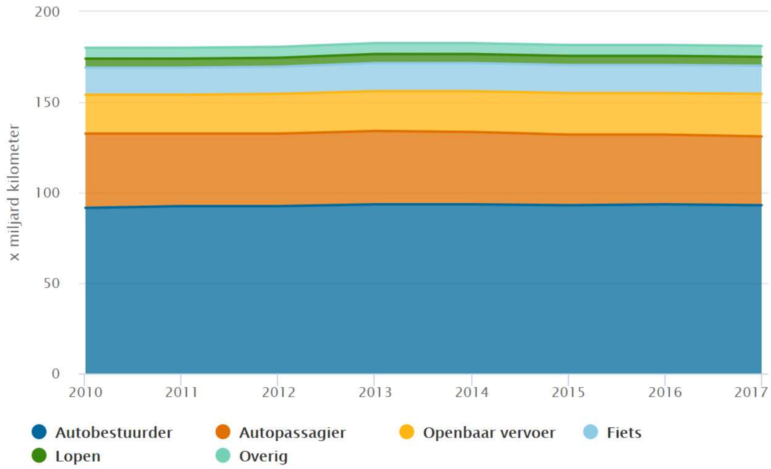


Figure 5: Organization of travel distance per mode in the Netherlands (Kennisinstituut voor Mobiliteit, 2019)

3.1.2 The constancy of travel time

Although the distance travelled by people has increased over the ages, the time people spent travelling is almost the same. This is called Marchetti's constant. This constant comes from an anthropological point of view that one needs to expand the territory and the need for shelter. This constant implies that even though the transportation and urban planning changes and that there are differences of people living in villages and in cities, people adjust their travel behavior in a way that the average travel time stays approximately the same (Ausubel et al., 1998; Ausubel & Marchetti, 2001; Marchetti, 1994).

From a more economical point of view, there is traffic-related principle explained by Hupkes in 1977. This principle refers to the by Hupkes created law of conservation of travel time and displacement (Dutch: Wet van het Behoud van Reistijd en Verplaasing); the BREVER-law. it is the average travel time per capita in all transport systems over a period of a certain length. The longer the period, the smaller the spread over the average person (Directoraat-generaal Rijkswaterstaat, 2001). This law is applicable all around the world, with a travel-time of 70 – 90 minutes regardless of different travel modes. Also according to this law, people's distance travelled has been enlarged which can be related to the increase of travel-speed and improved infrastructure.

Later, discussion was renewed on the constancy of travel time. Therefore, van Wee et al. (2006) explored if the average daily travel time is constant. In their case study of the Dutch population, they found that there is an increased average time spent on travelling. Besides that, they also found a rise in income, which they say is possibly resulted in an increase in both travel costs and benefits. The benefits increased more rapidly than the travel costs and possibly increased the comfort level of cars. Lastly, the time spent during travelling is used more efficiently (van Wee et al., 2006). People conduct other activities during travel such as working, daily reading, calling and eating (Ausubel & Marchetti, 2001; van Wee et al., 2006). Therefore, travel does not feel as wasted time, but as time spent effectively. But, a distinction has to be made between the mobility with the highest utility and the mobility that is the easiest in use and most sustainable.

3.1.3 Sustainable mobility

To create a society that is gradually moving towards using sustainable mobility by public transport, instead of the mobility with the highest utility or which is the easiest to use, such as a car, people have to change their behavior and change modes to use the train. For example, using the train is a lot more sustainable than using car considering e.g. pollution, and oil and gas consumption. But, because the train station is often not the starting point or endpoint of traveler's journey, people have to use different modes to get to the train station and go from the train station to their destination (NS Productmanagement, 2002).

Users play a central role in the value of nodes. Therefore, Peek (2006) state that it is important to pay extra attention to stations and their surrounding location (Peek, 2006). He created a model to understand and explain the experience of train users when different modes are used and transfer time is present which is shown in figure 6. From left to right on the horizontal axis, the figure describes the travel journey. It starts with the origin, access the station, transfer, train ride, transfer, egress the station and the destination. The vertical axis describes the user's valuation.

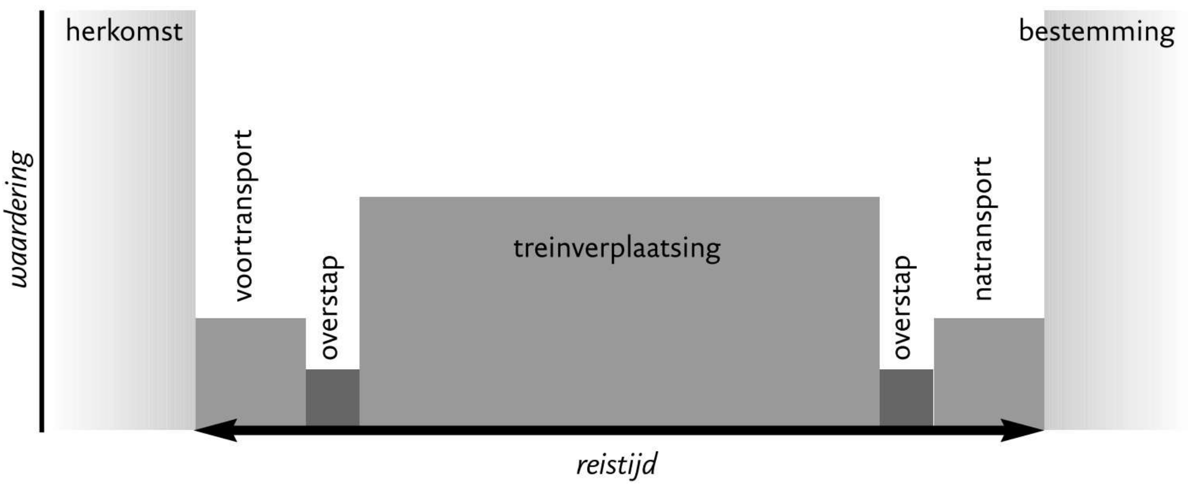


Figure 6: User's valuation versus travel time (Peek, 2006)

To add more value to travelling, Peek (2006) gives two approaches that are possible; shorten the travel time and increase the experience of the low- valued parts of the journey (transfer and modes). Three principles to increase value on travelling to users can be distinguished:

1. Accelerate the train by shortening the travel time;
2. Densify transit area by creating dense and mixed land-use around the station;
3. Making the trip more comfortable by creating more value to parts that are experienced as unpleasant (Peek, 2006).

More value can be created by accelerating the travel time, which is shown in figure 7. This allows users to reach their destination faster, which increases travel experience. Here, focus lies only on shortening the time that is spent by using the train. Later in sub-section 3.1.5 the benefits of shortening travel time is explained.

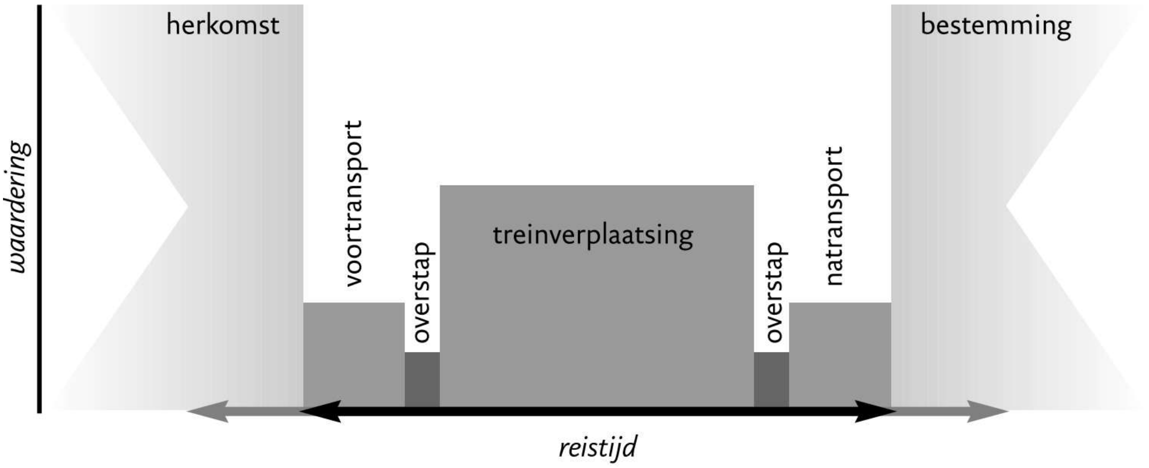


Figure 7: Accelerate the travel time of main transit mode (Peek, 2006)

Densification of land use can also create more value to travel experience, which is shown in figure 8. When people live close to the station and do not need to use other transport modes to access or egress the station, their experience will increase.

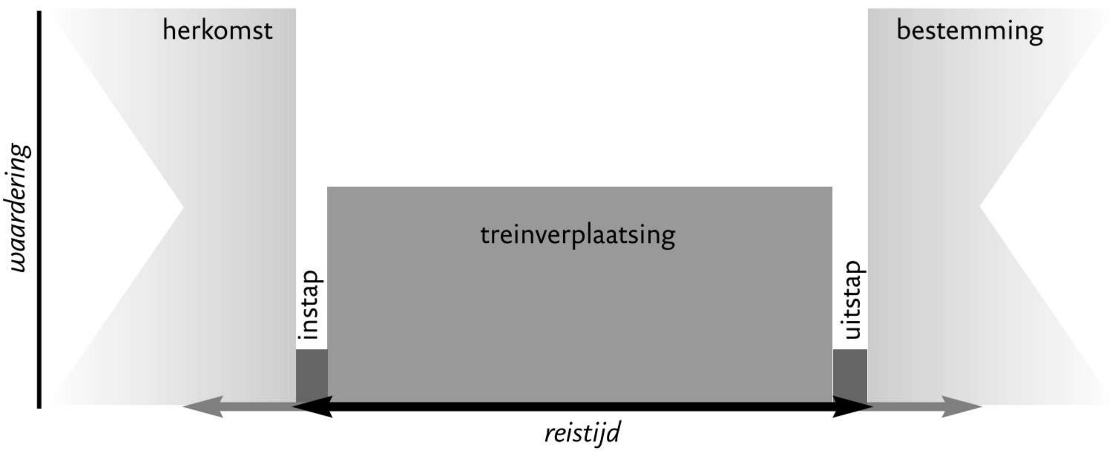


Figure 8: Densification of transit area (Peek, 2006)

Lastly, figure 9 shows the result when the experience of the trip, during transfer or during the travel itself, is enhanced. When this experience is better, especially with changing modes, people are more likely to do this trip.

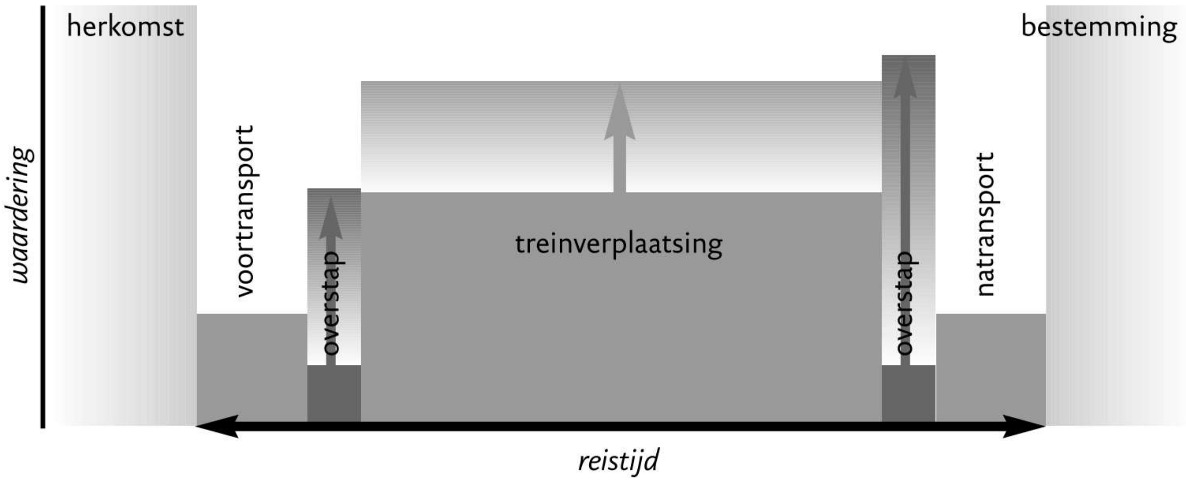


Figure 9: create more value to the trip experience (Peek, 2006)

Another principle that adds more value on travelling, is connecting with other networks such as road networks for cars and bikes and other public transport types (Provincie Noord-Brabant, 2018). This results in an attractive environment where multimodality is possible and thus also an interesting place to live. Besides that, when the connectivity with other networks is well integrated, a polycentric area could be created. This means that people not only travel from small cities and villages to large cities, but also between small cities and villages.

3.1.4 Move through or stay around transit areas

When people make a choice to use the train, there are several aspects to keep in mind. These aspects are safety, speed (travel time), convenience, comfort and experience (Van Hagen, 2011). These aspects all have their own importance and their influence on if people want to stay around a transit area or want to move through a transit area. In figure 10, the Maslow pyramid of these needs of users is shown, based on the importance of the aspects. At the base of the pyramid, the most important needs of users is shown; safety and reliability. After that, speed and ease are important aspects. Lastly, comfort and experience finish the pyramid.

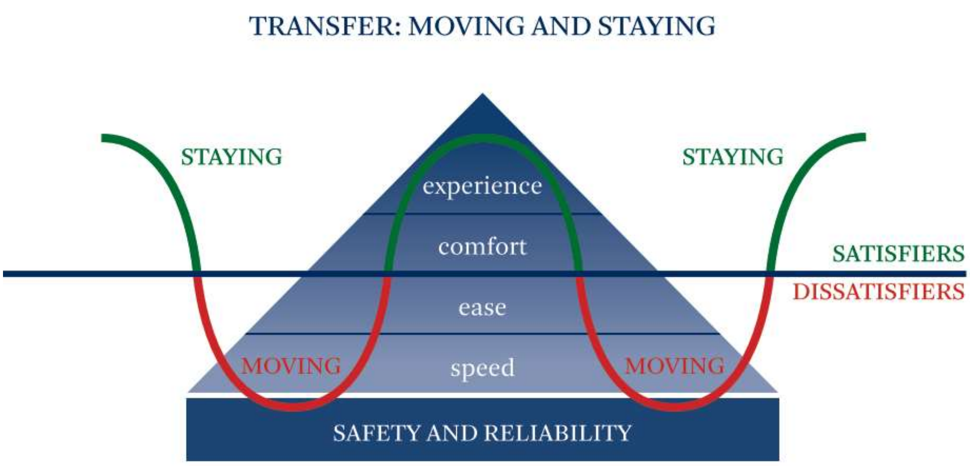


Figure 10: Maslow pyramid split in satisfiers and dissatisfiers (Van Hagen, 2011)

The Maslow pyramid can be split in two parts. The top part of the pyramid focuses on the amount of time users stay around the transit area and bottom part of the pyramid focuses on moving through the transit area. When people move through a transit area to use public transport, they want to do that as fast as possible in the easiest way possible. Therefore, when expectations of users for speed and ease are not met, these aspects are seen as dissatisfiers. It has a negative effect on the journey of users. But, when people are using stations and the experience and comfort are at a higher level than they expect, they are likely to stay there or spend some time at the station/ transit area. Therefore, it can be seen as a satisfier (Herzberg et al., 1959).

For transit areas, it is important to put effort in these different needs of users (van Hagen & Exel, 2012). When this is done, people can be attracted to make use of the transit mode that is offered or to make use of the facilities that are present around the transit area.

3.1.5 First mile and last mile

When people are travelling from their home to a station/ transit area, they accept a relatively large travel distance. This is because people can use their own modality for the "first-mile". But, there is a lot of potential to attract people to make use of public transport when the access to the station is improved. When the routes to the station are improved and the time traveled to the station can be shortened, it can attract more users of the train station. For every 1% of time that is saved to go to the station, 0,5% more travelers are attracted to make use of the station with an average daily travel of 100 minutes (Balcombe et al., 2004; Movares Nederland B.V., 2019b). For the "last-mile" this is different. Here, people are not willing to travel a long distance from the station they arrive at. It is important for different establishments to be close to the station of people's destination. The first mile to the train station is mostly done by bike, but walking at the last mile from a train station has a much more prominent role, which is shown in figure 11 (Ministerie van Infrastructuur en Waterstaat, 2019b). Therefore, a distinction must be made between the catchment area for the first mile and the last mile. Also NS works with different areas for defining the catchment area for accessing stations and egressing stations (Movares Nederland B.V., 2019a). This is in line with the research by Guerra et al. (2012) where they researched the catchment areas of a transit station to predict ridership. They found a distinction between the catchment area of population and offices. For population, the catchment area of a half-mile radial works best versus the quarter-mile radial for jobs (Guerra et al., 2012). A distinction must be made between the catchment area for accessing and egressing a station.

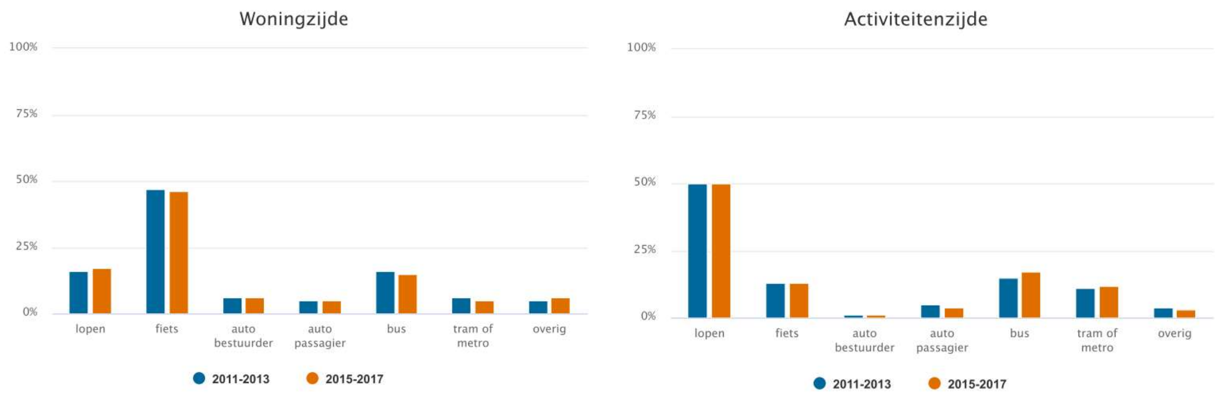


Figure 11: Mode choice of the first mile and the last mile of a train stations of multimodal users (Ministerie van Infrastructuur en Waterstaat, 2019b)

As stated before, the first-mile and last-mile are important for the use of the transit areas on different aspects. The approach of TOD is a planning strategy which focusses on this first and last-mile. This will be explained in section 3.2.

3.1.6 Sub-conclusion

Nowadays, the car in the Netherlands is a popular travel mode to use compared to public transport because of the ease, highest utility and comfort that comes with it. Although the travel speed is increased over the years, the average time spent on travelling is not changed much which results in an increased travel distance. For a more sustainable mobility, people will have to change modes to access or egress the station of the public transport mode that is to be used, due to the fact that the starting point or endpoint of their journey is often not at the station.

Users play a central role in the value of a node. To add more value on traveling for the users, there are two approaches that are possible; increase the travel time and increase the experience of the low- valued parts of the journey (transfer and modes). This is in line with the aspects that are important around transit stops; safety, speed, convenience, comfort and experience.

When people make use of public transport, the first-mile and last-mile are important for accessing and egressing a station. In the first-mile, people often make use of their own transport mode, such as a bike, from their home to access the station. When this is travel time could be shortened, more people will make use of the station. For the last-mile, it is important that the destinations of users, for example work, school and shops, are close to the station because own modalities are less available and walking is a prominent way to egress the station. Therefore, different sizes of areas have to be used to identify the catchment areas of a station.

3.2 TOD’s

To understand the context of transit-oriented development, a brief history of the Dutch spatial planning strategies in general will be given and where TOD stands in this history. The mechanism of TOD will be explained, an in-depth explanation of the definition and the proven advantages of TOD’s will be given. Lastly, an overview is shown of different TOD’s worldwide to show the wide variety of TOD establishments.

3.2.1 History of the Dutch Spatial Planning Policy

Before the idea of TOD is explained, the history of the Dutch national spatial planning policy is briefly summarized to see what planning strategies have been implemented by the Dutch government and where the TOD approach comes from and where it stands in this timeline.

The national spatial planning in the Netherlands has a long history. Since the Second World War, the Dutch government was involved intensively with the reconstruction of the Dutch economy and the spatial development with spatial planning. The idea was that it is possible to socially engineer society by interfering in the spatial economy of the country (Bruinsma & Koomen, 2018). This resulted in a strategy in 1956 that focused on the development of “de Randstad” in the West of the Netherlands. After that, the government noticed an increase of inhabitants in “de Randstad” and a decrease of inhabitants in the rural areas. This resulted in a notification by the government with the First National Spatial Strategy in 1960. This act focused on post war reconstruction and housing shortage by de-concentration of the West (Evers, 2018). The Second National Spatial Strategy in 1966 was more oriented on the international context and the polycentric development, which was modified to a more inward-looking focus and analysis in the Third National Spatial Strategy in 1973 (de Boer & Kooijmans, 2007). The Fourth National Spatial Strategy in 1988, was a large change in the spatial policy compared to the first three strategies. Here, the development of the Mainports and creating a robust road network were the main strategy. In a modified spatial strategy, the Fourth National Spatial Strategy Extra in 1991, the Dutch government pointed out exact locations for new construction sites, the construction volume and when projects had to be delivered (Evers, 2018). This resulted in many construction projects on the outskirts of cities. After this spatial strategy, decentralization of national planning took place by participation of other private parties and other governments (Bruinsma & Koomen, 2018). This “Fifth” National Spatial Strategy in 2002 and the new National Strategy Plan in 2004 targeted on room for development.

Since the last “official” National Spatial Strategy initiated by the Dutch government, the interference decreased more and more and transformed into a National Policy Strategy for Infrastructure and Planning in 2012. From then on, focus was placed on improving the mobility and increasing the urbanization instead of creating new residential areas and expanding cities (Ministry of Infrastructure and the Environment, 2012). Nowadays, instead of the spatial plans, the Dutch government makes use of an independent advisory board. This board advises on different aspects of urban quality, including infrastructure, urban development and the livability of cities (College van Rijksadviseurs, 2017). Their main strategy is to link the urban environment with mobility, like TOD. To do this, three key points are explained. First, there must be more freedom of choice between transport options of the public transportation to ensure that everyone is able to participate in society and that everyone is able to make use of their own region and the rest of the country. Second, change car use and road development. The focus is placed more on quality and coherence on the main road networks instead of increasing capacity. Lastly, strive for a healthy urbanization by giving priority to slow modes as walking and using bikes. This ensures that the urban design contributes to a healthy society (College van Rijksadviseurs, 2017).

Research has been carried out by the independent advisory board to test three different urbanization models and to give insight into how the housing challenge can provide added value for society. Model one focused on the city region by building new houses within cities and villages. The second model focused on using more open space around existing cities and villages. The third and last model focused on densifying around public transport hubs (which is similar to the TOD approach). By studying the impacts on nine different themes, they concluded that the third model, constructing and densifying within cities, near existing dwellings, facilities and public transport hubs, is more expensive but provides more benefits and creates more profit in the long run (College van Rijksadviseurs, 2018). This suggests that the approach of TOD could have positive effects for current and future planning strategies.

3.2.2 Connection between land-use and transport

As explained above, the strategy to link land-use and mobility has attracted more interest and is proven to have several benefits. A model to explain this interaction is the "land-use transport feedback cycle" by Wegener & Fuerst (1999) (see figure 12). This model shows that land use and transport are closely inter-linked together.

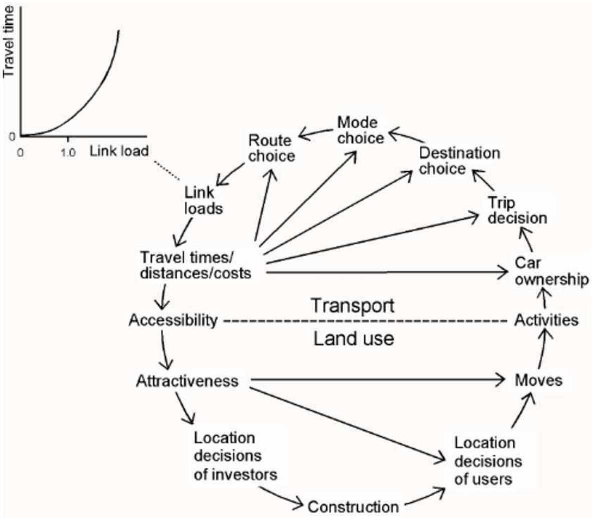


Figure 12:and-use transport feedback cycle (Wegener & Fuerst, 1999)

To clarify the model by Wegener & Fuerst (1999), the two sides of the model are explained shortly one by one per process.

Land use

In an area, the accessibility is important and determines its attractiveness. When an area is determined as attractive, it generates attention of investors and users to develop facilities and use the area. Investors then consider constructions (houses, offices, etc.), and this subsequently determines the location choice of its users. This generates moves (trips) in the area for the activities.

Transport

The activities in the area are important for the choice of car ownership. If enough activities are concentrated in an area, one could decide whether or not to own a car (if affordable). This determines the trip decision, the destination choice, the mode choice and the route choice. These choices together determine the travel times/ distances and costs. But, this works in two ways because one can decide to change this with modifying the trip/ destination/ mode or route. Altogether, the level of travel time/ distance and costs determine the accessibility, which completes the model again.

3.2.3 Transit-oriented development

An approach which integrates land-use with mobility is transit-oriented development and has a broad variety of definitions. A simple definition of a TOD is an urban development around railway stations (Duffhues et al., 2014). Other definitions of TOD's are the integration of mixed land use and high density (Center for Transit-Oriented Development, 2009; Renne, 2009; TCRP, 1996) and a combination of these with walkability (Schlossberg & Brown, 2004;

TCRP, 1996). Tan et al., (2013) focus more on the goals of TOD's, describing it as a way to achieve associated economic, sustainable and agglomeration benefits (Tan et al., 2013). The approach is focused on using/ transforming existing land around transit stops and its existing infrastructure network for better utilization instead of developing new areas on the outskirts of cities or villages. More efficient sub-center are created with increased densities and where most services are situated.

The aim of TOD's is that the development integrates the land use and transport system to increase access to public transportation, utilizing already serviced land rather than increasing urban sprawl, increasing transit ridership, reducing pollution by vehicular traffic, reducing the consumption of oil and gas and benefit to healthier lifestyles (Singh et al., 2017). Other benefits of TOD are linking sparsely populated areas of the province to jobs and amenities of the larger cities through public transport and respond to socio-economic trends as teleworking and face-to-face contacts in the economic sectors where easily accessible locations are important (Provincie Noord-Holland & Vereniging Deltametropool, 2013). This means that a TOD is not only just a development near public transit, but also has to include: "location efficiency", that people can use their bike or go by foot to take public transport; a boost of transit ridership and minimize the impacts of traffic; a rich mix of housing, jobs, shopping and recreational choices; value for the public and private sectors, and for both new and existing residents, a sense of community and of place (Center for Transit-Oriented Development, 2009).

3.2.4 Proven successes of TOD

Having shown some of the benefits of TOD previously, proven successes of TOD with examples will be given below. First of all, TOD's contribute to improving public health. In communities with a strong and dependable transit system and streetscaping elements, it is noticed that it can discourage people to use private vehicles. When applying the principles of TOD, the community is thought to improve their health and even reduce obesity. In a research by MacDonald et al. (2010) in Charlotte (USA), they show that improving neighborhood environments and increasing the public's use of train systems improved health of people. Besides that, they found that people who make use of the train system weighed significantly less than those who continued driving to work (MacDonald et al., 2010).

Another proven TOD benefit is that it can create a more sustainable community. Center for Transit-Oriented Development (2007) stated that transportation contributes approximately 28% of all greenhouse gas (GHG) emissions. As described before, TOD has the potential to reduce pollution and GHG. In the Delaware Valley Regional Planning Commission, they found in their GHG inventory that Philadelphia (USA) had lower transportation-related emissions per capita due to a higher reliance on public transit (Center for Transit-Oriented Development, 2007).

Improving local public transport and TOD can support a strong regional economy by lowering the transportation costs and time spent on commuting, improving job access and creating a walkable area. People are able to spend more time and money at restaurants, shops, etc. and increases land values. This is in line with research in Philadelphia, where it has been shown that a compact community with a strong transit system can create jobs and attract a young and innovative talent pool (Center for Transit-Oriented Development, 2007).

In a project where the heavy rail system is transformed into a light rail system in the Den Haag- Rotterdam and Zoetermeer region in the Netherlands, new stations were added and spatial developments took place around the transit stops. Because the accessibility increased, the areas became more attractive for both users and developers. This resulted in an increase of users, even more than projected and which is still increasing (Tan et al., 2013).

Another Dutch example where the TOD approach had benefits is the Stedenbaan(Plus) project in the Southwing of Holland. By creating a total of nine typologies of all station areas in the region, all station areas were transformed according to the assigned typology. Existing lines were utilized and the service was intensified with creating attractive and dense areas around the stations with amenities and facilities. The plans were adopted by the local municipalities for implementation. This resulted in giving a boost to the slowing down economy (Balz & Schrijnen, 2009).

Looking at a research on benefits of TOD in Kuala Lumpur (Malaysia) by Gomez et al. (2019), environmental benefits are seen from a personal perspective. Because transit areas improved on giving priority to public transportation, creating a green transportation system and providing “co-located” facilities for living, working, shopping and relaxing. This resulted in an improved quality of urban design and the enhanced aesthetic beauty of the urban landscape (Gomez et al., 2019). This is not a benefit that could be measured directly, but it could help to enhance the perception of users around transit areas. This will be addressed further in sub-section 3.2.7.

3.2.5 TOD’s and typologies

Characterizing TOD’s is not as straightforward as it may seem. Cervero (2004) states that TOD designations are quite subjective: one person’s view on TOD may be viewed by others as little more than an office building with suburban parking ratios that happen to be near a train stop (Cervero, 2004). Besides that, TOD’s can be created around stops of different types of transport modes which can confuse as to what exactly constitutes a TOD.

In the literature, many studies are trying to create typologies of transit areas around stations/ transit areas. These typologies can help with planning, design and policy making for cities, municipalities or provinces. Furthermore, typologies can help to identify potential developments and opportunities for a certain area, but also where to support local transportation and urban planners. By creating typologies, areas with the same characteristics can be grouped and recognized.

Cervero & Kockelman (1997) claimed that there are three principal dimensions of the built environment that influence travel demand of public transport; the 3D’s. These three dimensions are density, diversity of land-use and design. They state that increased density stimulates public transport ridership, increasing the diversity of land use is better for the coverage of public transport and a pedestrian oriented design increases the non-motorized trips (Cervero & Kockelman, 1997). Later, Cervero & Murakami (2008) added two other dimensions, which are distance to transit and destination accessibility. These dimensions refer to how efficient the transit area is connected with the activities within it. The in total 5 D’s (see figure 13) contribute to a sustainable and high quality environment (Cervero & Murakami, 2008). The 5 D’s have been often used as a basis to measure transit areas in literature.

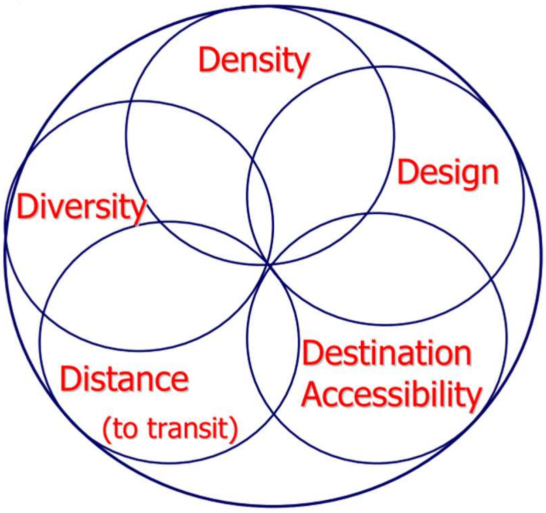


Figure 13: the 5 D's (Cervero & Murakami, 2008)

One of the first typologies of transit areas is done by Bertolini (1999) with the node-place diagram, which is shown in figure 14. In this diagram, research areas are divided in five different categories based on the potential of a node (how many destinations can be reached within a certain time span?) and the potential of the place of activity (how many, and how diverse are the activities that can be performed in an area?). These categories are "stress" with a high node and a high place score where conflicts could occur, "accessibility" with an average score of node and an average score of place, "dependency" with a low node and low place score which represent dependent areas and "unsustained node" or "unsustained place" where an unbalanced situation occurs. With this separation, an overview can be created on where to improve at the transit areas.

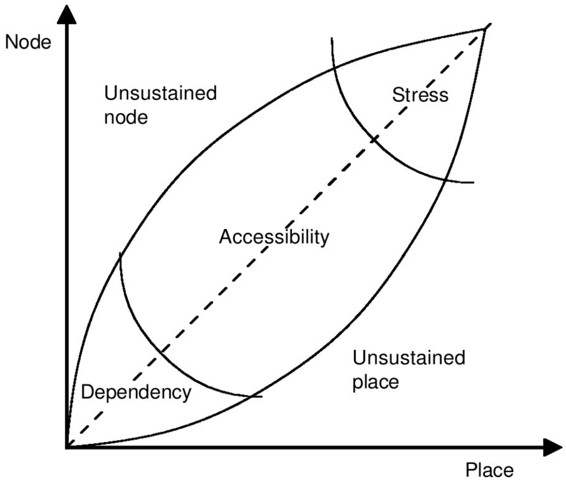


Figure 14: Node-place diagram (Bertolini, 1999)

Later, this node-place diagram has been used in many studies on TOD's. An example is a study by Kamruzzaman et al. (2014) who created a TOD typology with four clusters in the city of Brisbane, Australia, looking at the node and place characteristics. This is done by using data from districts in Brisbane and validated by a multinomial logistic regression model. The four clusters created are: residential TOD's, activity center TOD's, potential TOD's and TOD non-suitability. The Residential TOD's are areas where there is high quality of neighborhoods, good public transport and road connection, a specific housing density criteria and a mixed-land use which results in low employment opportunities. The activity center TOD’s are areas with high average net employment density. The potential TOD’s are areas within proximity of transit service, but where an increase of facilities and dwellings is needed. The non-TOD’s are areas which are not suitable for TOD development, because there is an insufficient road network, public transport connectivity levels or other place-related qualities.

Further research which created typologies with the node-place diagram is a study by Vale (2015) where walkability indicators are included. Five different typologies are created for the case study Lisbon with clusters, based on a node score, a place score and a score for pedestrian friendliness. The categories created are: Urban TOD’s with balance between node and place and high walking accessibility, Balanced TAD’s (Transit Adjacent Development) with balanced between node and place but poor pedestrian accessibility, Suburban TOD’s with very high walkability and a balance of node and place indexes, Undersupplied transit TOD’s with high walkability and place index and a low node index, Unbalanced TOD’s with an average node index and walkability but a low place index and Car dependent node-places with a low value for node, place and walkability.

Examples of TOD’s in high- density environments such as Hong Kong (Kowloon Metro Station) and Curitiba (development along the Bus Rapid Transit system (BRT)), are best known and also most effective compared to low-density areas such as Perth (Cervero & Dai, 2014; Cervero & Murakami, 2009; Curtis, 2012). But, because there are differences in land-use characteristics and connectivity, it is difficult to compare TOD’s with each other from different regions/ countries. Therefore, De Vos et al. (2014) had a different approach identifying TOD typologies. They created a more general typology of TOD’s, based on the initial stage of development (see figure 15):

- New TOD’s, with development of new neighborhoods around new public transportation services;
- High-density TOD’s, with new public transportation services in compact and mixed-use areas, where there is high-quality public transportation between existing neighborhoods with high density and diversity;
- Low-density TOD’s, with increasing density and diversity of suburban-style neighborhoods around new public transport services. It offers a combination of improved public transport services and increasing density and diversity of low-density developments (De Vos et al., 2014).

After this initial stage per typology, specific measures can be taken to develop infrastructure and/ or urban development that are suitable for each typology. For New TOD’s public transport lines must be created with small high-density developments along the lines as “pearls on a necklace”. High-density TOD’s must create high quality transportation lines in the area. Low-density TOD’s must create public transport lines with small mixed- use and dense neighborhoods along these lines.

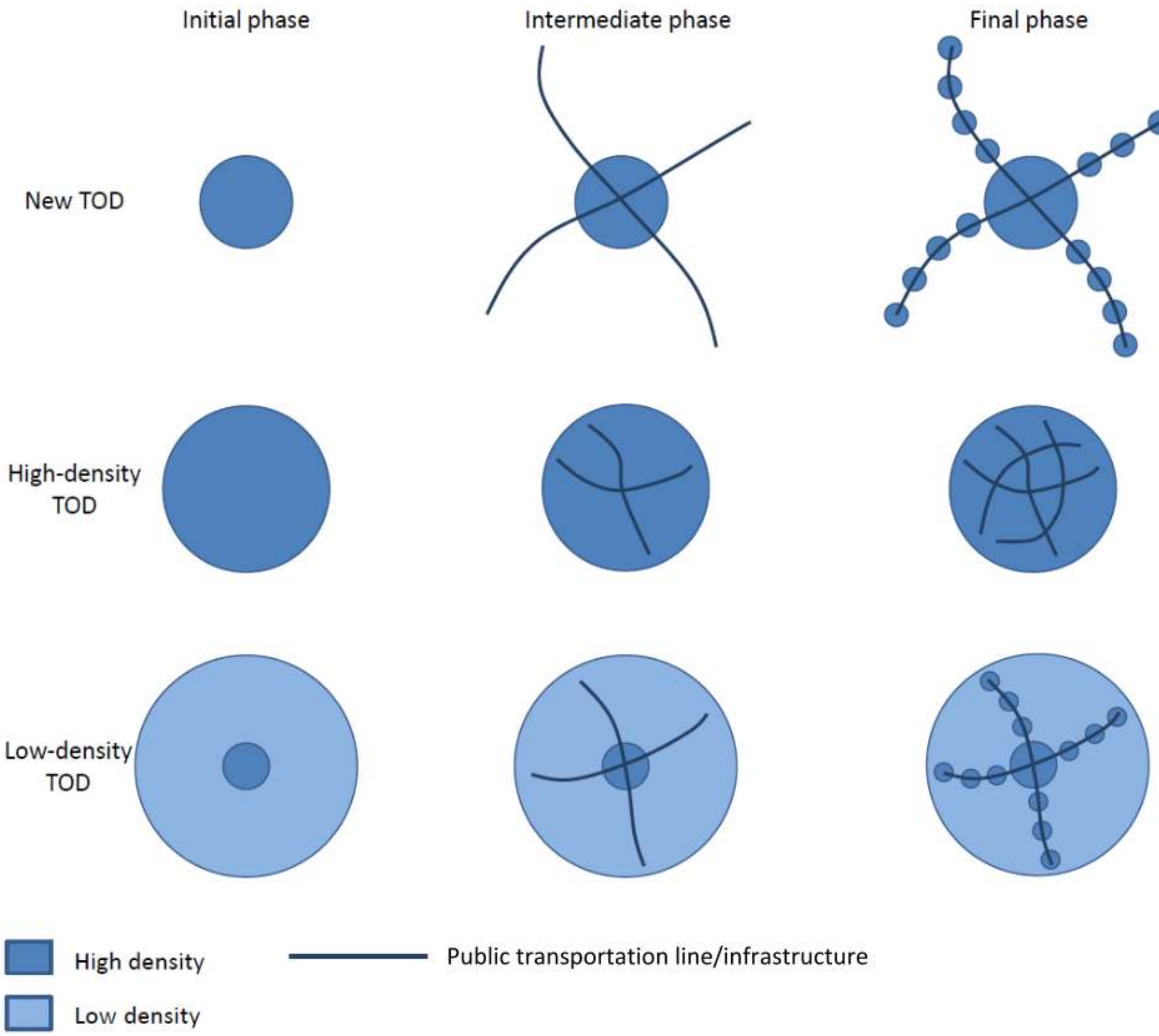


Figure 15: TOD-typology (De Vos et al., 2014)

With this typology, it is easier to give examples of TOD's per category and even TOD's with different transport modes can be compared. Examples of New TOD's are in Copenhagen and Curitiba (Cervero & Dai, 2014; Knowles, 2012), where cities tried to guide urban development along linear corridors with high quality PT. High-density TOD's are mostly found in Europe and in Asia, because there is in general a higher density than North-America. Low-density are mostly found in North-America and Australia.

3.2.6 Examples of TOD's

As mentioned before, there are many TOD related projects worldwide. These TOD's are created around stations of different kinds of transit modes and with different urban structures. In table 2, an overview is given of different TOD's that are mentioned before, including some other well-known and successful TOD projects. Per TOD, the type of TOD is given, the scale in which it is planned, which mobility is used for the projects and a brief description is given.

Table 2: Overview of TOD projects worldwide

LOCATION	TYPE	SCALE	MOBILITY	REFERENCE	DESCRIPTION
INTERNATIONAL					
COPENHAGEN (DENMARK)	New TOD	Regional	Train	(De Vos et al., 2014; Knowles, 2012)	Created a five finger profile along existing railways and densify areas around the transit stops.
CURITIBA (BRAZIL)	New TOD	Urban	BRT	(Cervero & Dai, 2014)	Create high density along the bus corridor with tall, commercial offices and residential buildings along the corridor.
HONG KONG	High Density TOD/ New TOD	Urban and Regional	Metro	(Cervero & Murakami, 2008; Loo et al., 2010)	Create more pedestrian friendly designs and building civic amenities around existing transit stops and enlarge the metro lines. Urban TOD's in a high density environment are created with new towns developed regionally as a New TOD type
PERTH (AUSTRALIA)	Low-density TOD	Regional	Train and Bus	(Renne, 2009; Tan et al., 2013)	Promoting TOD at a regional and urban scale to create transport corridors, activity corridors and activity centers
PORTLAND (USA)	Low-density TOD	Regional	Lightrail and bus	(Tan et al., 2013)	Using the existing transit lines, Portland was one of the pioneers of TOD. It was the first region where the regional government was responsible for the traffic/ transport and the urban planning. They invested in public transport and were against the loss of natural areas.
SINGAPORE	High Density TOD	Urban	Metro	(Yang & Lew, 2009)	Existing towns were made pedestrian friendly and led to an integrated land use transit system.
TOKYO (JAPAN)	High Density TOD	Urban	Train and Metro	(Chorus & Bertolini, 2016)	Changing zoning plans around existing railways to allow higher densities of development.
THE NETHERLANDS					
ARNHEM/ NIJMEGEN	New TOD	Regional	Train	(Singh et al., 2017; Tan et al., 2013)	In the third largest city region in the Netherlands, the vision was creating more housing and employment and providing a higher level of mobility and decreasing the car use in the region.
DEN HAAG/ ROTTERDAM	New TOD	Regional	Heavy rail with other public transport networks	(Balz & Schrijnen, 2009; Tan et al., 2013)	Stedenbaanplus. Using existing lines (train, randstadrail, metro, tramplus and bus) and intensified service and created new stations for higher connectivity to attract people to use public transport and create a mixed environment.
DEN HAAG/ ROTTERDAM/ ZOETERMEER	New TOD	Regional	Light rail	(Tan et al., 2013)	The Randstadrail. Transformed the heavy rail into a light rail with new stations and spatial development around stops. Maybe the biggest success in the Netherlands.
HEERHUGOWAARD - AMSTERDAM	New TOD	Regional	Train	(Provincie Noord-Holland & Vereniging Deltametropool, 2013; Tan et al., 2013)	Zaancorridor. Increasing the train frequency and increase the accessibility around stations to use them more intensively.

3.2.7 Perception of users

The perception of users is described as how users experience the transit area or station. As shown in the definitions, typologies and the examples of TOD's, little attention is paid to the perception of users at transit areas while this can have a positive influence on users (Gomez et al., 2019). Also, in the top of the Maslow pyramid by Van Hagen (2011), the most important values that influence the perception of users are comfort and experience. In some researches, the perceptions of users are taken into account. But, these researches mostly focus on smaller areas or on transit stops themselves. For example, NS created a vision on the surroundings close to the stations. They state that this area is a link between the station and the city center, the area is important for the connectivity to other transport modes, the area is an important part of the urban environment of the city and the focus is on pedestrians (NS Poort & Asset Development, 2011).

To distinguish what exactly could have a positive or negative influence on the perception of users in an area, Roger van Boxtel, top executive of the NS, explains that different amenities and facilities like Kiosks, wifi, workplaces and contact points in and around stations contribute to a positive perception (Eldering, 2019). In research concerning the train frequency in Zuidoost-Brabant, Movares also used the perception of users as an important factor for the use of public transport (Movares Nederland B.V., 2019b). Another important factor is that the station integrated in a transit area with the surroundings. It is stated that a poor integration of the station with the surroundings has a negative effect on the perception of users (Simkens, 2020; Van Hagen, 2011). This is also stated by experts of NS (see appendix III). Finally, in a research of Brouwer (2011), the link between the station and the city center is researched. Also here, the perception of users in the area plays an important role in the quality of the area. This suggests that the perception of users for measuring TOD's could also be an essential factor. Therefore, a sixth "D" is added in this research to the 5 D's by Cervero & Murakami (2008) to assess and evaluate facilities that influence the perception of users in transit areas and at stations. This "D" stands for the desirability of facilities. A visualization of the 6 D's is shown in figure 16.

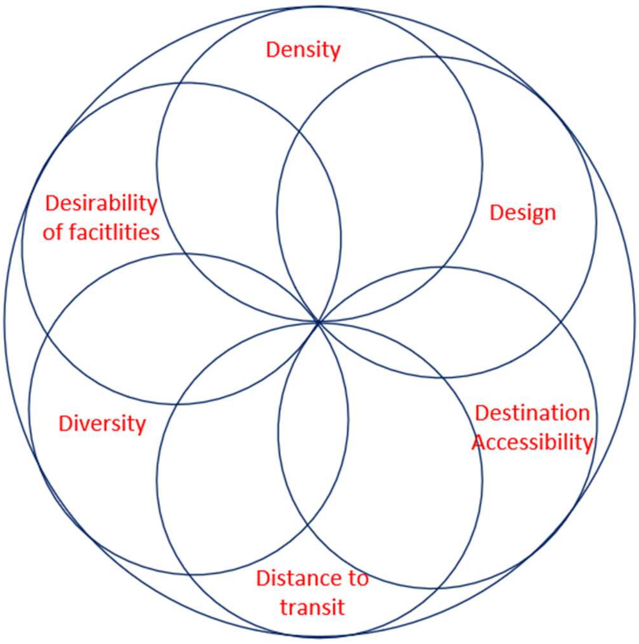


Figure 16: The 6 D's including Desirability of facilities

3.2.8 Sub-conclusion

After the Dutch government became less involved in planning strategies in the Netherlands and an independent advisory board became involved, the focus is more on linking the urban environment with mobility by using existing land in urban environments around stations. The approach of TOD is a strategy that integrates land-use with public transport. TOD is an integration of mixed land use and high density with walkability around transit nodes. Some proven benefits are that TOD increases access to public transportation, utilizes already serviced land instead of urban sprawl, increasing transit ridership, reduces pollution, reduces consumption of oil and gas and contributes to a healthier lifestyle.

In the reviewed literature, there are many kinds of typologies found for TOD. Most TOD's are classified or evaluated based on the 5 D's density, diversity of land-use, design, distance to transit and destination accessibility. The 5 D's are based on the node-place diagram or a combination of it. Often, TOD typologies are used in separate cases, because it is difficult to compare different TOD's due to differences in land-use characteristics, locations and connectivity. Therefore, another approach is used to compare different TOD's by categorizing them in new TOD's, high-density TOD's and low-density TOD's. This allows to compare TOD's with different sizes and categories with each other.

In the examples of TOD typologies, is the perception of users is rarely found. This is remarkable, because it is proven that it could have a positive influence on users and used as an aspect to focus on at and around transit nodes. This could increase the quality of the area and attract more people to make use of the public transportation. A sixth "D" is added in this research to assess and evaluate facilities in transit areas that have influence on the perception of users, which is the desirability of facilities.

3.3 TOD's at transit areas around small stations

This section gives insights into stations and transit areas of small cities and villages. It makes clear what is considered as small station and what the situation is in small cities and villages. Furthermore, the urban environment and infrastructure are described. Lastly, the important factors to focus on at small stations is described.

3.3.1 TOD in small cities and villages

As shown in the examples of TOD's in sub-section 3.2.6, most studies about land use and public transport integration focus on dense urban environments and large metropolitan areas. These are usually characterized by high population densities and activities, and high-capacity transport infrastructure. In reality, the conditions like these are not present everywhere. TOD's are mainly planned or constructed in a city center. But, TOD's could also be planned and constructed in a suburban region, small cities or villages. Differences are that city centers have higher levels of transit service that are available to more travel markets and have also a greater potential for generating transit ridership. But, as explained by Sohoni et al. (2017), designing and building TOD's in suburban regions is less interesting for urban planners and policy makers, compared to TOD's in city centers (Sohoni et al., 2017). However, promoting TOD in suburban regions can benefit to higher public transport use and benefit to a sustainable society. Sohoni et al. (2017) states six reasons for promoting TOD in suburban context. First of all, TOD is more sustainable by using land, energy and resources more efficiently. Second, it helps to conserve open space, encourages walking and creates a cleaner environment. Third, it minimizes private vehicle use which leads to of less oil and gas consumption. Fourth, it increases transit ridership at lower costs than in the case that bus services or parking structures are needed to bring riders to the stations. Fifth, it increases traffic by foot for local businesses and opportunities for mixed-income housing. Sixth, it promotes healthier lifestyles and safer neighborhoods because there are more people on the streets (Sohoni et al., 2017).

Few studies focus on the integration of land use and public transport in a geographical context characterized by medium or low densities of population and activities, the absence of high capacity public transport networks and slow rates of population growth. As explained by Nigro et al. (2019), the focus of present studies on the immediate "walkable" area around public transport stop as the relevant "place" and "node" is problematic, as it disregards the interactions of the transport node with a wider area (Nigro et al., 2019). This approach of the "walkable area" is difficult to apply in low-density areas. In low density areas, bicycles, public transport and cars are more favorable than walking due to bigger distances.

3.3.2 Classifications of train stations

Besides the different typologies for TOD's as described in sub-section 3.2.5, the train stations in the Netherlands are also divided in different categories. The NS categorizes the train stations in six different types, based on micro accessibility (activity places near the station) and macro accessibility (activity places further away from the station, accessible with other train ride) of the station. A typology is created on the status of the station operation and the location of the station in relation to the urban center. Figure 17 shows the overview of the classification by the NS with the six classifications (NS Productmanagement, 2002). In the left column, the different trains that serve the stations are presented. The top row shows the characteristic of the urban environment; city center, suburb or outlying area.

1. A very big station in the center of a large city;
2. A big station in the center of a middle-sized city;
3. A suburban station with a node function;
4. A station in the center of a small city or village;
5. A suburban station without node function;
6. A station in an outlying area near a small city or village.

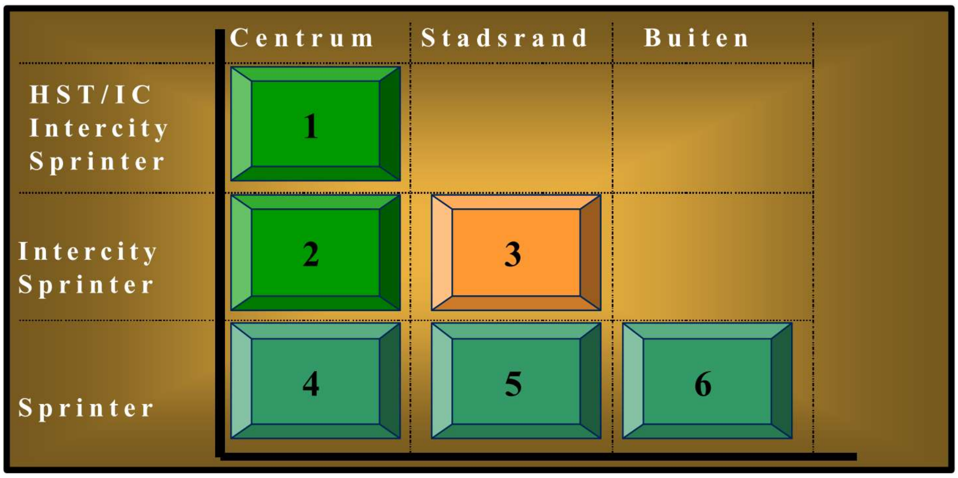


Figure 17: Station classification by NS (NS Productmanagement, 2002)

Policies for the different types of stations used by the NS are intensification of station areas by creating a dense and mixed environment (type 1 and 2), creation of P+R locations (type 4, 5 and 6) and a combination of both (type 3). This is an unusual policy, because this suggests that the NS is trying to direct people to small stations and use the train to go the big city for their activities which causes a centrifugal and centripetal effect. Instead, NS could also focus on creating more interesting environments around small stations to direct people from other areas to go to small cities/ villages.

ProRail, the rail infrastructure manager in the Netherlands, divides stations into five types, based on the estimated number of passengers getting on- and off the train at the station (ProRail, 2018). These types of stations are made to identify what amenities and facilities have to be at the different type of stations. The types are:

1. Cathedral, >75.000 passengers;
2. Mega, <75.000 passengers;
3. Plus, <25.000 passengers;
4. Basic, <10.000 passengers;
5. Stop, <1.000 passengers.

Also the province of Noord-Brabant classifies all the stations in the area. This classification of the stations in and by the province of Noord-Brabant is done to test the node values (operation of an area and accessibility) and place values (density and the number of key areas around the station). This resulted in five different classes of nodes for the stations and their surrounding transit area in Noord-Brabant (Provincie Noord-Brabant, 2018):

1. International node;
2. National node;
3. Brabant node;
4. Regional node;
5. Local node.

The goal of this classification of stations in Noord-Brabant by the province is to show per node what opportunities/ challenges could be improved, based on the four principles accelerate, connecting with other networks, densify and creating a more pleasant area stated in sub-section 3.1.3. Per classification, a target has been set to see how stations perform. This is interesting for the stations that will be evaluated later in chapter 6.

3.3.3 Importance of TOD’s in small cities and villages

The importance of the focus on developing TOD’s in small cities or villages is because there could be a lot of progress made on creating a sustainable society and mobility when more attention is paid to these areas. From an individual traveler’s perspective, it may seem as if there are few problems regarding traffic in small cities and villages outside city centers. These small cities and villages do not have problems regarding congestion, enough parking spots, poor air-quality, etc. But, mostly the traffic in the city centers originates from the areas around it. Besides that, city centers are increasingly attempting to ban cars, which makes traffic problems even worse when there will not be a shift to a more sustainable mobility.

To create a more sustainable society and mobility, multiple approaches are possible. First, the attitude of people has to change. Instead of choosing the mode with the highest utility such as a car, people have to change their behavior to make use of multiple modes to use public transportation. This applies in particular for existing residents of small cities and villages. Changing low-density areas, where car-oriented people live, to a high-density area and mixed environment can be challenging (De Vos et al., 2014). Especially when it comes to changing attitude. Therefore, “park and ride” or “kiss and ride” facilities at stations are important to implement (Nigro et al., 2019). Second, the TOD approach must be implemented at transit areas around small stations. When TOD’s are applied, a dense, mixed and attractive environment has to be created. Only applying parking facilities or other car-oriented improvements such as better car accessibility is not enough, because otherwise the transportation stop is like an island in a low-density car-based environment (Curtis, 2008). TOD’s offer the opportunity to create new dwellings (where the new TOD residents are likely to make use of public transport) and a mixed environment where people can make use of to create their new DUS where daily commuting takes place and where people move on a (mostly) daily basis. Also, it could attract people from other small cities and villages outside the city center, which can lead to a more polycentric region.

3.3.4 Sub-conclusion

Most examples of TOD’s and studies about integration of land-use and public transport are mostly focused on large cities and large metropolitan areas. This could be explained by the fact that these areas have a high population density and activity density and high capacity transport infrastructure. TOD’s in suburban regions are less interesting for policy makers and planners than in city centers or areas with a relatively high level of transit ridership. Furthermore, individuals may have the perception that areas outside city cores do not have problems regarding congestion, enough parking spots, bad air quality etc. But, car traffic in city cores originate from areas around and more often cities increasingly trying to ban cars from the center, which makes the problems worse if there won’t be a shift to a more sustainable mobility. Promoting TOD in suburban regions can lead to higher usage of public transport and can benefit to a more sustainable society.

To implement the TOD approach in areas with lower density, there are several things to keep in mind. First, attitude of inhabitants, who are often fervent car users, have to change. Instead of choosing the mode with the highest utility, people have to get used to making transfers or using multiple transport modes. Therefore, it is important to implement “park and ride” or “kiss and ride” facilities around stations. This is different for people who are going to live in new dwellings of a TOD, who probably choose to make use of public transport. Second, a DUS has to be created in the transit areas around small stations. This ensures that the TOD will not be an island in a low-density car-based environment. Besides that, it could attract people from other small areas outside the core city, which could lead to a polycentric region.

In this research, the focus will be on transit areas around stations with a NS classification of 4, 5 or 6 and a classification of ProRail of Basis or Stop. These types of stations are considered as small stations.

3.4 Measurement methods of TOD characteristics in transit areas

This section shows what is known regarding the measurements of TOD characteristics in transit areas. Here, the criteria to evaluate areas will be described, why the included criteria are relevant and what kind of areas are evaluated. Lastly, there will be shown what is known for measuring TASS.

3.4.1 Examples of transit area evaluations

Unlike creating typologies, transit areas can be evaluated based on different criteria. This has been done in different ways in the literature. The difference between creating typologies and evaluating transit areas is that transit areas are not classified in different groups, but evaluated on several conditions. This gives an objective score of how well the transit area scores on TOD characteristics, where a score per criteria and a total score is given. Here, the evaluation of transit areas in the Netherlands are reviewed. In appendix I, the criteria of each of the researches are shown.

NS Poort & Asset Development (2011) created a vision on the close surrounding station areas in the Netherlands. This is the vision of the NS themselves for their stations. In their vision, design principles are set for the experience of users and the functionality/ use value. They state that the area around the station is very important, because it is the link between the station and the center of the city/ village, it is the area where other public transport options is present and it is an essential part of the public space (NS Poort & Asset Development, 2011). This results in a vision that focusses on a balance between functionality and experience. The design principles for the perception of users is split in three criteria; the identity of the area, the social safety and comfort. Furthermore, the functioning of the area is split in four criteria; safety, accessibility, clarity of orientation and chain facilities. All these criteria are subdivided into indicators to evaluate the areas. Different sizes of stations are taken into account and criteria are adjusted accordingly. In a quick scan by NS & StudioSK (2010), all areas are evaluated by using the indicators and given a bad, medium or good score (see appendix I.I).

As stated by NS Poort & Asset Development (2011), the area around the station is the link between station and the center of the city/ village (NS Poort & Asset Development, 2011). In a thesis by Brouwer (2011), this link is researched in different cities in the Netherlands. In her research, the area between the train station and the city center of different cities are evaluated, based on several criteria. The main objective is to improve the link between the train station and the city center. This is because train stations are often built on borders of historical city centers, where the connectivity is unattractive and lacks vitality. The criteria that are tested are liveliness, human scale, legibility and safety and comfort (Brouwer, 2011) (see appendix I.II). This research is mainly focused on large cities/ big stations. She concluded that to improve the link, first, the quality of the link should be evaluated to find the strong and weak spots. Second, the train station environment and link should be considered on scale of the city center. Third, the train station must be integrated in the area where activities take place. Lastly, the link must meet the criteria stated above.

A research that evaluates transit areas around train stations, is by Singh et al. (2017). The TOD-ness of various transit areas in a metropolitan area is evaluated. Based on eight different criteria and measurable indicators, transit areas are evaluated on how well they score as a TOD. The criteria that are tested are density, land use diversity, walkability and cyclability, economic development, capacity utilization of transit, user-friendliness of transit system, access to and from the station and parking supply at the station (Singh et al., 2017) (see appendix I.III). Based on these eight criteria, the transit areas can be evaluated with an objective score of TOD-ness which can be used to evaluate where these areas score well and where improvements can be made. The transit areas evalutated in the research of Singh et al. (2017) are around both big stations and small stations, which can give a biased impression of the results because the stations are sometimes not comparable with each other. Transit areas of big stations have other qualities and needs than transit areas around small stations, because there is a higher density, there are more establishments and more people making use of these stations.

Provincie Noord-Holland & Vereniging Deltametropool (2013) did a similar research for the transit areas around all stations in the province Noord-Holland. Based on the "butterfly-model", which describes the correlation between node values and place values (Bertolini, 1999). There are three criteria tested per node and place value (see figure 18 and appendix I.IV). At the node side of the butterfly-model (in blue), the criteria are position in slow modes network, position in public transport network and position in road network. At the place side of the butterfly-model (in red), the criteria are proximity (of people), intensity (of people) and diversity (of people) in the area. Based on the outcomes of the criteria, recommendations for improvements are given. This evaluation shows the state of the area, focused on people and the area inside the network of mobility. What is not included in this research are the available amenities in the area or close to the station, while this is an important aspect of attracting people to make use of, and stay around the transit area/ train station.

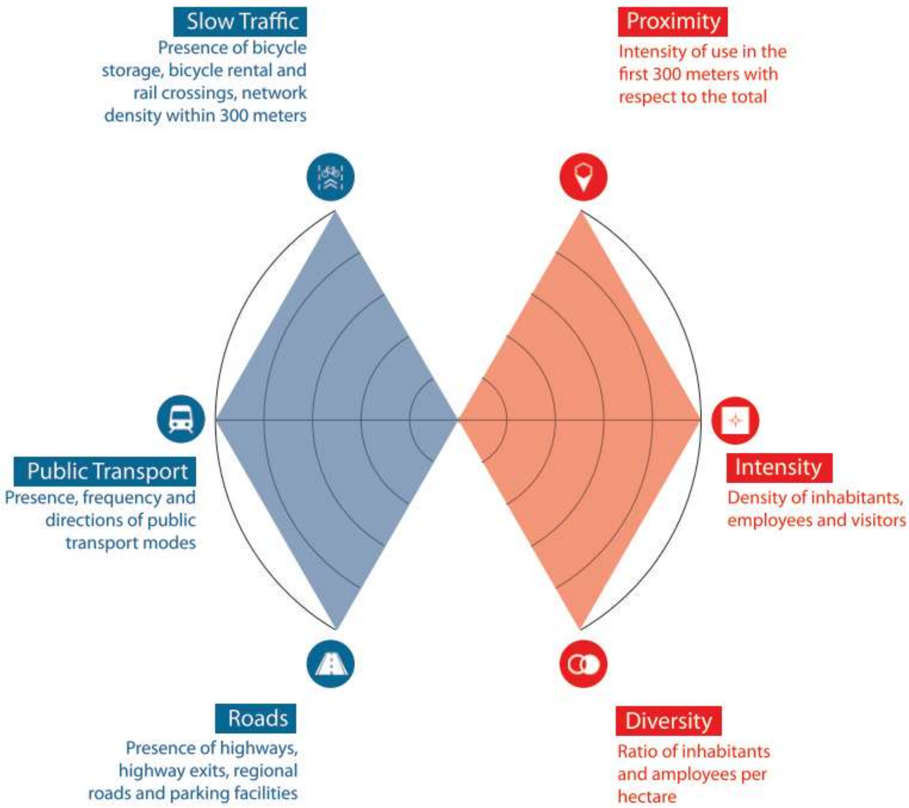


Figure 18: The butterfly model (Provincie Noord-Holland & Vereniging Deltametropool, 2013)

An adjusted model of the butterfly-model is used in a thesis by Simkens (2020). In his research, transit areas around big stations in the Netherlands are evaluated. A holistic assessment is done to identify elements that relate to the enhancement of the experience of travelers. Using the butterfly-model, he used the node values as used by Provincie Noord-Holland & Vereniging Deltametropool (2013), but the place values are modified. Instead of measuring the place values based on the number of people, facilities and the intensity of the facilities are measured. Furthermore, an extra value is added, namely the contextual value. The new values that is added to the butterfly model is related to the criteria that occur in the vision of the NS around train stations and the research by Brouwer (2011) about the link between the station and the city center. In figure 19, the adjusted butterfly model is shown. On the node side of the model (in red), the criteria are position in slow traffic, position in public transport and the position in the road network. Ob the place side of the model (in blue), the criteria are the number of residents in the transit area, the variety of facilities and the intensity of facilities per traveler. Finally, the contextual value is added (in green) with the criteria quality of life (livability score with the score of amenities), the embeddedness in the environment and the urban transition (linearity and barriers) (Simkens, 2020). This evaluation shows the state of the areas. In appendix I.V, a detailed representation is given of the criteria and indicators of the research.

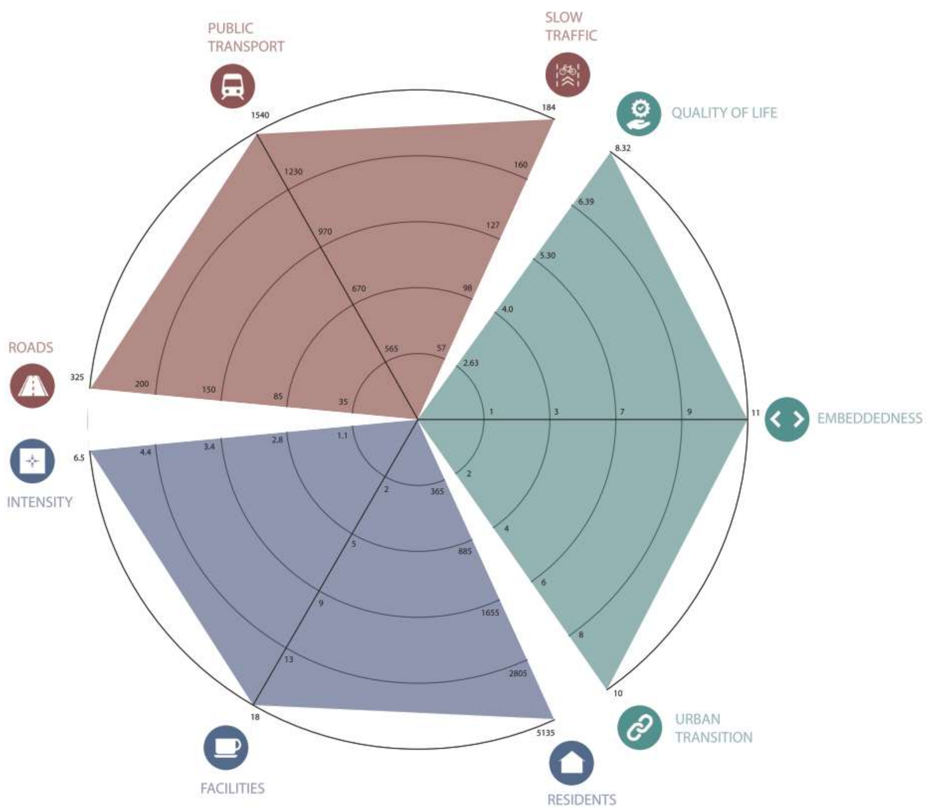


Figure 19: The adjusted butterfly model with three values (Simkens, 2020)

In Brabant, a research has been done to classify train stations and the surrounding transit areas in Noord-Brabant which is mentioned earlier in sub-section 3.3.2. To do so, the nodes are evaluated based on four values; space, connections, transfer and experience. Per value, there are three indicators that are measured. The spatial indicators are density of residents/work and school places, mixedness residents and work/school places and plan capacity (how many construction projects are planned in the area). The connection indicators are service with number of trains and busses in peak-hours, the accessibility of the daily urban system within 45 minutes and the international connection. The transfer indicators are the number of bike parking spots, bus connections to center locations and time to access the highways. Finally, the indicators for experience are facilities, rating of perception of the environment and the rating of perception of the station (Provincie Noord-Brabant, 2018). In figure 20, an example of an evaluation outcome for the station Rosmalen in Noord-Brabant, with scores per indicator, is shown. An overview of the criteria is given in Appendix I.VI. This research is a good test method for nodes around all sizes of stations but focuses mainly on creating typologies and not on giving an objective score for the TOD-ness.

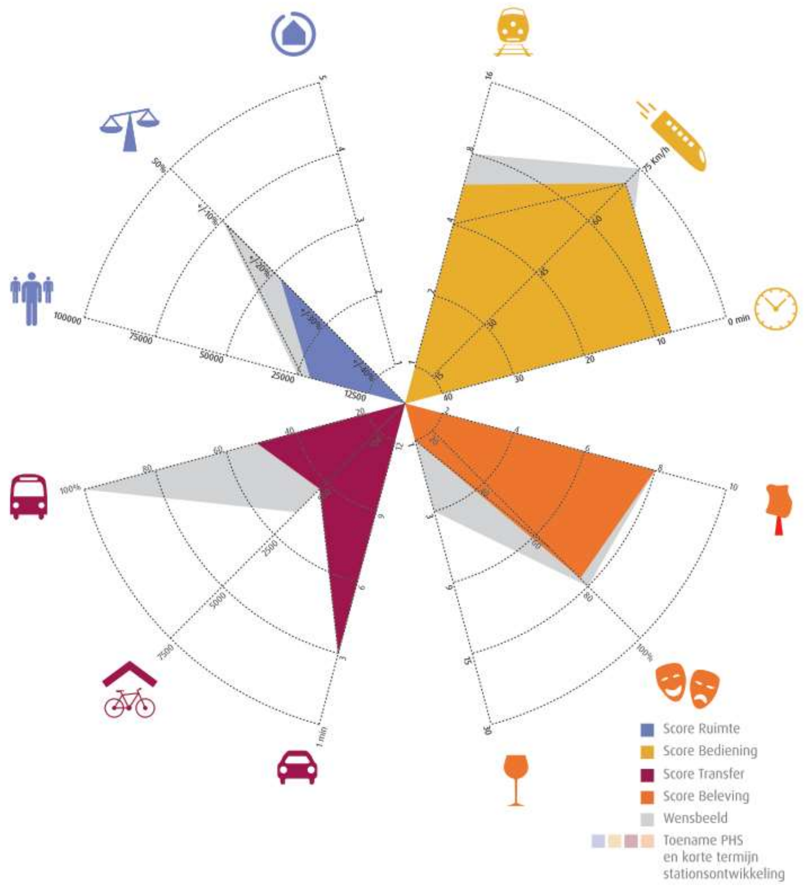


Figure 20: example of the four quadrants of the station Rosmalen (Provincie Noord-Brabant, 2018)

Finally, in the research by Movares Nederland B.V. (2019) concerning the increase of the train frequency in Zuidoost-Brabant, transit areas are evaluated on three different values. Like the butterfly- model, the node and place values are taken into account. But, an extra value is added, which is the value of the perception of users. This is in line with the vision of NS and some research mentioned before (Brouwer, 2011; NS Poort & Asset Development, 2011; Simkens, 2020). The value of perception is linked to facilities and amenities in and around the train stations. Thus, the three values that are tested for all the stations in the Zuidoost-Brabant region are node values, place values and values that measure the perception of users (Movares Nederland B.V., 2019b). The criteria that are evaluated are:

- Place-values
  - Forecast of production (residents and extra travelers)
  - Forecast of attraction (job facilities, school facilities and extra travelers)
- Node-values
  - P+R places
  - Bicycle parking
  - Taxi stands
  - OV-bikes
  - K+R places
  - Way findings
  - Mobility options pedestrians, cyclists, public transport and cars
- Values for the perception of users
  - Public spaces
  - Kiosks
  - Waiting room
  - Crowdedness
  - Cafes and terraces
  - Water taps
  - Station living room
  - Flex office
  - Daily shop

The overview of the tested criteria is shown in appendix I.VII. The aim of this research is to explore what attracts people to make use of the public transport by train in the area. Here, an estimation is used that every amenity/ facility that is present, will attract 0,25% more travelers (Movares Nederland B.V., 2019a).

3.4.2 Measurements in a low density-area

As seen in the research done around transit areas in the Netherlands, little focus is found on only evaluating TASS without comparing it with transit areas around stations of bigger sizes. Some research includes small stations, but they are evaluated with the same criteria, indicators and weights as big stations or stations in large cities. This can give a biased result, because some criteria or indicators are not as important in transit areas around small stations as transit areas around big stations. Transit areas around big stations have other qualities and needs than transit areas around small stations. Therefore, it is relevant to create a tool to measure TASS in small cities and villages to give a more applicable result. In a research by Nigro et al. (2019), they focused on reviewing the integration of land use and public transport in small cities and towns near Salerno and Mercato San Severino, Italy. Here, transit areas in a non-metropolitan area are evaluated by node values, place values (differentiated by catchment areas) and the feeder transport values (differentiated by transport modes). This feeder transport indicator is added in the research with different transport modes other than walking (bike, car, other transit), because in low-density areas different transport modes are used to reach the main transport node (Nigro et al., 2019). Especially in these areas, it is an essential component in the total door-to-door trip.

3.4.3 Sub-conclusion

In the different evaluation studies around transit nodes, objective scores are given on how well areas perform on TOD characteristics such as place values and node values. Mostly, studies use node and place values, but some studies also test facilities that contribute to a positive perception of users. In the Netherlands, no measurement studies are found that only focus on transit areas of small cities or villages where low density occurs. The study of Singh et al. (2017) about measuring the TOD-ness of transit areas in a bigger region is most similar to what is to be investigated in this research. But, it does not focus solely on only TASS without comparing it with transit areas around big stations or in large cities. Only one study is found that focuses on testing transit areas in a low density area near Salerno and Mercato San Severino, Italy. Therefore, it is important to create a measurement tool where the focus is to only measure transit areas of small cities or villages, where place values, node values and values that contribute to the perception of users.

3.5 Conclusion

Based on the literature review, TOD is an interesting approach to attract people to make use of transit nodes. It is important to focus on new developments around transit stops, but also to integrate with the existing area around these transit stops. People who are going to live in dwellings near or in a TOD, are likely to make use of the mobility that is present. For existing residents, it is important to try to change their behavior and attract them to the TOD by creating their daily urban system and focus on the accessibility to the transit node. The 5 D's have to be kept in mind; density, land-use diversity, design, distance to transit and destination accessibility.

TOD's in low-density areas or in areas outside city centers are not of much interest to policy makers and planners because of a relatively low transit ridership, while many mobility problems in city centers are originated from areas around it. Therefore, it is essential to also implement TOD's in areas with lower density such as in small cities and villages.

Multiple studies are found which evaluate areas around transit nodes. These studies often test areas based on the node-values and place-values, but also some studies that only focus on the experience of users in transit areas. In these studies, different types and sizes of transit areas in a bigger region are compared with each other which can cause biased results. Therefore, it is important to create a tool to test transit areas around stations on the level of TOD-ness.

TO evaluate the level of TOD-ness in transit areas around small stations, several aspects are important. First, the place-values have to be tested to check how many destinations can be reached. Second, the node-values have to be tested to see how many and how diverse the activities are that can be performed in an area. This can be done based on the 5 D's. Third, the perception of users plays an important role around transit stops. This suggests that is also important to test for TOD's. A sixth D is added to assess and evaluate the facilities that influence the perception of users, which is the desirability of facilities. Fourth, different catchment areas have to be used to identify the catchment areas of a station for the users and the establishments around the transit node.

4. Conceptual model

In this chapter, the conceptual model is represented and explained that is used in this research.

4.1 The TOD-index as basis for this research

As shown in the literature review, much research and measurements have been done regarding the role of transit areas in travel behavior. The evaluation of TOD-ness by Singh et al. (2017) will be used as the basis of this research. In their research, a TOD-index is created to measure the current state of different transit areas of a bigger region e.g. a metropolitan region. The other researches mentioned in the literature review also evaluated areas around train stations, but with a different approach or goal. However, the approaches of the different researches could be helpful for the conceptual tool to evaluate the level of TOD-ness for TASS.

The TOD-index by Singh et al. (2017) is used to measure transit areas with a Euclidian distance of 800m around the stations. This is the distance that approximately can be accessed by foot in 10 minutes. Singh et al. (2017) make use of eight different criteria:

1. Urban densities
2. Land use diversity
3. Walkability and cyclability
4. Economic development
5. Passenger load in peak and off peak hours
6. User-friendliness of transit system
7. Access to and access from the node
8. Parking at the node

To measure the criteria, indicators are identified. In total, 21 indicators are used to measure the TOD characteristics in the different transit areas. But, not every indicator is equally important for realizing TOD's. Therefore, weights are used to balance the importance of the criteria and indicators. The TOD Index is calculated following the principles of Multi Criteria Analysis (MCA). A representation of the MCA is given in figure 21, every category gets a weight to represent the importance. Here I represents the measurable indicator and S represents a transit area. All weights multiplied the values of the criteria sum up to a score of 1.0, which represent the TOD Index for a transit area. Within the criteria, one or more measurable indicators are present. Also here, the total sum of the scores is 1.0. In the research of Singh et al. (2017), aldermen of the City Region were involved to differentiate the weights. In table 3 the criteria and indicators with accompanying weights are shown.

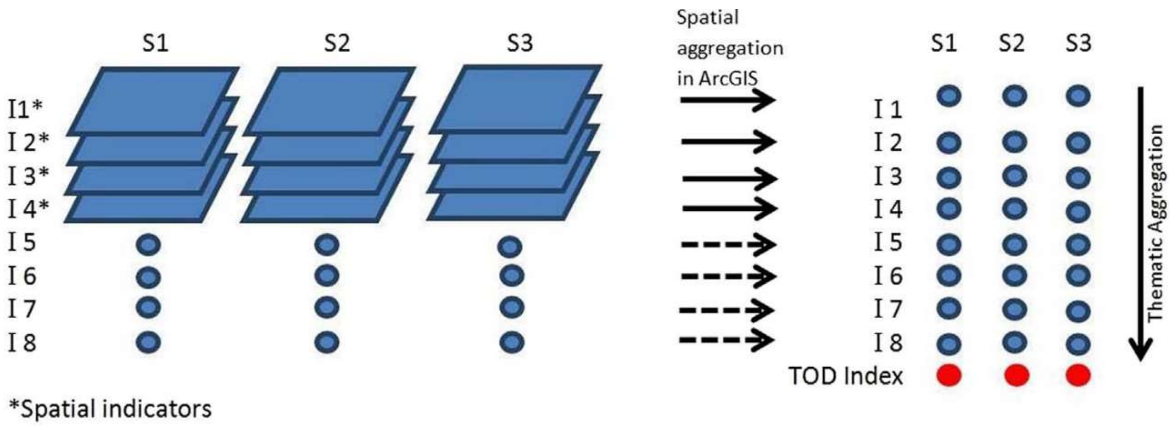


Figure 21: Visual representation of MCA (Singh et al., 2017)

Table 3: Criteria, indicator and weights of the TOD-index (Singh et al., 2017)

S.no.	Criteria		Indicators	
	Description	**Weights**	**Description**	**Weights**
1.	Density	0.15	Population density	0.67
			Commercial density	0.33
2.	Land use diversity	0.03	Land use Diversity	1
3.	Walkability and Cyclability	0.06	Mixedness of residential land use with other land uses	0.1
			Total length of walkable/cyclable paths	0.4
			Intersection density	0.2
			Impedance Pedestrian catchment area (IPCA)	0.3
4.	Economic development	0.22	Density of business establishments	1
5.	Capacity Utilisation of transit	0.19	Passenger load at peak hours	0.67
			Passenger load at off-peak hours	0.33
6.	User-friendliness of transit system	0.11	Safety of commuters at the transit stop	0.5
			Information display systems	0.5
7.	Access to and from the station	0.15	Frequency of transit service	0.4
			Interchange to different routes of same transit	0.3
			Interchange to other transit modes	0.2
			Access to opportunities within walkable distance from train station	0.1
8.	Parking supply at the station.	0.08	Parking supply-demand for cars/four wheelers	0.67
			Parking supply-demand for cycles	0.33

4.2 Conceptual model for measuring the TOD's around small stations

Before the indicators are picked and adjusted to evaluate the transit areas, the applicability for TASS is checked. This is because the criteria and indicators from the research by Singh et al. (2017) are created for TOD's in general. For TOD's at small stations, some rules and criteria are adjusted or added. Based on the literature review, there are some important differences are identified when looking at TOD's at TASS.

First of all, there has to be a difference in catchment area around train stations for residents and establishments. Therefore, the Euclidian distance of 800 m around the train stations used by Singh et al. (2017) has to be changed or split into two different catchment areas based on different travel modes. For measuring the land use diversity, amenities, walkability and cyclability and accessibility, this Euclidian distance of 800 meters will remain constant (rounded: average walking speed of 5km/h in 10 minutes is 833m). If the station is the destination of travelers, the distance of shops, schools and workplaces have to be within walking distance. However, for measuring residents, this Euclidian distance will be larger. This distance will be increased to a cycling distance of 10 minutes, which is equivalent to 2200 meters (rounded: average cycling speed of 13km/h in 10 minutes is 2167m (CBS, 2018; Nigro et al., 2019)).

Second, the weights of the criteria and indicators are different in this research. This is because now the weights are applicable for TOD's at transit areas around stations with different sizes. In this research, the weights have to be appropriate and adjusted to focus on TASS. This will be addressed more in depth in sub-section 6.2.2.

Third, the economic development and business development, together with restaurants and bars is combined in a criterion. In the research of Singh et al. (2017), no indicator to measure restaurants and bars is included. This is unusual, because these amenities could attract people to the transit areas. This new criteria with the different indicators gives a clear overview that can be used for amenities that attract people in a TOD environment.

Fourth, to give a better representation of the connectivity by public transport of the TOD areas to other places in the region, two new indicators are included. This will be done for two modes; the main public transport mode train and for the second public transport mode busses. These indicators are "Reachable area of main transit" and "Reachable area of other transit modes" and are calculated in the "Access to and from station" criterion.

Fifth, because the centrifugal and centripetal effect in a metropolitan area and at small stations, a new indicator "centrifugal/centripetal effect" is included in the criterion "Capacity utilization of transit". With this indicator, a clear representation of the level of centrifugal and centripetal effect is shown.

Lastly, the perception of users will be implemented as a criterion. This is suggested to have a positive influence on attracting people to make use of transit areas. This criterion will measure the facilities or amenities close to the station or inside the station that have a positive influence on the perception of users in transit areas as the indicator "user friendliness". This new indicator will replace the indicator "User friendliness of transit system" that is used by Singh et al. (2017). To indicate what facilities and indicators could have a positive influence on the perception of user, different experts from NS are approached (see appendix III). Unfortunately, they stated that it is really difficult to significantly link the presence of amenities/ facilities to the perception of users in a transit area. Therefore, two other indicators will be added; the ratings of the train stations and the rating of the surroundings by the users which are linked to the user friendliness. These indicator values are from a survey conducted by NS, the "station experience monitor".

Now that the main differences are mentioned, the conceptual model is shown in a visualization in figure 22 and in appendix II. It consists of three different values: "Place" with four criteria and nine indicators, "Node" with three criteria and 12 indicators and "Perception" with one criterion and three indicators. In chapter 6, the data collection is described for all the criteria and indicators to measure the TOD-ness of 10 transit areas of the small stations in Zuidoost-Brabant.

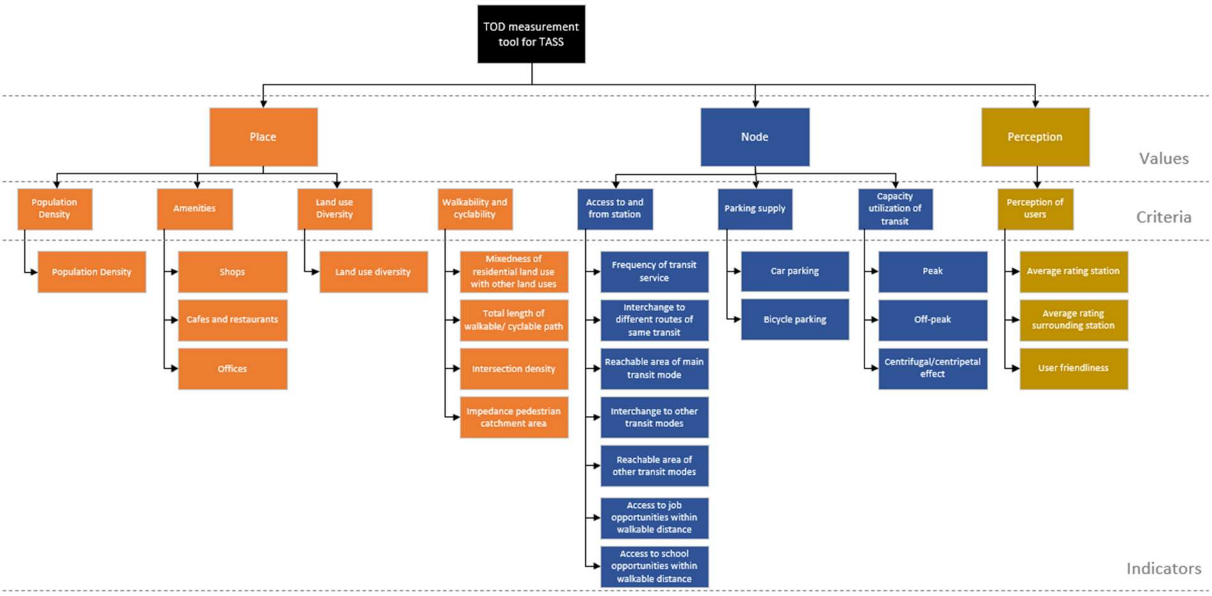


Figure 22: Conceptual model of the TOD-measurement tool for transit areas around small stations

5. Case study

In this chapter, the case study is explained. Here, the region with the stations and transit areas within the scope is shown and the ambition of the region is described.

5.1 Zuidoost-Brabant

For this research, a case study is used to test the TOD measurement tool for TASS. The area selected for this case study is the area of Zuidoost-Brabant, also called the Metropolitan Region of Eindhoven (MRE) and is the third metropolitan region in the Netherlands after the Amsterdam metropolitan area and Rotterdam- The Hague metropolitan area. Zuidoost-Brabant consists of 21 municipalities with approximately 750,000 inhabitants, about 35,000 workspaces and important locations such as an international airport, a university of technology and the High Tech Campus Eindhoven with "the smartest km^2" in Europe with companies and people working on the development of future technologies and products (High Tech Campus, 2020). In figure 23 the location of Zuidoost-Brabant is represented.

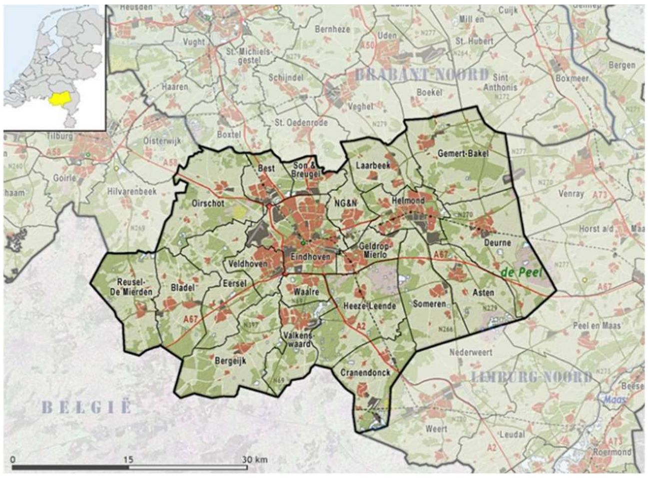


Figure 23: Zuidoost-Brabant (van Aalst, 2010)

Although Zuidoost-Brabant is called a metropolitan region, it is in fact a really small area with relatively few inhabitants compared to other metropolitan areas in the Netherlands (see table 4). Except for the municipalities of Eindhoven (234.456 inhabitants) and Helmond (92.432 inhabitants), all municipalities have a population of less than 50.000 inhabitants (CBS, 2020).

Table 4: population density of three metropolitan areas

Metropolitan Region	Inhabitants	Area (km^2 land)	Population density (inhabitants/ km^2)
Metropolitan Area of Eindhoven (Metropoolregio Eindhoven, 2020b)	766941	1458	515
Metropolitan Area of Amsterdam (Municipality of Amsterdam, 2019)	2480995	1602	1549
Metropolitan Area of Rotterdam- Den Haag (Metropoolregio Rotterdam- Den Haag, 2019)	2347331	1256	1869

As shown in table 4, there is a relatively low population density in Zuidoost-Brabant. In contrast, the car use in Eindhoven is relatively high compared to other large cities in the Netherlands (see figure 24), 52% of the use of modes in Eindhoven is by car. This suggests that Zuidoost-Brabant is a car oriented region and therefore an interesting region to stimulate the use of public transport.

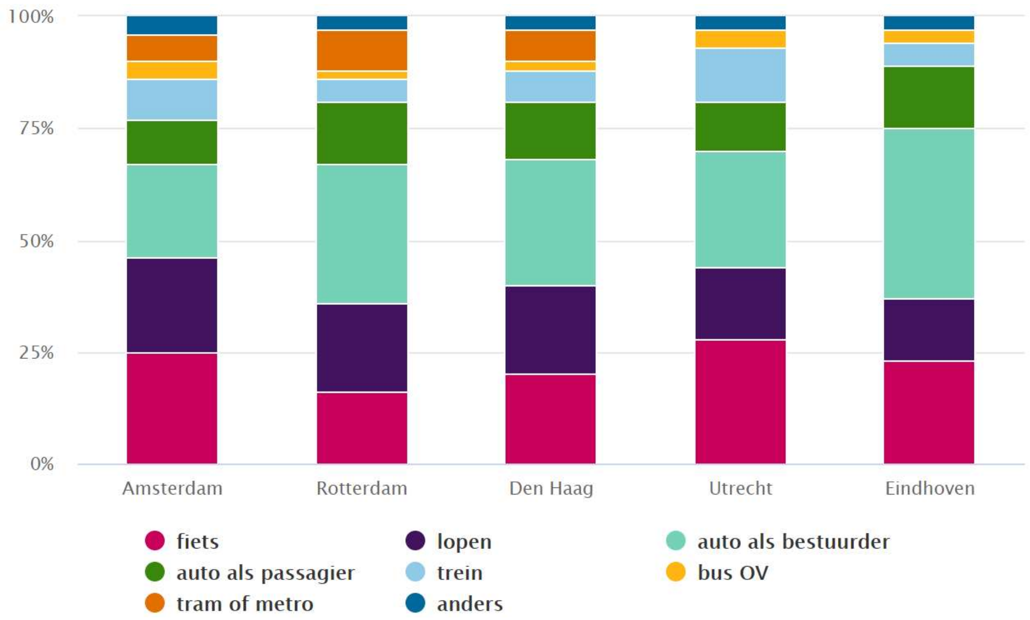


Figure 24: Comparison of mode choices between the five largest cities in the Netherlands (CBS, 2020)

In Zuidoost-Brabant, a rail network with a total of 11 stations is shown in figure 25 (including the surrounding stations Boxtel and Oisterwijk). These stations all have different classes and types which is shown in table 5.

Figure 25: Heavy rail network of the Zuidoost-Brabant region (NS, 2020)

Table 5: Classification of stations by NS and ProRail

Station	Class (NS)	Type of station (ProRail)
Best	4	Basic
Deurne	4	Basic
Eindhoven Centraal	*1*	*Mega*
Eindhoven Strijp-S	5	Basic
Geldrop	4	Basic
Heeze	4	Stop
Helmond	4	Basic
Helmond Brandenvoort	5	Basic
Helmond Brouwhuis	5	Basic
Helmond ‘t Hout	5	Basic
Maarheeze	6	Stop

As shown in table 5, there are some differences in station types as used by NS and station classes used by ProRail. Except for Eindhoven Centraal, all stations meet the requirements set in the literature review for testing the transit areas. This means that there are 10 stations left for evaluating the TOD-ness within the scope of this research.

5.2 The ambition of Zuidoost-Brabant

In the region Zuidoost-Brabant there is an ambition to maintain/ increase its competitive economic position. Accessibility to and between cities is one of the preconditions to achieve this competitive economic position. High quality rail transit and a densification of urban development around rail network stations through a regionally planning is needed to increase the competitive economic position (Movares Nederland B.V., 2019b). The Metropolitan region of Eindhoven sets six specific challenges for mobility (Metropoolregio Eindhoven, 2020a);

- International connectivity with the important locations e.g. the High Tech Campus in the region;
- Connectivity in the daily surroundings through multiple transport flows to each part of the region;
- Livability, traffic safety and sustainability;
- Stimulate smart mobility in the region;
- Connecting mobility with other regional themes such as economy, energy transition and rural transition;
- Logistics to bring economic opportunities.

An example of the ambition of Zuidoost-Brabant, is that the province of Noord-Brabant and the NS want to increase the frequency of trains in 2030 and 2040; 6 intercity (IC) trains per hour between Eindhoven and Amsterdam, 4 IC trains per hour between Eindhoven – Breda – Rotterdam – Den Haag and a Sprinter train (the train that stops at every station between large cities) frequency of 2 to 4 per hour in the province of Noord-Brabant (Ministerie van Infrastructuur en Waterstaat, 2019a; Provincie Noord-Brabant, 2012). But only increasing the frequency of trains in the area is insufficient to attract more people to make use of public transport. Furthermore, the current trains on the rail networks are not always fully occupied.

Only in some parts of the network, close to Eindhoven and Helmond during peak hours, the Sprinters are fully occupied (NS, 2019b). Therefore, NS states that the surroundings of the small stations in the region must become more attractive (see appendix III). To create an interesting public transport product in the area of Zuidoost-Brabant with trains, there is a more integrated approach needed between the rail network and the urban development to increase the use of trains in the area and to compete with the car system (Movares Nederland B.V., 2019b). The TOD approach could be an interesting way to enhance these transit areas and with that attract people to the stations and to take the public transport options.

6. Methodology

In this chapter, the methodology of the research will be described. First, after the conceptual model is created, the data will be collected and the indicators will be calculated. Second, the weights are determined for the criteria and indicators. This results in the overview of the TOD measurement tool. Third, the results of the overall level of TOD-ness per transit area and per criterion are presented. Fourth, a sensitivity analysis is performed to check the robustness of the model. Finally, recommendations for improvement per transit area are given.

6.1 Introduction

As described in the chapter 4 Conceptual model, a Multi Criteria Analysis (MCA) is used to evaluate the TOD-ness of each of the selected transit areas in the case study Zuidoost-Brabant. This MCA method allocates every criterion and every indicator an individual level of importance, because not every criterion or indicator is of equal importance. To give every criterion or indicator a weight, the weights by Singh et al., (2017) are adapting the new values based on the literature review and information from talks with experts, which are summarized in appendix III. This is explained in more detail in sub-section 6.2.2. The data collection and the calculation of the value of each of indicator is done in various ways; via spatial analyses with GIS, using the Verbindingswijzer of Movares, using public data from municipalities, provinces and the NS, using information from earlier studies in this region and with information from talks with experts. The data collection is explained in more detail next sub-section 6.2.1.

An example of the calculation of the indicators, criteria and overall TOD score is shown in figure 26. If a criterion consists of three indicators, each indicator is multiplied by its weight and then added up with the other indicator scores within the criterion. This gives the score for the criterion. After that, if all the criteria are calculated, each criterion is multiplied by its weight and added up with the other criteria which gives the overall TOD score.

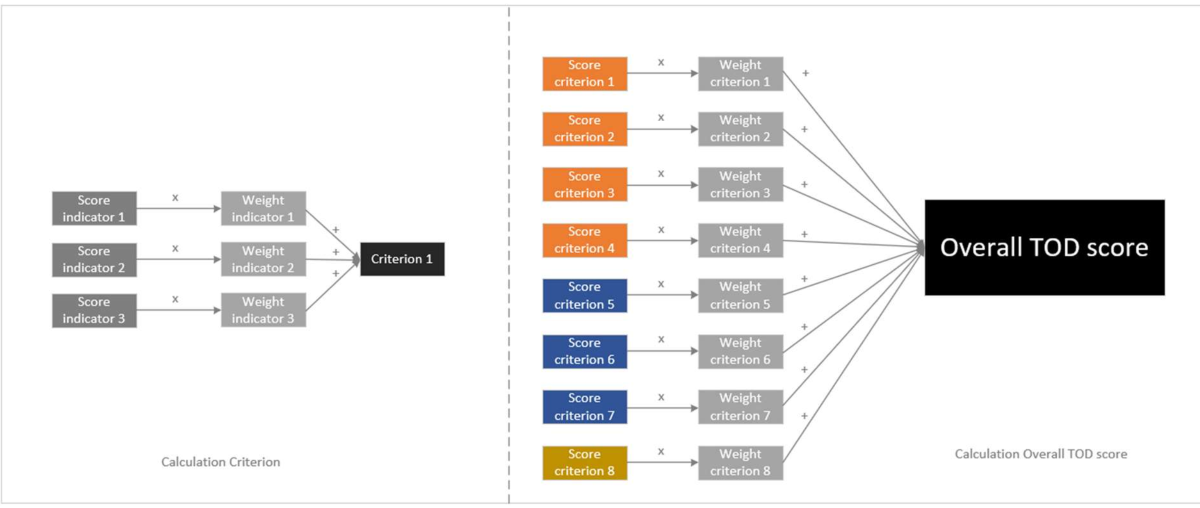


Figure 26: Calculation of a criterion and the overall TOD score

6.2 Data collection

6.2.1 Calculating indicators

Before calculating the values of the indicators, two different buffers are created around the stations with an Euclidian distance of 800 meters, a walking based buffer, and 2200 meters, a bicycle based buffer. When there is an overlap of buffers, the buffers are split equally. The Excel sheets that store the calculations per indicators are presented in appendix IV.

Population density

Population density is calculated as a representation of the number of people that live close to the transit station. The higher the population density, the higher the level of TOD-ness.

To calculate the population density, data is extracted from the CBS 100x100 spatial dataset that is provided by Movares. This dataset contains statistical population data in the Netherlands that is shown in tiles of 100x100 meters. Per tile, the number of inhabitants is presented in the attribute table. To extract and calculate the number of inhabitants within a buffer. The tiles are transformed in QGIS in center points. Now, the information of the number of residents of the center points that are within the bicycle based buffer from the stations are counted. (this indicator is the only indicator that uses the buffer of 2200 meters). In the figure 27, the buffers are shown. If the buffers overlap, they are split equally (Eindhoven Strijp-S is cut, because the bicycle based buffer has overlap with Eindhoven Centraal which is outside of the scope and therefore is deleted). The total number of residents is divided by the area of the buffer per station. This gives the population density. Finally, the population density of all transit areas is transformed in a scale between 1 and 0 where the maximum is the score of the transit area with the highest number of population density and the minimum is 0.

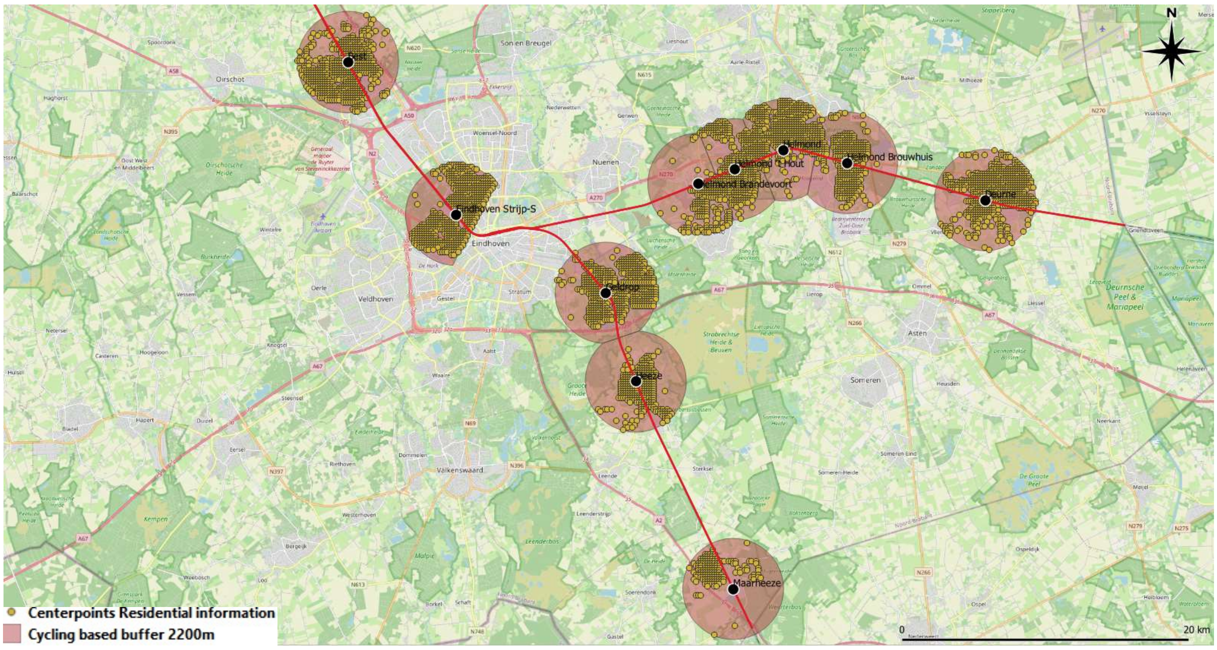


Figure 27: Overview of measurement of population density

Leisure and work amenities

The number of amenities are counted to show the attractiveness of the transit area for people to go for leisure activities or work activities. A high level of amenities contributes to a high level of TOD-ness.

For the criterion Amenities, the shops, cafes/pubs/bars/restaurants (CPBR) and offices are calculated by counting the total number of amenities per indicator, per buffer of 800 meters. An example is shown in figure 28. Here, the information is extracted from OpenStreetMap (OSM) in QGIS. The points that indicate the amenities are counted and scaled between 1 and 0, with a maximum of the highest scoring transit area with the highest number of amenities per indicator and a minimum of 0.

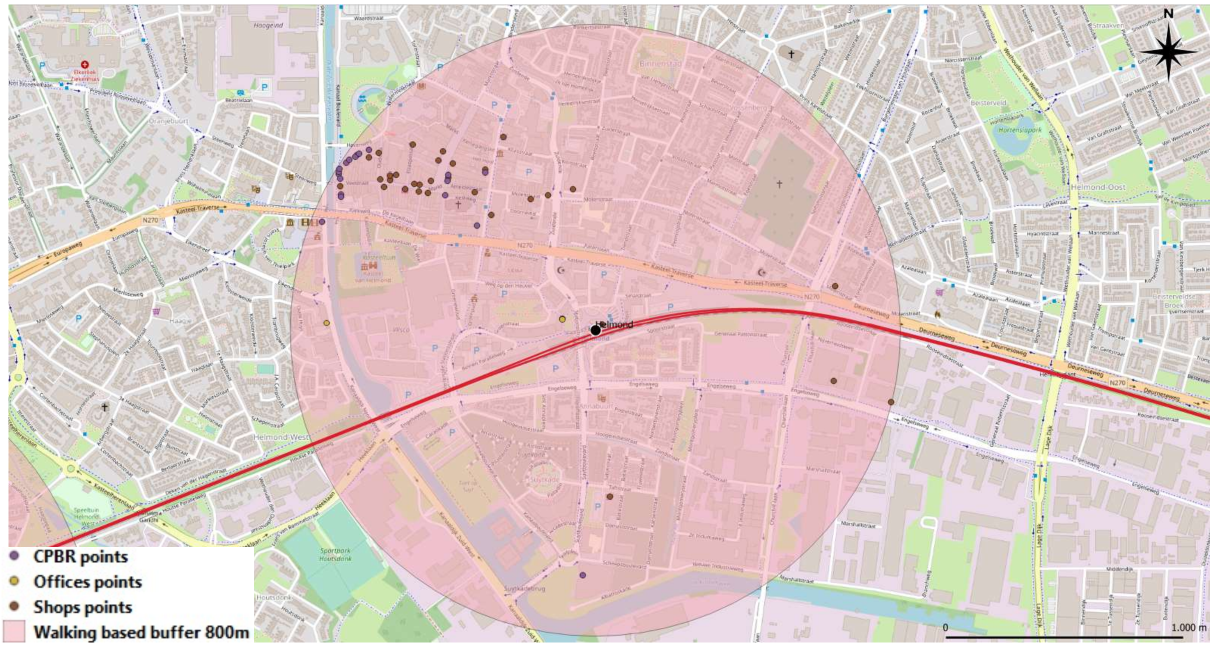


Figure 28: Overview of the amenities in Helmond

Land use diversity

The land use diversity of the transit areas is measured by using the “entropy” method by (Ritsema Van Eck & Koomen, 2008). This method is widely used in the literature. The surface areas of different land uses are measured. In this research, six different land uses are used; Education, Commercial, Sport, Industrial, Retail and Residential (see figure 29). When the different land uses are equally divided in a transit area, the higher the score will be and the greater the contribution to the TOD-ness. The formula to calculate the entropy from Ritsema Van Eck & Koomen, (2008) and that is adopted by Singh et al. (2017) is used in this research (see formula 1 and 2).

$$LU_d(\mathrm{i}) = \frac{-\sum Q_{lu_i} \times \ln\left(Q_{lu_i}\right)}{\ln(\mathrm{n})} \qquad (1)$$

Where

$$Q_{lui} = \frac{S_{lu_i}}{S_i} \qquad (2)$$

$LU_d(i)$= land use diversity in analysis area *i*
lu_{i}= land uses class (1,2,3,…,*n*) within the analysis area *i*
Q_{lui} = Share of specific land use within the analysis area *i*
S_{lui} = Total area of specific land use within the analysis area *i*
S_i = Total area of analysis *i*

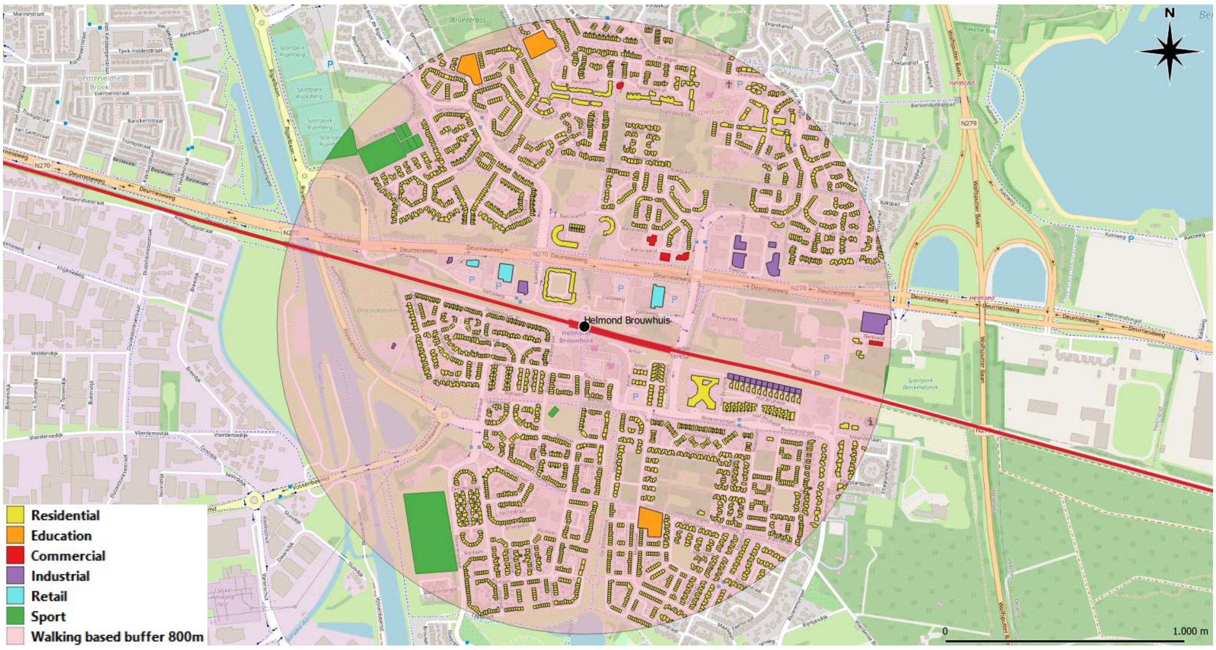


Figure 29: Overview of the land use diversity in Helmond Brouwhuis

Mixedness of residential land use with other land uses

The mixedness of residential land use with other land uses is measured to represent the mix between residential and non-residential land use of the transit areas. The better the mix, the more trips are done by foot or by bike (Zhang & Guindon, 2006). The information to calculate this indicator is the same as the indicator “Land use diversity”, but, the residential land use is compared to the other land uses together. This is calculated with a formula by Zhang & Guindon (2006) and adopted by Singh et al. (2017) (see formula 3).

$$MI(i) = \frac{-\Sigma_{\cap i} S_c}{-\Sigma_{\cap i}(S_c + S_r)} \; \forall i \qquad (3)$$

Where

MI(i) = Mixedness of residential with other land uses Index in analysis area i
S_c = Total area of non- residential land uses
S_r= Total area of residential land use

The value of MI gives a score between 1 and 0, where 0,5 is an equal share of residential land use with non-residential land use. To ensure that the score of the outcome is highest when the MI value is 0,5, the MI score is transformed. This is done by transforming it into a new scale where MI = 0,5 gets a score of 1 and where MI = 0 or 1 get a score of 0.

Road length

The road length in the transit areas are calculated, because when the total length of the roads is high, a larger area can be accessed. To calculate the total walkable/cyclable road length, data is collected from OSM in QGIS. Here, all the roads within the buffers of the researched transit areas are extracted. Not all roads are taken into account here, because they are not walkable or cyclable. Therefore, using Google Street view and the typologies of OSM, the road types “Primary”, “Secondary”, “Tertiary”, “Service” and “Motorway” are excluded here (see figure 30). Finally, the total length of the roads is counted per buffer and scaled to a score between 1 and 0, where the maximum is the score of the transit area with the longest total road length and the minimum is 0.

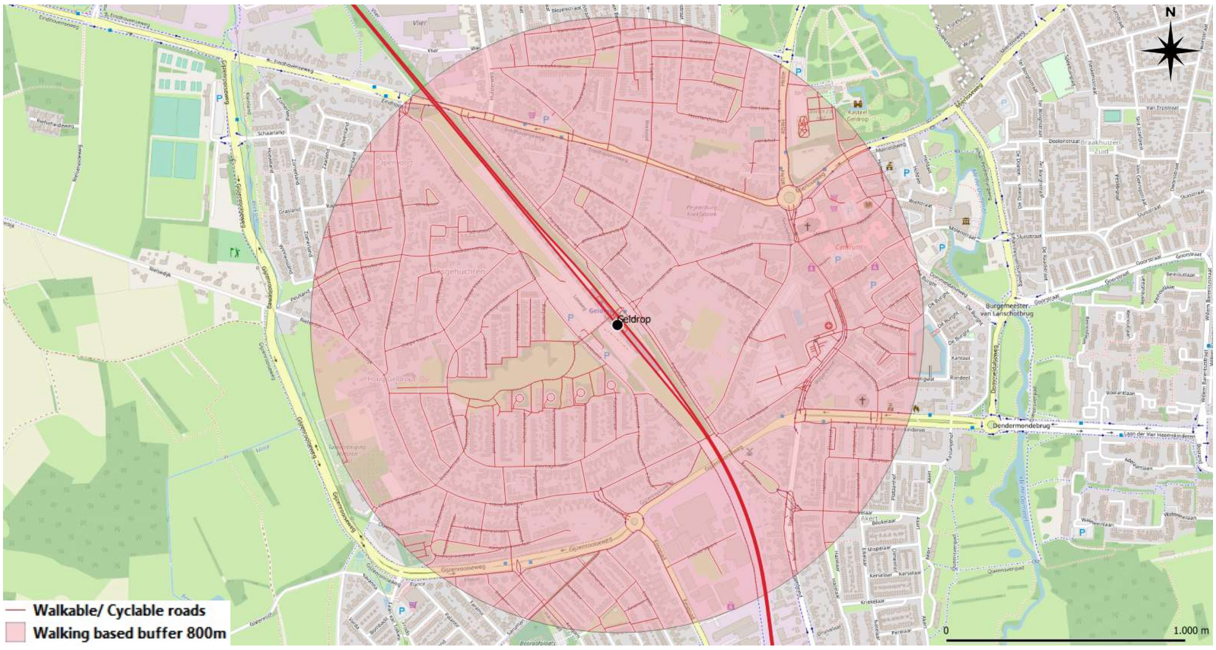


Figure 30: Overview of the walkable and cyclable roads in Geldrop

Intersection density

The intersection density is calculated by counting the number of intersections of the walkable/ cyclable roads in the transit areas. The higher the number of intersections in the transit areas, the higher the level of TOD-ness. A higher number of intersections means that the users that walk or cycle in the area have more choices to shorten their routes (Schlossberg & Brown, 2004; Singh et al., 2017). The calculation is done by using the roads from the indicator “road length” and using the Vector-analyzing tool “intersection of lines”, which is shown in figure 31. Now, intersections receive a point in QGIS and can be counted within the buffer. The total crossings are finally scaled between 1 and 0, where the maximum is the score of the highest scoring transit area and the minimum is 0.

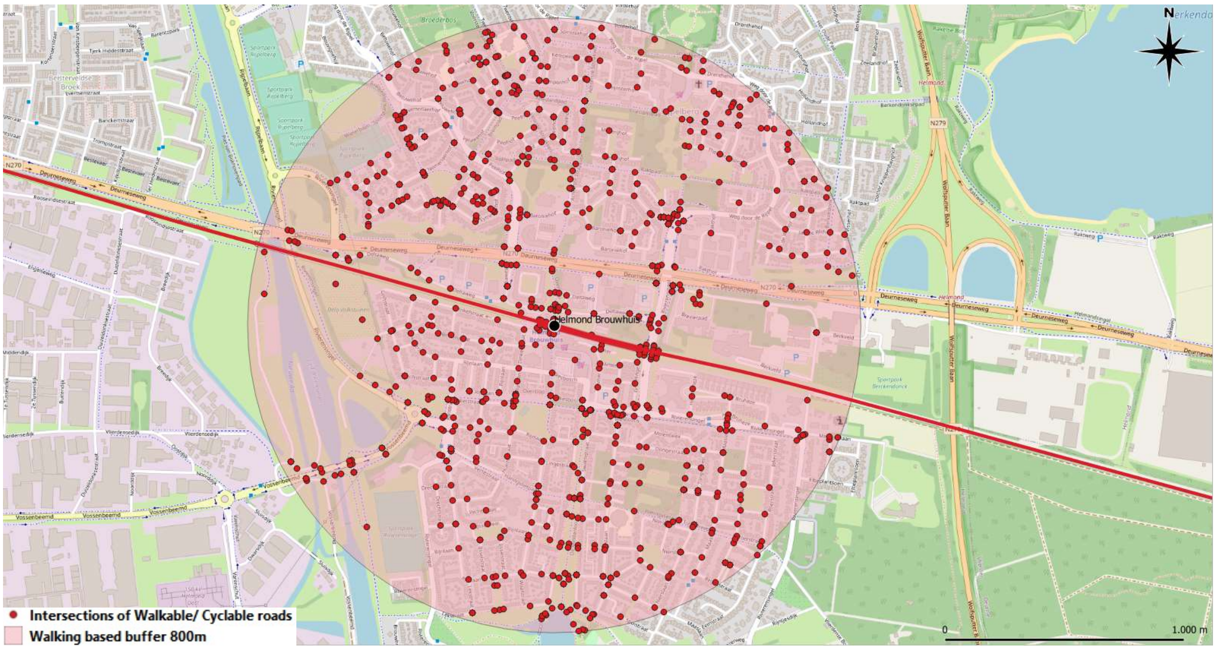


Figure 31: Overview of the intersections of walkable and cyclable roads in Helmond Brouwhuis

Impedance Pedestrian Catchment Area

By using the Impedance Pedestrian Catchment Area (IPCA), the actual area that can be accessed from the station in 10 minutes can be calculated. This is because the buffer around the station is 10 minutes walking in a straight line, which is normally not the case in real life. The bigger the actual area is that can be accessed within 10 minutes walking, the higher the score of the IPCA. This indicator is calculated by using the tool the Verbindingswijzer of Movares. This is an online application which can be used to visualize areas that can be accessed within a certain time frame. Unlike Singh et al. (2017), the Verbindingswijzer is used instead of visualizing the surface by hand. An example is presented in figure 32. In this research, this point at the station and the time frame is 10 minutes. The result of the tool is exported to QGIS and the total area of this result is divided by the area of the buffer of the transit area.

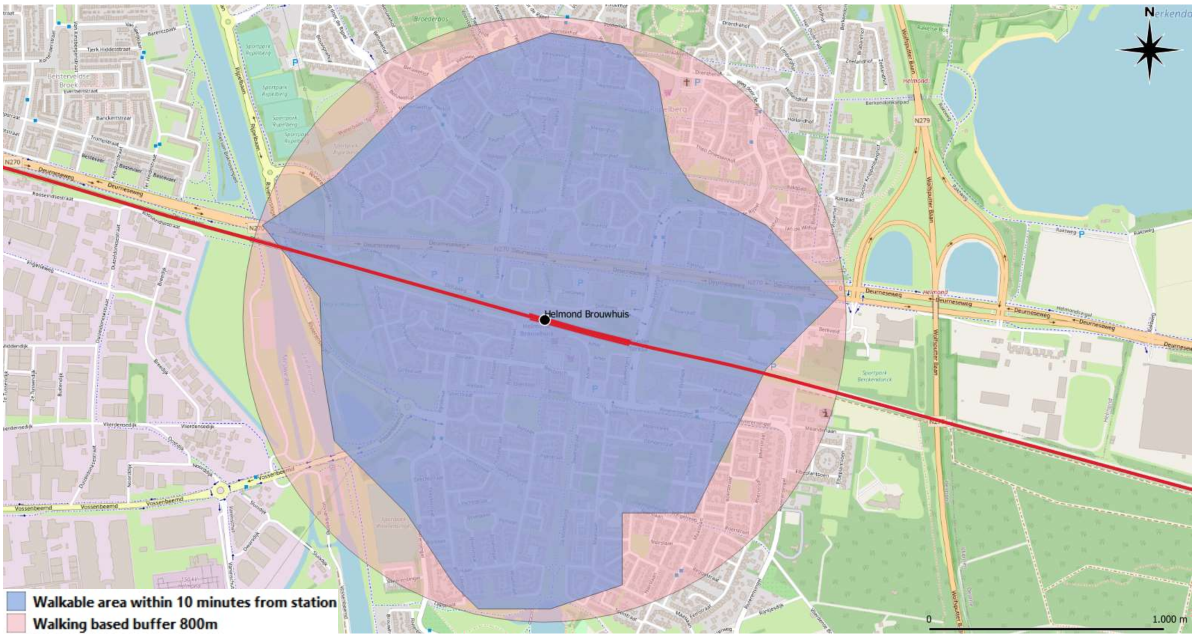


Figure 32: Overview of the Impedance Pedestrian Catchment Area in Helmond Brouwhuis

Frequency of transit

The frequency of the main transit is calculated by counting the number of trains that are serving a station within an hour. The information for this indicator is gathered from Knooppuntenboek by the Provincie Noord-Brabant (2018) and the journey planner by the NS. Unlike the Knooppuntenboek, the intercity trains that access several stations do not get a double score, because it would give an unfair disadvantage to the small stations in the scope of this research. Finally, the score is scales between 1 and 0, with a maximum score of the highest scoring transit area and the minimum score of 1 (because 0 is not possible and 1 is the lowest number of trains per hour e.g. a terminus station).

Interchange of main transit

For the interchange of the main transit, the number of possible interchanges per station is counted. This is done by checking the Spoorkaart Nederland 2020 (NS, 2020), which is shown in figure 33. The different train lines per station are shown, which can be used to see the number of options for the users. The more options there are, the higher the score of this indicator. Finally, the total interchanges per station are scaled between 1 and 0, with a maximum score of the highest scoring station and the minimum score of 1 (a terminus station with just one connected line).

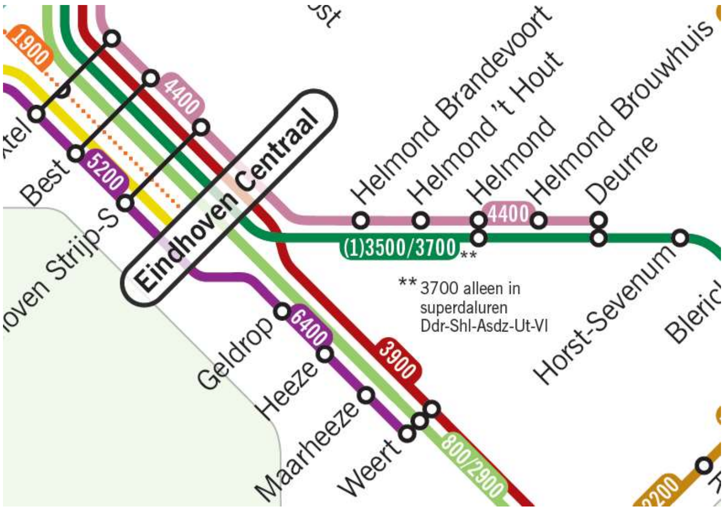


Figure 33: Overview of interchange options of main transit (NS, 2020)

Interchange with other transport modes

Within the transit areas, the total number of possibilities to travel with other transport modes is calculated. In the area of Zuidoost-Brabant, the only other public transport mode available is the bus. The information regarding bus routes is gathered from the Lijnennetkaart 2020 Zuidoost-Brabant by Bravo (2020) and checked in QGIS if the bus stops are within the buffers around the stations (see figure 34). The number of bus routes are counted that have a stop within the buffers of the transit areas. The total number of bus options are scaled to a score between 1 and 0, with a maximum score of highest scoring transit area and the minimum score of 0.

Figure 34: Overview of interchange option of other transport modes in Deurne (Bravo, 2020)

Reachable area by train or bus

Two new indicators that are created compared to the study of Singh et al. (2017), are the reachable area by train and by bus. These indicators give a good visualization and calculation of the actual area that can be accessed from a station. Here, the departure point is the train station of each transit area. Using the Verbindingswijzer of Movares, the total area that can be reached is shown. For the calculations, a time frame of 45 minutes is used due BREVER-wet by Hupkes (1977) and the fact that people on average travel a maximum of a total of 90 minutes per day (Directoraat-generaal Rijkswaterstaat, 2001). An overview of the reachable area by train per station is shown in figure 35 and an overview of the reachable area by bus is shown in figure 36. In the calculations, the settings for the train are that people only can walk and use the train and the settings for the bus are that people only can walk and use the bus. Per departure point in a transit area, the total reachable area is calculated. Lastly, the total scores are scaled between 1 and 0, with a maximum score of the highest scoring transit area and the minimum score of 0.

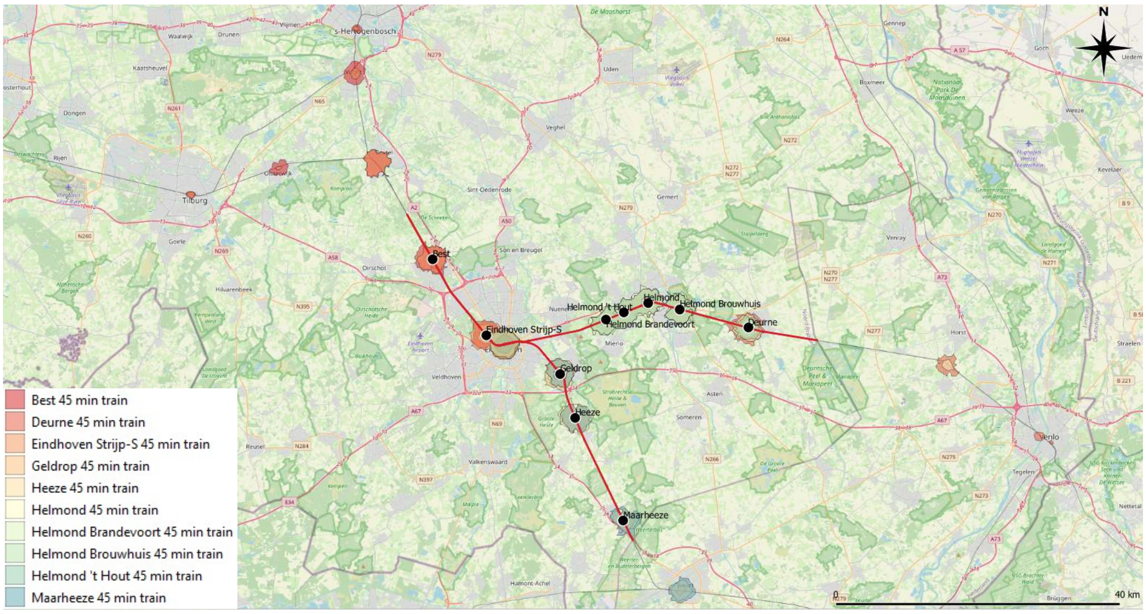


Figure 35: Overview of reachable area by foot and by train in 45 minutes from each station

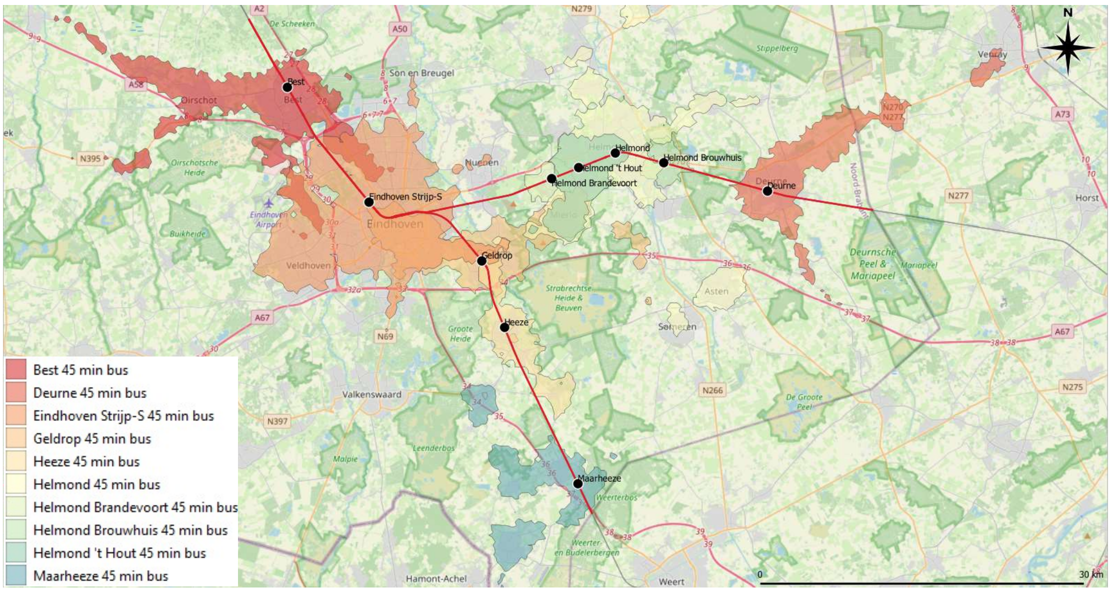


Figure 36: Overview of reachable area by foot and by bus in 45 minutes from each station

Opportunities within walkable distance from the station

To measure the opportunities within walkable distance from the station, the number of job opportunities and the number of school opportunities within the transit areas are counted. The information for both indicators are extracted from the research Ruimte voor de Sprinter (Movares Nederland B.V., 2019b). In this research, the information was present for a buffer of 1000 meters around the stations. Therefore, the scores are transformed into a buffer of 800 meters for this research. The final score per transit area is scaled from 1 to 0 where the maximum is the score of the highest scoring transit area and the minimum is 0.

Parking supply car and bicycle

Measuring the parking supply for cars and bicycles around stations, the number of parking spaces are counted. This information is extracted from the Knooppuntenboek Brabant by the Provincie Noord-Brabant (2018). The number of parking spaces for both cars and bicycles are available. The supply of the parking spaces is calculated based on the number of users per station and the average percentage of users that access train stations by car or by bicycle. As shown in figure 11 concerning accessing and egressing the station by Ministerie van Infrastructuur en Waterstaat (2019b) in sub-section 3.1.5 approximately 45% or users access train stations by bicycle and 10% by car. Egressing the station, approximately 15% use their own bike and 0% use their own car. Adding these numbers together with an additional margin of 5%, there must be a car parking supply for 15% of the users and a bicycle parking supply for 65% of the users. These percentages are multiplied by the number of daily users. Lastly, the available number parking spaces is divided by the percentage of users that use their bicycle or car, which gives a score between 1 and 0.

Capacity utilization peak hours

To measure the capacity utilization during peak hours in the train, information from the Sprinter frequency research by Movares Nederland B.V. (2019b) is used. The information available is the percentage of occupation of the busiest train during the morning peak and the average train occupation of several trains during the day at different times. In the calculations, only the information of Sprinter trains was available and is used. In total, there are four different scores for peak hours; morning peak to and from Eindhoven and the evening peak to and from Eindhoven. Since no precise information for the evening peak is available, the percentage of occupation during the evening peak is estimated as accurately as possible by comparing the busiest train during the morning peak with the average occupation of the evening peak trains.

When the percentages of occupation of the trains are below 90%, so that people can still find a place to sit easily, and above 10%, considering the feeling of safety with "eyes" on the streets or in public transportation, the score will be 1. Otherwise the score is 0. Adding the scores together and dividing them by four, a score per station for the capacity utilization in the peak hours is calculated between 1 and 0.

Capacity utilization off-peak hours

For the capacity utilization in off-peak hours, the average occupation of trains is available from the Sprinter frequency research by (Movares Nederland B.V., 2019b). As the capacity utilization calculation during peak hours, the stations get a score of 1 when the percentage of occupation is between 10% and 90% during off peak hours. Two scores are given; a score for off peak-hours from a certain station to Eindhoven and a score for off-peak hours from Eindhoven to a certain station. Because all scores during off-peak are between 10% and 90%, all stations get a score of 1.

Centrifugal/centripetal effect

Because one of the problems in the area of Zuidoost-Brabant (but also at other small stations or regions) is the centrifugal/centripetal effect, a new indicator is created to measure this. With this indicator, the difference of occupation in two ways from the stations is compared. The capacity utilization of the morning peak to and from Eindhoven is compared and the capacity utilization of the evening peak to and from Eindhoven is compared. The average of the percentual differences of both peaks are calculated and normalized between 1 and 0. The lower the average difference of capacity utilization, the higher the score of this indicator.

Rating stations by users

The station is the main point and the center of the transit area. The rating of the station is therefore an important factor. This data is from the “station experience monitor” by the NS and collected from talks with experts from NS, which is summarized in appendix III. The average rating of the stations is gathered from the station experience monitor and gives a between 1 and 10. These ratings are transformed in this research to a scale between 1 and 0.

Rating station surroundings by users

As stated before, it is important that station and its surroundings are well integrated. Therefore, the next indicator that is measured to test this, is the rating of the station surroundings by users from the station experience monitor by the NS. The information that is gathered, is a score of the stations compared to other stations in the Netherlands of the same type. The scores vary from much lower to much higher compared to the benchmark. These scores are transformed to a scale between 1 and 7, where 1 is much lower and 7 is much higher compared the benchmark. Later, for this research, the scores are converted to a scale between 1 and 0.

User friendliness

The user friendliness of the transit areas is measured by counting the basic available facilities in and close to the stations. This is done in the same way as counting the values that contribute to the perception of users in the research by Movares Nederland B.V. (2019b). Also experts from NS state that they try to improve the “4 W’s”; Wifi, Warm drinks, WC’s and Wait at a warm place. Besides that, at small stations the information availability is important for the attractiveness of small stations (see appendix III). Therefore, the following facilities, including some basic facilities, are counted that contribute to a positive perception of users; toilet, service and information pole, a Kiosk, a waiting room, a water tap and a daily store. This information is gathered from the station information page from the NS. The total number of facilities per station are counted and scaled to a score between 1 and 0, where 1 is a score for when all the facilities that are present and 0 for when there is no facility present.

6.2.2 Determining weights

To determine the importance of the criteria, the weights of the criteria must sum up to a total of 1.0. This also applies for the indicators within a criterion. Below, explanation will be given showing how the weights are determined. The final results are represented in table 6 and a visualization of the complete TOD measurement tool for TASS with the indicators, criteria and weights is shown in figure 37.

Criteria

As described before, the weights of all criteria and indicators are determined by using the weights of the TOD-index of Singh et al., (2017) and adjust them in a way that the scores will be appropriate for TASS. For the adjustments of the weights, findings from the literature study in combination with findings from interviews with experts (which is summarized in appendix III) are used to determine what is most important.

Weighing the criteria, it was clear that one criterion was most important for the TASS; “Amenities”. This is because the biggest issue of these areas is that they are not as attractive as transit areas in city centers where lots of offices, shops and cafes/ restaurants are present. To make TASS more attractive, focus must be placed on amenities, which is stated in the literature and stated by experts of NS (see appendix III). This ensures that people make use of the small station as their station of destination and not only use the small station to go to more attractive big stations. This criterion gets a weight of 0.25.

The second highest weight is given to a total of three criteria; “Walkability/ cyclability”, “Accessibility to and from station” and “Perception of users”. “Walkability/ cyclability” is important, because in transit areas with lower density, car use is relatively high. Therefore, the walkability and cyclability must be of a high level to attract people to use their bike or walk to and from the station. This criterion must be in combination with the criterion “Accessibility to and from station”. To ensure people are willing to walk or cycle, the accessibility of the station also has to be attractive. Furthermore, accessibility to other places outside of the transit area is important for TOD’s to have a large catchment area. The third criterion with this same weight is “Perception of users”. These criteria get a weight of 0.15.

The third highest weight is given to a total of two criteria; “Population density” and “Capacity of utilization of transit”. Because the TASS are often in areas with lower density than in cities, these weights are less important that in a general TOD-index. The “Capacity of utilization of transit” has the same importance. These criteria get a weight of 0.10.

The final criteria with the lowest importance are “Parking supply” and “Land use diversity”. Although parking close to the station is important for using the transit stop, this criterion is not as important as the other criteria. The transit area itself is part of a larger area which also offers parking spaces. The criterion “Land use diversity” is also important for TOD’s, but by changing other criteria that can be measured and adjusted in a more specific way, it gets the lowest importance. Therefore, these criteria will get a weight of 0.05.

Indicators

Within the criterion “Population density”, there is just one indicator; “Population density”. Therefore, it gets a weight of 1.0.

The criterion “Amenities” consists of three different indicators with different weights; a work amenity “Offices” and leisure amenities “Shops” and “Cafes and restaurants”. The work and leisure amenities are as important, because they will attract both people that go to and from the transit area for work and people that go to and from the transit area for leisure reasons. But, within the leisure amenities, shops are slightly more important than cafes and restaurants. Therefore, the indicators “Offices”, “Shops” and “Cafes and restaurants” get a respective weight of 0.5, 0.3 and 0.2.

“Land use diversity” consists of just one indicator; “Land use diversity” and therefore gets a weight of 1.0.

Four indicators are in the criterion “Walkability/ Cyclability”. These are “Total length of walkable/ cyclable path”, “Impedance pedestrian catchment area”, “Intersection density” and “Mixedness of residential land use with other land use”. The weights of these indicators are respectively 0.4, 0.3, 0.2 and 0.1.

For the criterion “Accessibility to and from station”, there are a total of seven indicators. The most important indicator is “reachable area of main transit mode” with a score of 0.25, followed by the “frequency of transit service” with a score of 0.2 and “reachable area of other transit modes” with a score of 0.15. These are most important indicators for TASS, because this indicates best the level of accessibility. The other indicators are “Interchange to different routes of same transit”, “Interchange to other transit modes”, “Access to job opportunities within walkable distance from train station” and “Access to school opportunities within walkable distance from train station”, all with a weight of 0.1.

The criterion “Parking supply” has two indicators; “Car parking” and “Bike parking”. Both considered to be equally important and both get a weight of 0.5.

“Capacity of utilization of transit” is split in three different indicators. The most important indicator for TASS is “Centrifugal effect”, because this is one of the important issues in these areas. This is also stated by different experts by NS to focus on this problem at transit areas around small stations (see appendix III). Therefore, it gets a weight of 0.5. The two other indicators are the capacity measurement in the “Peak” and “Off-peak”. Because the capacity of the trains in peak hours are mostly higher, the weight will be higher to indicate the crowdedness. Therefore, the “Peak” indicator gets a weight of 0.4 and the “Off-peak” indicator gets a weight of 0.1.

The last criterion “Perception of users” is divided in three indicators. The most important indicator to measure the perception of users is “Average rating station”, with a weight of 0.45. Next, the “Average rating surrounding station” gets a weight of 0.35. This is because, especially for TASS, that the integration of the station is in line with the surroundings of the station (Simkens, 2020; Van Hagen, 2011). Lastly, the “User friendliness” is an indicator with a weight of 0.2. This is based on that NS is trying to improve the information availability and the “4 W’s” at small stations, which is stated to have a positive effect perception of users.

Table 6: Weights of criteria and indicators of the TOD measurement tool for TASS

Values	Criterion	Weight	Indicator	Weight
Place	**1. Population density**	0.15	**Population density**	1.0
	2. Amenities	0.25	**Shops**	0.3
			Cafes and restaurants	0.2
			Offices	0.5
	3. Land use diversity	0.05	**Land use diversity**	1.0
	4. Walkability/ Cyclability	0.10	**Mixedness of residential land use with other land use**	0.1
			Total length of walkable/ cyclable path	0.4
			Intersection density	0.2
			Impedance pedestrian catchment area	0.3
Node	**5. Accessibility to and from station**	0.15	**Frequency of transit service**	0.2
			Interchange to different routes of same transit	0.1
			Reachable area of main transit mode	0.25
			Interchange to other transit modes	0.1
			Reachable area of other transit modes	0.15
			Access to job opportunities within walkable distance from train stations	0.1
			Access to school opportunities within walkable distance from train stations	0.1
	6. Parking supply	0.05	**Car parking**	0.5
			Bike parking	0.5
	7. Capacity of utilization of transit	0.1	**Peak**	0.4
			Off-peak	0.1
			Centrifugal effect	0.5
Perception	**8. Perception of users**	0.15	**Average rating station**	0.45
			Average rating surrounding station	0.35
			User friendliness	0.2

Figure 37: Overview of TOD measurement tool for TASS

6.3 Results

6.3.1 Overall TOD scores

Now that the values and weights of the criteria and indicators have been explained, the results are calculated for the 10 transit areas in this research. All transit areas get a score per criteria and a total score for the level of TOD-ness, focused on TASS which is presented in table 7 and in appendix V. All scores have a range between 1.0 and 0.0, where a score between 0.80-1.0 is very high, a score between 0.6-0.8 is high, a score between 0.4-0.6 is medium, a score between 0.2-0.4 is low and a score between 0.0-0.2 is very low.

Table 7: Overall scores of the TOD measurement tool for TASS

TOD measurement tool for TASS	Place				Node			Perception	TOD Score
	1. Population density (Weight: 0,1)	2. Amenities (Weight: 0,25)	3. Land use diversity (Weight: 0,05)	4. Walkability/ Cyclability (Weight: 0,15)	5. Accessibility to and from station (Weight: 0,15)	6. Parking supply (Weight: 0,05)	7. Capacity of utilization of transit (Weight: 0,1)	8. Perception of users (Weight: 0,15)	
TOD area	Score	Score	Score	Score	Score	Score	Score	Score	Total
Best	0,50	0,42	0,18	0,64	0,68	0,28	0,57	0,61	0,53
Deurne	0,37	0,05	0,21	0,55	0,62	0,45	0,27	0,77	0,40
Eindhoven Strijp-s	1,00	0,80	0,26	0,85	0,85	0,05	0,57	0,48	0,70
Geldrop	0,51	0,42	0,20	0,68	0,44	0,29	0,21	0,63	0,46
Heeze	0,17	0,05	0,18	0,61	0,36	0,37	0,21	0,69	0,33
Helmond	0,82	0,34	0,26	0,79	0,89	0,28	0,27	0,70	0,58
Helmond 't Hout	0,57	0,13	0,19	0,72	0,38	0,23	0,27	0,75	0,42
Helmond Brandevoort	0,22	0,09	0,17	0,73	0,35	0,26	0,27	0,73	0,37
Helmond Brouwhuis	0,40	0,16	0,22	0,80	0,35	0,23	0,27	0,55	0,38
Maarheeze	0,09	0,00	0,11	0,31	0,35	0,59	0,21	0,46	0,23

As presented in table 7, the TOD scores of the transit areas vary between the lowest score 0,23 for the transit area of Maarheeze and the highest score 0,70 for the transit area of Eindhoven Strijp-S. None of the transit areas have a very high score. But, one station has a score that is high, which is Eindhoven Strijp-S. Transit areas that have a medium score are Best, Deurne, Geldrop, Helmond and Helmond ‘t Hout. Low scoring transit areas are Heeze, Helmond Brandevoort, Helmond Brouwhuis and Maarheeze. None of the transit areas has a very low score. In figure 38, a map is presented to visualize the overall scores in the area of Zuidoost-Brabant.

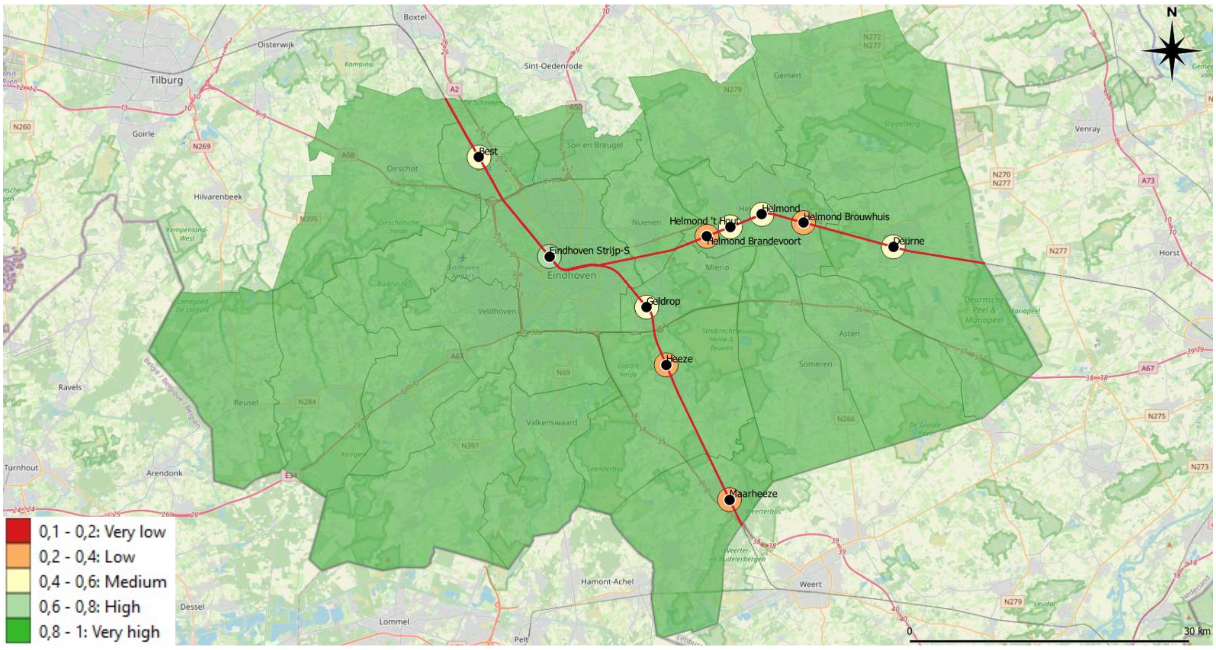


Figure 38: Overview of the overall level of TOD-ness of the transit areas in Zuidoost-Brabant

6.3.2 Relation between the level of TOD-ness and the number of users

To see if there is a relation between the level of TOD-ness and the number of users, a graph is created. In the graph, the overall level of TOD-ness per transit area is used as the independent variable and the number of users as the dependent. The number of daily users per station are (NS, 2019a):

- Best: 6027;
- Deurne: 4486;
- Eindhoven Strijp-S: 3184;
- Geldrop: 1511;
- Heeze: 1628;
- Helmond: 7419;
- Helmond 't Hout: 1344;
- Helmond Brandevoort: 1493;
- Helmond Brouwhuis: 1766;
- Maarheeze: 1347.

With the results of the overall level of TOD-ness per station from table 7 and the number of daily users per station, a scatter plot with a fit line is created in figure 39.

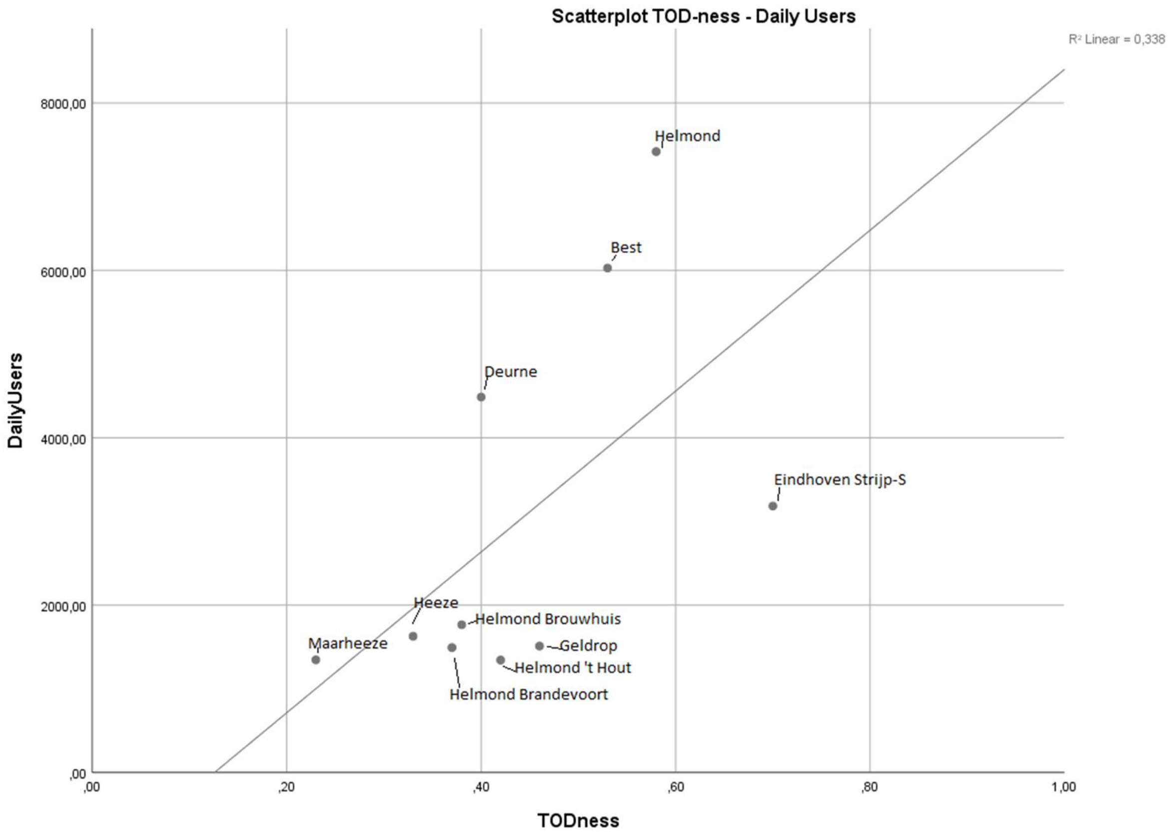


Figure 39: The level of TOD-ness versus the daily users per station

With a positive fit line and an R^2 –value of 0.338, a weak positive relation between the overall level of TOD-ness and the number of daily users per station is shown. This suggests that a higher overall level of TOD-ness contributes to a higher number of daily users. But, a side note has to be made. Because of the low number of total transit areas that are evaluated in this research, no statistical conclusions can be drawn. However, this graph gives an indication that the overall level of TOD-ness has positive influence on the daily users.

6.3.3 Results per criterion

In this sub-section, the results of all criteria are presented. The accompanying tables are presented in appendix VI.

Population density

Looking at the scores for population density, there are two transit areas that stand out with a higher score than the rest; Eindhoven Strijp-S and Helmond. This is because these transit areas are in the dense urban areas of the cities Eindhoven and Helmond. Another transit area that stands out is Maarheeze. This is because the station of the transit area is relatively far away from residential buildings. There are only a few residential buildings in the north-west of the transit area. The rest of the transit areas score relatively average on population density.

Amenities

In the transit areas included in this research, the number of amenities is low. This is because most amenities normally concentrate more in large cities or city centers, that are outside the scope of this research. Besides that, the amenities near the transit areas of this research are not close to the station, but just outside of the buffer of the transit areas. Eindhoven Strijp-S has a high score for amenities compared to the other transit areas, probably due to the fact that it is on the edge of the city of Eindhoven, the main city of the region, where a lot of amenities are concentrated.

Land use diversity

The scores of all transit areas for land use diversity is low. In the transit areas, except for Maarheeze, the total surface of residential buildings is much higher compared to the surface other land uses. This gives an unbalanced land use diversity, which results in the low scores. In Maarheeze, the surface of industrial buildings is primarily present. But, as in the other transit areas, the land use diversity is unbalanced.

Walkability/ Cyclability

The walkability and cyclability of the transit areas is on average quite good, except for the transit area of Maarheeze. Breaking down the indicators that create the score of the criterion Walkability/ Cyclability, there are some differences and interesting results.

The mixedness of residential land use with other land uses differs greatly between the transit areas. The results that stand out in this indicator with high scores are Helmond and Maarheeze. Helmond scores high, due to the good mix of all different kinds of land use. The score of Maarheeze is interesting, because the relatively high level of industrial land use and the low level of residential land use. A score that stands out with a low score is Best. This is because almost all buildings in the transit area are residential.

The total length of walkable/ cyclable path in almost all transit areas have a high score. Only the transit area of Deurne has an average score and Maarheeze has a low score compared to the other transit areas. Deurne has fewer roads than the other transit areas, while the area is in an urban area. Maarheeze has few walkable and cyclable roads, because the transit area is quite far from the urban area and is surrounded with non-walkable roads such as the highway that is next to the station.

The intersection density of the transit areas in this research in general are high. Except for Deurne and Maarheeze, due to the facts that are described above.

The IPCA of almost all the transit areas have a high score. Only Maarheeze has a medium score because there are fewer paths available, which causes a smaller accessible area within 10 minutes.

Access to and from station

The accessibility of the stations in the transit areas differs a lot. The very high scoring transit areas are Helmond and Eindhoven Strijp-S, followed by the high scoring transit areas Best and Deurne. The other stations have a low score.

Looking at the indicators that create the result for the accessibility, the frequency of transit service between the stations has differences. This is because the high scoring stations, Helmond and Deurne, both are connected with Sprinter trains and Intercity trains. Best and Eindhoven Strijp-S have a connection on two different sprinter lines, which results is more trains per hour. The other stations only have Sprinter trains of one line that accounts for the low frequency.

The connectivity of the main transit is partly influenced by last indicator. It checks the interchange options and the reachable area by train. The interchange options for the stations mentioned before are higher compared to the other stations which gives a higher score. For the indicator that measures the reachable area by train and foot in 45 minutes, Helmond has the highest score because of the many interchange options and the central location. The other stations all have a medium to high score.

The connectivity of other transit modes is split in two indicators. The interchange options with other transit modes (bus) has a high score for the transit areas of Eindhoven Strijp-S, Best, Helmond and Geldrop. These transit areas have different bus connections and bus stops in the transit area. What is remarkable, is that the transit areas of Helmond Brandevoort and Helmond Brouwhuis do not have any bus connections or bus stops within the buffer, which causes a score of 0. The other transit areas have a one to a few bus stops and bus connections. The reachable area by bus is calculated in the same way as for the train; travel by walking and by bus in 45 minutes. The scores of this indicator are in line with the interchange options for the bus.

The access to opportunities within walkable distance from the train station is split into job opportunities and school opportunities. On average, the job opportunities are low, except for Eindhoven Strijp-S and Helmond that score high and Geldrop that scores average. The school opportunities in Eindhoven Strijp-S are high, followed by Helmond and Best that score average. The other transit areas have a low to very low score.

Parking supply

The parking supply for cars on average is low for the transit areas, except for Maarheeze. This is because of the large parking area near the station for P+R. This station is also known as a “P+R station”, due to the location of the station next to the highway. On the other hand, Eindhoven Strijp-S and Helmond ‘t Hout do not have any parking facilities for cars.

The parking supply for bicycles is scored low by all the transit areas. Eindhoven Strijp-S scores even lower than the other stations, because of the low number of parking facilities and the relatively high number of users.

Capacity utilization of transit

The capacity utilization of transit is calculated using three indicators; the occupation during peak hours, the occupation during off-peak hours and the centrifugal/ centripetal effect.

The scores of the capacity utilization in peak hours is measured with four different peak situations. The best scoring station is Geldrop, with just one peak situation that is overcrowded. Best has the lowest score, because of three situations that are too crowded. The other stations have two peak hour situations where it is too crowded. During off-peak hours, there are two situations. Between the stations, there are no differences, because trains of the stations are not too crowded and within the capacity range of 10% and 90%.

The results of the centripetal and centrifugal effect are interesting. All stations have a low score for this indicator, except for Best and Eindhoven Strijp-S. Here, there is no big difference between the direction and occupation of the users. This is due to the fact that these two stations are located between the big cities Eindhoven on one side and Tilburg and 's Hertogenbosch on the other side. This ensures that the occupation of trains at these stations are almost even, which give Best and Eindhoven Strijp-S a high score for this indicator.

Perception of users

The perception of users is split in three different indicators. The average rating of the station, the average rating of the surrounding and the user friendliness.

Looking at the ratings by users for the stations, all stations have a score, which is based on a grade between 1.0 and 10. But, there are some interesting results. Although Eindhoven Strijp-S has the highest average TOD score, it has a quite low score compared to the other stations. The opposite is noticeable for Maarheeze. With the lowest average TOD score, the station has a fairly high score compared to other stations.

The ratings of the surroundings of the stations are based on the comparison of the station with the benchmark of the average of stations from the same type in the Netherlands. Interesting results here are that again, Eindhoven Strijp-S scores fairly low compared to the other stations of this research, while it has the highest TOD score. It is also remarkable that the stations Heeze, Helmond 't Hout and Helmond Brandevoort have the highest score compared to the other stations and to the stations of the same type, while the overall TOD score is low.

The user friendliness is based on counting numerous facilities that are present in and around the stations of the transit areas. Again, a remarkable score is for Eindhoven Strijp-S with the lowest score, together with Heeze and Maarheeze, for the user friendliness. The highest score is for Helmond, with all tested facilities present.

6.3.4 Sensitivity analysis

Finally, a sensitivity analysis is conducted to test the robustness of the model. Because the weighing might be somewhat subjective and some results of indicators or criteria could be measured by using more accurate information, the robustness of the model must be checked. In the literature, many different possibilities to do a so-called sensitivity analysis are presented. Focusing on a sensitivity analysis of a MCA with spatial indicators, changing the weights is the most common way to test the robustness of the model (Delgado & Sendra, 2004). For the sensitivity analysis in this research, the weights of the criteria are changed one by one with plus or minus 5% per criterion (so plus or minus 0.05), where the other criteria are balanced equally. This percentage is chosen, because the lowest weight of the criteria is 0,05 and a negative weight is not possible. In total, 16 different models are created to test the robustness which is shown in table 8 and appendix VII.

Table 8: Sensitivity analysis

	Sensitivity Analysis																
	Original score	**Population Density +5%**	**Population Density -5%**	**Amenities +5%**	**Amenities - 5%**	**Land use diversity +5%**	**Land use diversity - 5%**	**Walkability/ Cyclability +5%**	**Walkability/ Cyclability - 5%**	**Accessibility to and from station +5%**	**Accessibility to and from station -5%**	**Parking supply +5%**	**Parking supply -5%**	**Capacity utilization +5%**	**Capacity utilization - 5%**	**Perception of users +5%**	**Perception of users -5%**
Eindhoven Strijp-s	***0,702***	0,724	0,679	0,712	0,691	0,682	0,721	0,715	0,688	0,715	0,688	0,670	0,733	0,699	0,704	0,694	0,709
Helmond	***0,577***	0,593	0,562	0,566	0,589	0,561	0,593	0,592	0,563	0,597	0,558	0,562	0,592	0,562	0,593	0,586	0,569
Best	***0,525***	0,526	0,524	0,522	0,529	0,508	0,542	0,534	0,516	0,536	0,514	0,513	0,537	0,530	0,520	0,532	0,518
Geldrop	***0,464***	0,469	0,459	0,464	0,464	0,451	0,477	0,479	0,449	0,465	0,463	0,456	0,472	0,452	0,476	0,476	0,452
Helmond 't Hout	***0,415***	0,424	0,406	0,400	0,430	0,403	0,427	0,433	0,397	0,414	0,416	0,405	0,425	0,407	0,423	0,435	0,395
Deurne	***0,400***	0,397	0,402	0,379	0,420	0,388	0,411	0,407	0,392	0,411	0,388	0,402	0,397	0,392	0,407	0,420	0,379
Helmond Brouwhuis	***0,383***	0,384	0,381	0,370	0,395	0,374	0,391	0,407	0,358	0,381	0,384	0,374	0,391	0,377	0,388	0,393	0,373
Helmond Brandevoort	***0,366***	0,358	0,373	0,351	0,381	0,355	0,376	0,387	0,344	0,365	0,366	0,360	0,371	0,361	0,370	0,387	0,344
Heeze	***0,326***	0,317	0,335	0,310	0,342	0,317	0,334	0,342	0,310	0,328	0,324	0,328	0,324	0,319	0,332	0,346	0,305
Maarheeze	***0,233***	0,223	0,243	0,218	0,248	0,224	0,242	0,236	0,230	0,238	0,228	0,251	0,215	0,230	0,236	0,244	0,222

Computing the sensitivity analysis, the order of the transit areas remains identical in all different scenarios. The highest score of the transit areas varies between 0.670 and 0.733 and the lowest score of the transit areas varies between 0.215 and 0.251. This implies that the model is robust and that the results are reliable.

6.3.5 Overview per transit area

Now all the scores of the criteria are explained. An overview for all transit areas is given. This overview is shown in figure 40 and in appendix VIII, which gives a visualization of the scores per criteria per station in radar graphs.

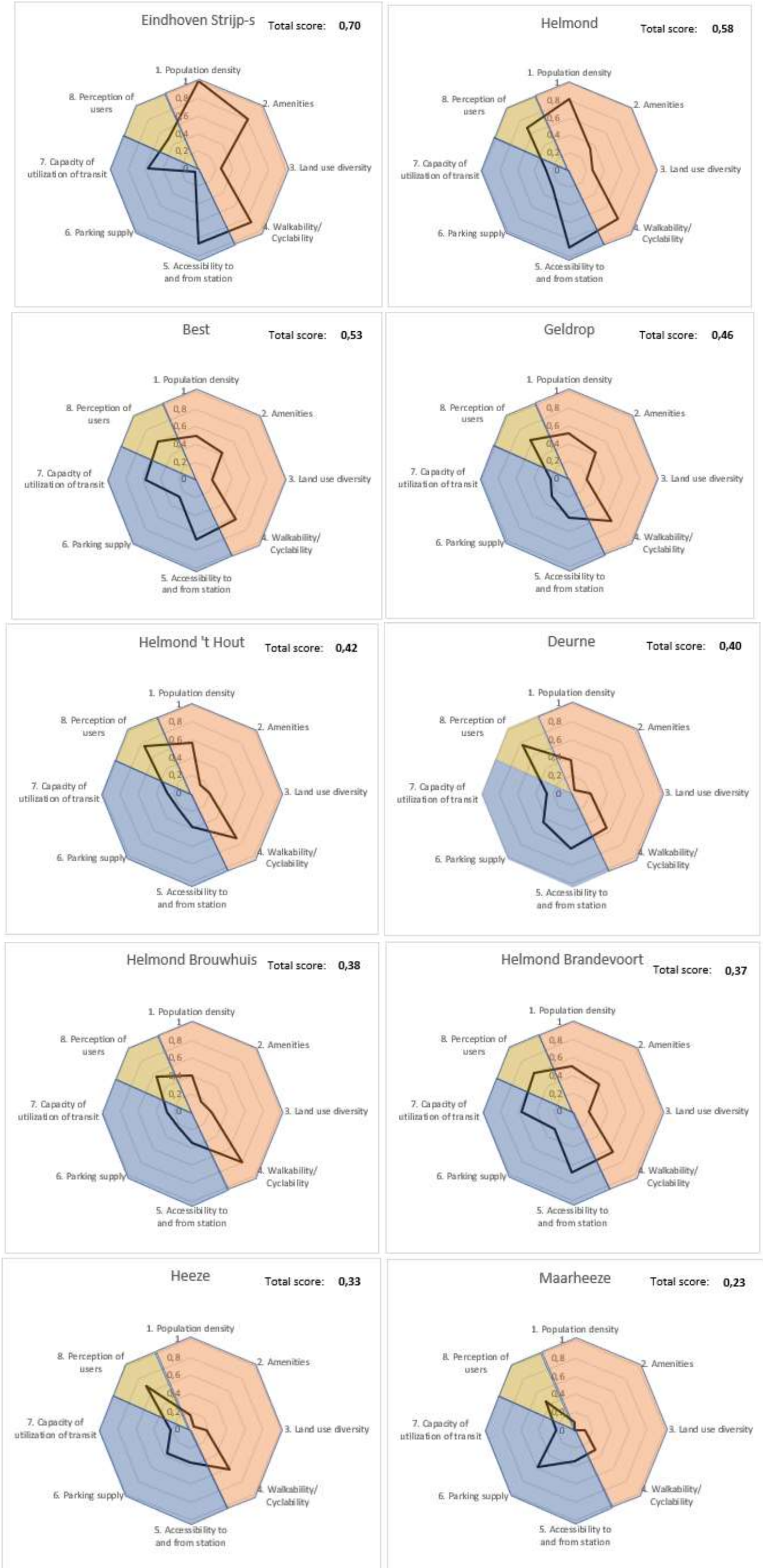


Figure 40: Scores per transit area presented in radar graphs

6.3.6 Recommendations for improvement

Based on the scores per criteria per TOD area, recommendations can be given as to where improvements can be made. This is done by checking each criterion at the transit areas. When the score of a criterion is below 0.5, it is considered to recommend for improvement for that criterion. To indicate the recommended improvements, symbols are used which are;

 Population density

 Amenities

 Land-use diversity

 Walkability/ Cyclability

 Accessibility to and from station

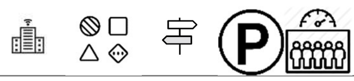
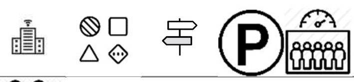
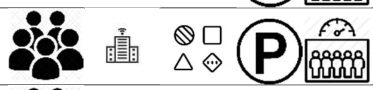
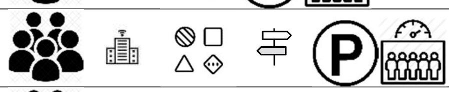
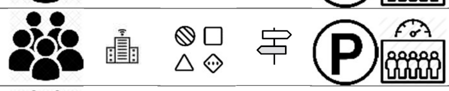
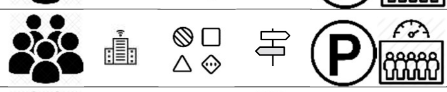
 Parking supply

 Capacity utilization of transit

 Perception of users.

Per TOD area, the recommendations for improvement are presented in table 9.

Table 9: Overall level of TOD-ness per transit area with recommendations for improvement

Transit area	TOD score	Recommended Improvements
Eindhoven Strijp-S	0.70	
Helmond	0.58	
Best	0.53	
Geldrop	0.46	
Helmond 't Hout	0.42	
Deurne	0.40	
Helmond Brouwhuis	0.38	
Helmond Brandevoort	0.37	
Heeze	0.33	
Maarheeze	0.23	

To explain table 9 for where improvements are recommended, an example is given for Deurne. This transit area has an overall TOD score of 0.40 and improvements are recommended for the criteria population density, amenities, land-use diversity, parking supply and capacity utilization.

Improving the level of TOD-ness of the transit area of Deurne, the scores of the criteria where improvements are recommended must be increased. The criterion population density in the transit area of Deurne has a score of 0.37. This could be increased by creating more residential buildings or by densifying the residential buildings which leads to a higher number of residents. The criterion amenities has a score of 0.05. This is based on the scores of the indicators that count the number of shops, cafes and restaurants and offices. In the transit area, there are 11 shops, 1 cafe or restaurant and no office buildings. By increasing the number of shops, cafes and restaurants and the number of offices, the score of the criterion amenities will be higher. Looking at the criterion land-use diversity, Deurne has a score of 0.21. This is because the surface of residential buildings compared to other land-uses is relatively high. This is in line with the score for the criterion amenities. By increasing the number of amenities, or other non-residential land-uses, the score for the criterion land-use diversity will also increase. Another improvement is recommended for the criterion parking supply, which has a score of 0.45. This is based on the indicators car parking supply and bicycle parking supply. Both indicators have a score of 0.45. Therefore, small increases on the number of parking places of both cars and bicycles make the score of the criterion parking supply sufficient. Lastly, recommendations for improvement are for the criterion capacity utilization which has a score of 0.27. This is based on the scores of the indicators capacity utilization during peak hours, capacity utilization during off-peak hours and the centrifugal/centripetal effect. Both indicators for the capacity utilization during peak hours and off-peak hours are acceptable with a respective score of 0.50 and 1.0. The score for the indicator centrifugal/centripetal effect is 0.34. This is because most people travel in the morning peak hour to region's main city Eindhoven and in the evening peak hour back to Deurne (which also explains the peak hour capacity utilization score of 0.5 where 2 of the 4 peaks are too crowded). By creating a more attractive transit area at Deurne for people to travel to or stay at, the centrifugal/ centripetal effect will decrease which leads to a higher score for the corresponding indicator and the criterion capacity utilization.

Overall, the transit areas around small stations in the region of Zuidoost-Brabant all have room for improvement. By looking at the individual transit areas and the corresponding criteria where improvements are recommended, higher levels of TOD-ness can be created. This leads to more attractive transit areas, more users of public transport and a more polycentric region. Per transit area improvements can be made, but also by checking criteria that have a more region-wide impact such as access to and from station and capacity utilization that are mostly affected by the public transport companies in the region. Therefore, the synergy between urban planning and mobility and the cooperation between the different stakeholders involved is crucial to maintain/ increase the economical position of the region Zuidoost-Brabant.

6.4 Conclusion

Based on a Multi-Criteria Analysis, a tool is created to measure the TOD-ness of TASS in the area of Zuidoost-Brabant. This tool consists of three values with eight criteria and 24 indicators to calculate the TOD-ness per transit area. These indicators measure the characteristics of the transit areas, the characteristics of the transit service and the perception of users. Per transit area, scores are given for criteria separately, that lead to a total score for the level of TOD-ness. The outcomes of the tool give an objective overview of the state of each transit area on TOD characteristics.

Looking at the results of the application of tool in the case study of Zuidoost-Brabant, the overall level of TOD-ness of the transit areas are presented in table 10.

Table 10: Overall level of TOD-ness per transit area

Transit area	Overall level of TOD-ness
Eindhoven Strijp-S	0.70
Helmond	0.58
Best	0.53
Geldrop	0.46
Helmond ‘t Hout	0.42
Deurne	0.40
Helmond Brouwhuis	0.38
Helmond Brandevoort	0.37
Heeze	0.33
Maarheeze	0.23

After the results, the model is checked on robustness by doing a sensitivity analysis. By changing the weight of each criteria with +0.05 and -0.05, where the other criteria are balanced equally, 16 different models are created. Looking at the overall level of TOD-ness of the transit area, each of the 16 models has the same order of the transit areas. Therefore, there can be concluded that the model is robust.

Lastly, transit area specific recommendations for improvement can be given to increase the level of TOD-ness. But, also region-wide improvements can be recommended. This leads to more attractive transit areas, more users of public transport and a more polycentric region. Synergy between urban planning and mobility and the cooperation between the different stakeholders involved is crucial to maintain/ increase the economical position of the region Zuidoost-Brabant.

7. Conclusion and Discussion

In this chapter, the conclusion and the discussion are addressed. In the conclusion, the overall findings of the research are reviewed. In the discussion, the scientific relevance, the social relevance, the research limitations and the recommendation for future research are described.

7.1 Conclusion

In this research, a tool is created to measure the TOD-ness of transit areas around small stations. With this tool, recommendations are given to the transit areas of the case study where improvements can be made to increase the use of public transport and the transit areas.

To answer the main research question *"How can transit areas around small stations be improved to increase the use of public transport by creating a tool to measure the level of TOD-ness?",* the sub-questions are answered following the structure of this research.

Literature study

From the results of the literature, it can be concluded that car usage in the Netherlands is a popular travel mode because of the ease, high utility and comfort that comes with it. For a more sustainable mobility by public transport, people have to change modes to access or egress the station of the public transport mode because the station is often not the starting point or end point of the journey. Adding more value to the journey of the users can be done in two ways; shorten the travel time and increase the experience of the low- valued parts of the journey such as transfer between modes, which is in line with the important factors safety, speed, convenience, comfort and experience around transit stops.

Because the land-use and mobility are strongly related, it is important that these are connected with each other. The approach of TOD connects the land-use with mobility. It is an integration of mixed land use and high density with walkability around transit nodes, which increases the access to public transportation, utilizes already serviced land rather than increasing urban sprawl, increasing transit ridership, reducing pollution, reduces consumption of oil and gas and contributes to a healthier lifestyle.

Many different ways to measure transit areas are found in the literature. Mostly by measuring the 5 D's density, diversity of land-use, design, distance to transit and destination accessibility and based on the node-place diagram. What is not found explicitly in the measurement methods is the perception of users, while it is proven to have a positive effect on the users and the use of transit areas. Therefore, a sixth "D" is added to assess and evaluate facilities in transit areas that influence the perception of users, which is the desirability of facilities. Answering the first sub-question *"How can a TOD be a stimulator for the use of public transport in small cities and villages?"*, focusing on these six D's at transit areas around small stations could stimulate people to make use of public transport and the transit area.

Most TOD studies are focused on large cities and/or large metropolitan areas with high population and activity density and high-capacity transport infrastructure, which makes them more interesting for policy makers and planners than TOD's in suburban regions. But, many problems in city centers originate from the areas around it. Therefore, the TOD approach in suburban regions can increase use of public transport and benefit a sustainable society.

To implement the TOD approach in areas with lower density, two things must change; the attitude of existing inhabitants and creating a daily urban system around the transit nodes. This ensures that the fervent car users change their behavior to use public transport and that the TOD will not be an island in a low-density environment.

To give answer to the second sub-question *"How can the level of TOD-ness of transit areas around small stations be measured?",* different studies are evaluated to find out how the level of TOD-ness can be measured. The evaluation method by Singh et al. (2017) regarding measuring the TOD-ness of transit areas is most similar to what has to be investigated in this research. Therefore, the tool created by Singh et al. (2017) is used as the basis for the TOD measurement tool for transit areas around small stations and will be adapted to create a measurement tool that is focused on transit areas around small stations.

The TOD measurement tool

The model of this research consists of a total of three values, eight criteria and 24 indicators to measure the TOD-ness of the ten small stations in the case area of Zuidoost-Brabant. Per indicator, a score is given between 1 and 0 which is calculated by using geographical data, data from other researches, documents from provinces and municipalities and by the public transportation providers in the area.

After collecting the data for the indicators, weights are given to the indicators within a criterion and for the criterion themselves. Based on the criteria and the weights, the total TOD-index score per transit area is given. Finally, per transit area, recommendations for improvements are given per criterion. An overview of the criteria, indicators and weights is given in figure 41 which gives answer to the third sub-question *"What does the TOD measurement tool include to evaluate transit areas around small stations?"*.

Figure 41: Overview of the TOD measurement tool for TASS

Results

The results of the TOD measurement tool for transit areas around small stations create an overview of the transit areas and how well they score according to each criterion. Based in the results, Eindhoven Strijp-S is the best scoring transit area, followed by Helmond and Best. The worst scoring transit area is Maarheeze. An overview is shown in figure 42, which gives answer to the fourth sub-*question "What is the state of the transit areas around small stations in the case study of Zuidoost-Brabant?*". Following the sensitivity analysis, the model is robust and the results are reliable.

By checking the relation between the level of TOD-ness and the number of daily uses, it is suggested that the level of TOD-ness has a weak positive influence on the number of daily users of the train stations.

Giving answer to the last sub-question *"What could be changed to increase the level of TOD-ness of the transit areas around small stations in the case study of Zuidoost-Brabant?"* there is room for improvement to increase the TOD-ness for each station/ transit area. The criteria that could be improved at most stations are Amenities, Land-use diversity, Accessibility to and from station, parking supply and capacity utilization of transit. By checking the indicators that calculate these criteria, recommendations can be given more specifically per transit area.

Overall, this research gives answer to the research question *“How can transit areas around small stations be improved to increase the use of public transport by creating a tool to measure the level of TOD-ness?”.* This TOD measurement tool focuses on transit areas around small stations and gives a clear and objective overview on how well the areas score on TOD-ness. Per transit area, specific recommendations for improvements can be given to create a more polycentric region. This tool is useable for any transit area around small stations in the Netherlands.

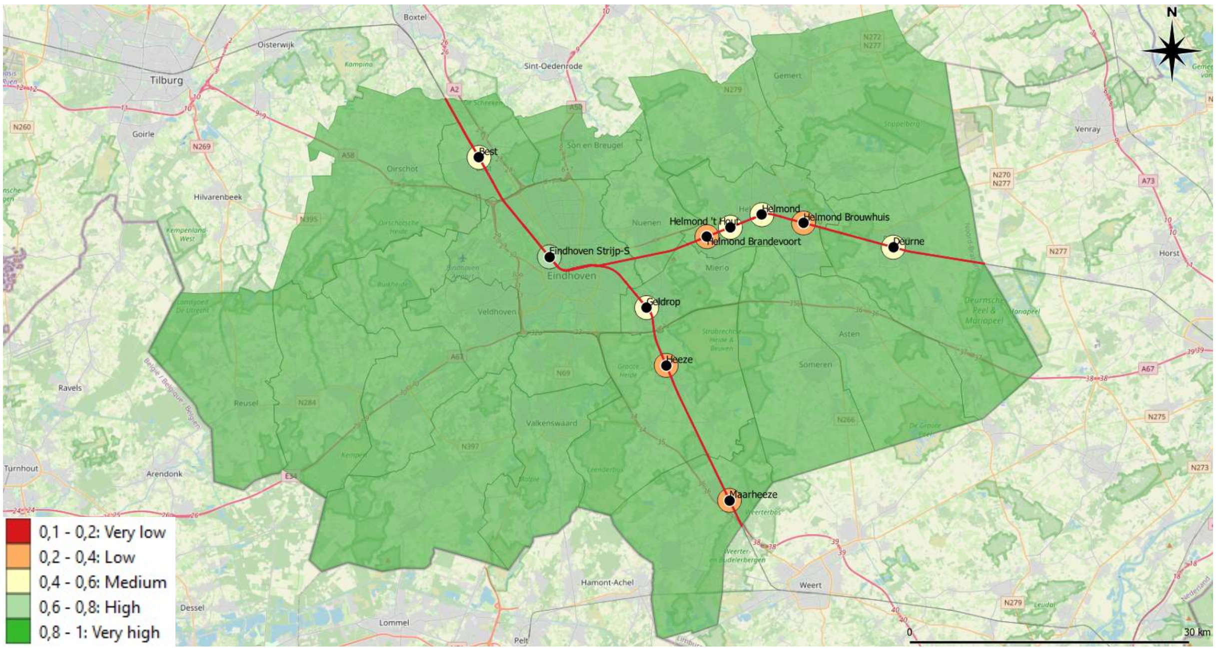


Figure 42: Overview of the overall level of TOD-ness of the transit areas in Zuidoost-Brabant

7.2 Discussion

Scientific relevance

In the literature, there is much discussion of the TOD approach and the benefits of increasing the TOD-ness of a transit area. But, this is mostly done in dense urban areas, because this is of greater interest for urban planners and policy makers compared to lower density areas (Sohoni et al., 2017). This research explains what is important to implement the TOD-approach in the lower density areas.

Also, the measurement tools found in the literature often focus on only the node values, place values or perception of users. Just a few measurement tools are found that measure all these values together. Therefore, the measurement tool of this research measures the node values, place values plus the perception of users together, which makes it a complete TOD measurement tool.

Finally, the measurement tools found in the literature mostly focus on TOD’s in dense urban areas or TOD’s in a larger region where no distinction is made between big stations and small stations. No measurement tool is found that only focus on transit areas around small stations. To fill this scientific gap, the measurement tool of this research focuses on only the transit areas around small stations, so that biased results are avoided.

Social relevance

With this research, a tool is created to evaluate transit areas around small stations. This tool can be used by for example urban planners and decision-makers of municipalities, provinces and advisory companies to get a clear overview on how well the TOD-ness is of a certain transit area and how to improve the level of TOD-ness. From the user's perspective, improvements of transit areas on TOD criteria could help to increase the sustainability of mobility by creating a more attractive area with high quality transit service. In this way, a daily urban system can be created around small train stations that enhances the polycentrism of a region and decreases the congestion problems in the city center.

Research limitations

The first group of limitations are related to the scope of the research. The scope of the research only focusses on transit areas around small stations in Zuidoost-Brabant. Because in this region there are just ten stations that are within the scope, no hard evidence of a statistical relation could be drawn from the results of the TOD-index with the number of users. It would be ideal to draw a relationship between the scores of the criteria and/or the total score of the TOD-index with the number of users per station, which could lead to a conclusion that the higher a score of a certain criteria, more users would be attracted to make use of the transit area.

The second group of limitations are related to the available data in the data collection. The data that is used in the data collection, is the most accurate data that is available. The used data from OSM is open source data, which may not be the most accurate data there is. Also, some data from institutions such as NS is not available publicly. Therefore, approximations of the actual data are made to create results of the indicators. With more accurate data, the evaluations of the transit areas become more reliable.

The third group of limitations are related to the perception of users. Prior to the start of this research, the goal was to link the presence of different facilities or amenities to the effect on the perception of users. But, after information from experts and the literature review it is found to be almost impossible to link this statistically. Within stations it is found that more facilities or amenities have positive effects on perceptions of users, but in a larger areas such as the transit areas it is difficult to draw these conclusions.

Another group of limitations, which is a continuation of the previously mentioned, is the inability to go to the transit areas/ train stations of the case study in Zuidoost-Brabant due to the worldwide COVID-19 pandemic. This limitation made it difficult to find out what facilities and amenities could lead to a positive or negative perception of users in a transit area by providing a survey to the users of these areas. Also, the users could be asked to rank the importance of the indicators or criteria in and around a transit area which could affect the determination of the weights. These weights are now based on the literature, information from experts and own insights. Finally, because of the limitation of not visiting the case areas within the timeframe of the research, a location research to check the transit areas in person was also not possible. This could give a better understanding of the transit areas and the train stations in the area.

Recommendations for future research

According to the results and the limitations of this research, there are some recommendations for future research. These recommendations are split in recommendations for Movares and recommendations for scientific purposes.

The first recommendation, for Movares, is to try to gather more accurate data for the data analysis. Now, some results of the indicators are based on approximations, while there is data available from different institutions that could give more precise results.

The second recommendation, for scientific purposes, is to execute further research with this tool for more transit areas around small stations. This will lead to more TOD-scores that could be linked to the number of users per station in the transit area. With more results from different TOD areas, statistical relations can be researched between the criteria and the number of users. This will give more insight in which criterion has a positive effect on the number of users.

The third recommendation, for scientific purposes, is to execute a more in depth research about what users find most important at the transit areas. This leads to a more accurate determination of the weights of the criteria and indicators in the MCA. What users find most important and what attracts them to make use of the transit areas and the public transportation can be asked by means of a survey to the users of the transit areas.

The fourth recommendation, for scientific purposes, is to determine more in depth which facilities/ amenities or characteristics of a transit area have a positive influence on the perception of users. This insight can also be asked by means of a survey to the users of the transit areas.

The last recommendation, for scientific purposes, is to execute further research on the tool's bandwidth. The tool in this research focusses on transit areas around small train stations, but this tool might also apply to transit areas around, for example, bus stations.

Bibliography

Antrop, M. (2004). Landscape change and the urbanization process in Europe. *Landscape and Urban Planning*, *67*, 9–26. https://doi.org/10.1016/S0169-2046(03)00026-4

Ausubel, & Marchetti. (2001). The evolution of transport. *Industrial Physicist*, *7*(2), 20.

Ausubel, Marchetti, & Meyer. (1998). Toward green mobility: the evolution of transport. *European Review*, *6*(2), 137–156. https://doi.org/10.1017/S1062798700003185

Balcombe, R., Mackett, R., Paulley, N., Preston, J., & Shires, J. (2004). The demand for public transport: a practical guide. *Transport Policy*, *13*, 295–306.

Balz, V., & Schrijnen, J. (2009). From concept to projects: Stedenbaan, The Netherlands. *Transit Oriented Development: Making It Happen*, *January 2009*, 75–90.

Bertolini, L. (1999). Spatial development patterns and public transport: The application of an analytical model in the Netherlands. *Planning Practice and Research*, *14*(2), 199–210. https://doi.org/10.1080/02697459915724

Bravo. (2020). *Lijnennetkaart 2020 Zuidoost-Brabant*. https://www.connexxion.nl/getmedia/8131f7f1-e26a-47f5-a60e-aa942aeec4ee/Lijnennetkaart_Hermes_ZuidoostBrabant_dec2019.pdf

Brouwer, I. (2011). *Fixing the link: Creating a strong, vital and attractive link between the Dutch central railway station and city centre*. 1–8.

Bruinsma, F., & Koomen, E. (2018). Ruimtelijke ordening in Nederland. *VU Amsterdam*.

Calthorpe, P. (1993). The Next American Metropolis: Ecology, Community, and the American Dream. *Princeton Architectural Press*, 175. https://doi.org/loc? not in merlin

CBS. (2018). *StatLine - Personenmobiliteit; vervoerwijzen en reismotieven, regio's, 2010-2017*. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83500NED/table?fromstatweb

CBS. (2020). *StatLine - Regionale kerncijfers Nederland*. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/70072NED/table?fromstatweb

Center for Transit-Oriented Development. (2007). *Planning for ToD at the regional Scale*. *https://ctod.org/pdfs/tod204.pdf*

Center for Transit-Oriented Development. (2009). *Why transit oriented development and why now?* https://doi.org/10.1080/01944369908976035

Cervero, R. (2004). *Transit-oriented Development in the United States: Experiences, Challenges, and* https://books.google.nl/books?id=a6__pNpM44MC&pg=PA13&lpg=PA13&dq=TOD+designations,+ofcourse,+are+quite+subjective:+one+person's+TOD+may+be+viewed+by+others+as+little+more+than+an+office+building+with+suburban+parking+ratios+that+happens+to+be+near+a+trai

Cervero, R., & Dai, D. (2014). *BRT TOD: Leveraging transit oriented development with bus rapid transit investments*. https://doi.org/10.1016/j.tranpol.2014.08.001

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

Cervero, R., & Murakami, J. (2008). Rail + Property Development. *UR Berkeley*. https://doi.org/10.11436/mssj.15.250

Cervero, R., & Murakami, J. (2009). Rail and property development in Hong Kong: Experiences and extensions. *Urban Studies*, *46*(10), 2019–2043. https://doi.org/10.1177/0042098009339431

Chorus, P., & Bertolini, L. (2016). Developing transit-oriented corridors: insights from Tokyo. *International Journal of Sustainable Transportation*, *10*(2), 86. https://doi.org/10.1080/15568318.2013.855850

College van Rijksadviseurs. (2017). *Ontwerpen aan een rijker , hechter en schoner Nederland*. https://www.goudenpiramide.nl/clientdata/downloads/cra-agenda-jaarprogramma-a4digital-170508-282-29.pdf

College van Rijksadviseurs. (2018). *Dashboard Verstedelijking*. https://www.collegevanrijksadviseurs.nl/projecten/dashboard-verstedelijking

Curtis, C. (2008). *Evolution of the Transit-oriented Development Model for Low-density Cities: A Case Study of Perth's New Railway Corridor*. https://doi.org/10.1080/02697450802423559

Curtis, C. (2012). *Transitioning to Transit-Oriented Development: The Case of Perth, Western Australia, Urban Policy and Research*. *30*(3), 275–292. https://doi.org/10.1080/08111146.2012.665364

de Boer, J., & Kooijmans, J. W. (2007). *Vijftig jaar rijksbeleid voor Randstad Holland*. *4*(40). http://archief.rooilijn.nl/download?type=document&identifier=630504

De Vos, J., Van Acker, V., & Witlox, F. (2014). The influence of attitudes on Transit-Oriented Development: an explorative analysis. *Transport Policy*, *35*, 326–329.

Delgado, M. G., & Sendra, J. B. (2004). Sensitivity analysis in multicriteria spatial decision-making: A review. *Human and Ecological Risk Assessment*, *10*(6), 1173–1187. https://doi.org/10.1080/10807030490887221

Directoraat-generaal Rijkswaterstaat. (2001). Wegen naar de Toekomst. *University of Maastricht*, 1–96.

Duffhues, J., Mayer, I. S., Nefs, M., & Van Der Vliet, M. (2014). Breaking barriers to Transit-Oriented development: Insights from the serious game SPRINTCITY. *Environment and Planning B: Planning and Design*, *41*(5), 770–791. https://doi.org/10.1068/b39130

Eldering, P. (2019). Make-over voor 200 treinstations. *Telegraaf*. https://www.telegraaf.nl/nieuws/3218852/make-over-voor-200-treinstations

Evers, D. (2018). Dutch National Spatial Planning in transition. *PBL Netherlands Environmental*, *September*, 1–78.

Filarski, R. (2004). *The rise and decline of transport systems. Changes in a historical context*. 1–100.

Gomez, C. P., Omar, M., & Nallusamy, R. (2019). A Study on the Benefits of Transit Oriented Development in Malaysia And Incoporation of Those Benefits in Planning. *MATEC Web of Conferences*, *266*, 06016. https://doi.org/10.1051/matecconf/201926606016

Guerra, E., Cervero, R., & Tischler, D. (2012). Half-Mile Circle: Does It Best Represent Transit Station Catchments? *Transportation Research Record: Journal of the Transportation Research Board*, *2276*(1), 101–109. https://doi.org/10.11436/mssj.15.250

Herzberg, F., Mausner, B., & Snyderman, B. B. (1959). *The Motivation to Work*. https://books.google.nl/books?redir_esc=y&hl=nl&id=KYhB-B6kfSMC&q=dissatisfier#v=snippet&q=dissatisfier&f=false

High Tech Campus. (2020). *High Tech Campus Eindhoven: Who We Are*. https://www.hightechcampus.com/who-we-are

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2014). Advance transit oriented development typology: Case study in brisbane, australia. *Journal of Transport Geography*, *34*, 54–70. https://doi.org/10.1016/j.jtrangeo.2013.11.002

Kennisinstituut voor Mobiliteit. (2019). *Mobiliteitsbeeld 2019 | Mobiliteitsbeeld en Kerncijfers Mobiliteit*. https://www.kimnet.nl/mobiliteitsbeeld/mobiliteitsbeeld-2019#/rapport/1.1

Knowles, R. D. (2012). Transit Oriented Development in Copenhagen, Denmark: from the Finger Plan to Ørestad. *Journal of Transport Geography*, *22*, 251–261. https://doi.org/10.1016/j.jtrangeo.2012.01.009

Loo, B. P. Y., Chen, C., & Chan, E. T. H. (2010). Rail-based transit-oriented development: Lessons from New York City and Hong Kong. *Landscape and Urban Planning*, *97*, 202–212. https://doi.org/10.1016/j.landurbplan.2010.06.002

MacDonald, J. M., Stokes, R. J., Cohen, D. A., Kofner, A., & Ridgeway, G. K. (2010). The effect of light rail transit on body mass index and physical activity. *American Journal of Preventive Medicine*, *39*(2), 105–112. https://doi.org/10.1016/j.amepre.2010.03.016

Marchetti, C. (1994). Anthropological Invariants in Travel Behavior. *Technological Forecast and Social Change*, *47*, 75–88.

Metropoolregio Eindhoven. (2016). *Aanbod Bereikbaarheidsakkoord*. 1–38. https://www.smartwayz.nl/media/1053/aanbod-bereikbaarheidsakkoord-zuidoost-brabant.pdf

Metropoolregio Eindhoven. (2020a). *Een beter bereikbare regio*. https://metropoolregioeindhoven.nl/thema-s/mobiliteit

Metropoolregio Eindhoven. (2020b). *Programmabegroting 2020*. http://metropoolregioeindhoven.nl/

Metropoolregio Rotterdam- Den Haag. (2019). *Gemeenten | Metropoolregio Rotterdam Den Haag*. https://mrdh.nl/gemeenten

Ministerie van Infrastructuur en Waterstaat. (2019a). *Contouren Toekomstbeeld OV 2040*. *https://www.rijksoverheid.nl/documenten/rapporten/2019/02/06/contouren-toekomstbeeld-ov-2040*

Ministerie van Infrastructuur en Waterstaat. (2019b). *Mobiliteitsbeeld 2019*. https://www.kimnet.nl/publicaties/%0Ahttps://www.kimnet.nl/publicaties/rapporten/2019/11/12/mobiliteitsbeeld-2019-vooral-het-gebruik-van-de-trein-neemt-toe

Ministry of Infrastructure and the Environment. (2012). Samenvatting Structuur-visie - Infra-structuur en Ruimte. *Den Haag*. *https://www.rijksoverheid.nl/documenten/rapporten/2012/03/13/samenvatting-structuurvisie-infrastructuur-en-ruimte*

Movares Nederland B.V. (2019a). *Monitor gebruikte kentallen Sprinterfrequentie Zuidoost-Brabant*.

Movares Nederland B.V. (2019b). *Ruimte voor sprinters in zuidoost brabant*.

Municipality of Amsterdam. (2019). *Metropoolregio Amsterdam in cijfers 2019*. *https://data.amsterdam.nl/publicaties/publicatie/metropoolregio-amsterdam-in-cijfers-2019/d04804fa-4474-4141-bc67-71c34f3df3c5/*

Nigro, A., Bertolini, L., & Moccia, F. D. (2019). Land use and public transport integration in small cities and towns: Assessment methodology and application. *Journal of Transport Geography*, *74*(February 2018), 110–124. https://doi.org/10.1016/j.jtrangeo.2018.11.004

NS. (2019a). *In- en Uitstappers per station bij NS*. NS. https://doi.org/10.1017/CBO9781107415324.004

NS. (2019b). *meer Sprinters Brabant Nut en Noodzaak 20mei19*.

NS. (2020). *Spoorkaart 2020*. https://nieuws.ns.nl/spoorkaart-2020-hier-te-downloaden/

NS & StudioSK. (2010). *leefbaarheidscan - omgevingsdomein*.

NS Poort & Asset Development. (2011). *visie op het Omgevingsdomein*. 1–24. *https://issuu.com/bureauspoorbouwmeester/docs/20120625_visie_omgevingsdomein*

NS Productmanagement. (2002). *Typisch NS Elk station zijn eigen rol*. *https://www.cvs-congres.nl/cvspdfdocs/cvs02_40.pdf*

Ory, D. T., Mokhtarian, P. L., Redmond, L. S., Salomon, I., Collantes, G. O., & Choo, S. (2004). When is commuting desirable to the individual? *Growth and Change*, *35*(3), 334–359. https://doi.org/10.1111/j.1468-2257.2004.00252.x

Peek, G.-J. (2006). *Locatiesynergie. december. https://repository.tudelft.nl/islandora/object/uuid%3Afe2c8782-f31e-4183-b1a7-66d7e177e24e*

ProRail. (2018). *Netverklaring 2020*. https://www.prorail.nl/sites/default/files/netverklaring_2020_versie_1.0.pdf

Provincie Noord-Brabant. (2012). *Brabantse Spooragenda 2030*. *https://www.brabant.nl/-/media/7a6c903a60d643598d1f1dc1168f6a74.pdf*

Provincie Noord-Brabant. (2018). *Bereikbaar en Concurrerend Brabant. Knooppuntenboek Brabant.*

Provincie Noord-Holland, & Vereniging Deltametropool. (2013). *Maak Plaats! https://www.noord-holland.nl/Onderwerpen/Ruimtelijke_inrichting/Projecten/OV_Knooppunten/Voor_samenwerkingspartners*

Renne, J. L. (2009). From transit-adjacent to transit-oriented development. *Local Environment*, *14*(1), 1–15. https://doi.org/10.1080/13549830802522376

Ritsema Van Eck, J., & Koomen, E. (2008). Characterising urban concentration and land-use diversity in simulations of future land use. *Ann Reg Sci*, *42*, 123–140. https://doi.org/10.1007/s00168-007-0141-7

Schlossberg, M., & Brown, N. (2004). Comparing transit-oriented development sites by walkability indicators. *Transportation Research Record*, *1887*, 34–42. https://doi.org/10.3141/1887-05

Schwanen, T., & Mokhtarian, P. L. (2005). What affects commute mode choice: Neighborhood physical structure or preferences toward neighborhoods? *Journal of Transport Geography*, *13*(1 SPEC. ISS.), 83–99. https://doi.org/10.1016/j.jtrangeo.2004.11.001

Simkens, B. (2020). *Experiencing station locations*. Technische Universiteit Delft.

Singh, Y. J. (2015). *MEASURING TRANSIT-ORIENTED DEVELOPMENT (TOD) AT REGIONAL AND LOCAL SCALES – A PLANNING SUPPORT* [Technische Universiteit Twente]. https://webapps.itc.utwente.nl/librarywww/papers_2015/phd/singh.pdf

Singh, Y. J., Lukman, A., Flacke, J., Zuidgeest, M., & Van Maarseveen, M. F. A. M. (2017). Measuring TOD around transit nodes - Towards TOD policy. *Transport Policy*, *56*(February), 96–111. https://doi.org/10.1016/j.tranpol.2017.03.013

Sohoni, A. V., Thomas, M., & Rao, K. V. K. (2017). Application of the concept of transit oriented development to a suburban neighborhood. *Transportation Research Procedia*, *25*, 3220–3232. https://doi.org/10.1016/j.trpro.2017.05.135

Sutton, P. C. (2003). A scale-adjusted measure of “Urban Sprawl” using nighttime satellite imagery. *Remote Sensing of Environment*, *86*(3), 353–369. https://doi.org/10.1016/S0034-4257(03)00078-6

Tan, W., Koster, H., & Hoogerbrugge, M. (2013). *Knooppunt- ontwikkeling in Nederland*. Universiteit van Amsterdam - VU Amsterdam.

TCRP. (1996). Transit and Urban Form. *Transit Cooperative Research Program*, *2*(3), 1–57. *http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_16-3.pdf*

The Guardian. (2016). *The curse of urban sprawl: how cities grow, and why this has to change*. https://www.theguardian.com/cities/2016/jul/12/urban-sprawl-how-cities-grow-change-sustainability-urban-age

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography*, *45*, 70–80. https://doi.org/10.1016/j.jtrangeo.2015.04.009

Van Aalst, J (2010). Zuidoost-Brabant basisbeeld. Janwillemvanaalst / CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0) *https://commons.wikimedia.org/wiki/File:2010-R22-Zuidoost-Brabant-basisbeeld.jpg*

Van Hagen, M. (2011). Waiting experience at train stations. *University of Twente*. *https://ris.utwente.nl/ws/portalfiles/portal/6066520/thesis_M_van_Hagen.pdf*

van Hagen, M., & Exel, M. (2012). De reiziger centraal. *Spoorbeeld Bureau Spoorbouwmeester*. *https://www.spoorbeeld.nl/sites/default/files/issuu/BSM-20130117-website%20inspiratie-essay_De%20reiziger%20centraal.pdf*

van Wee, B., Rietveld, P., & Meurs, H. (2006). Is average daily travel time expenditure constant? In search of explanations for an increase in average travel time. *Journal of Transport Geography*, *14*(2), 109–122. https://doi.org/10.1016/j.jtrangeo.2005.06.003

Wegener, M., & Fuerst, F. (1999). Land-Use Transport Interaction: State of the Art. *SSRN Electronic Journal*, *November 2017*. https://doi.org/10.2139/ssrn.1434678

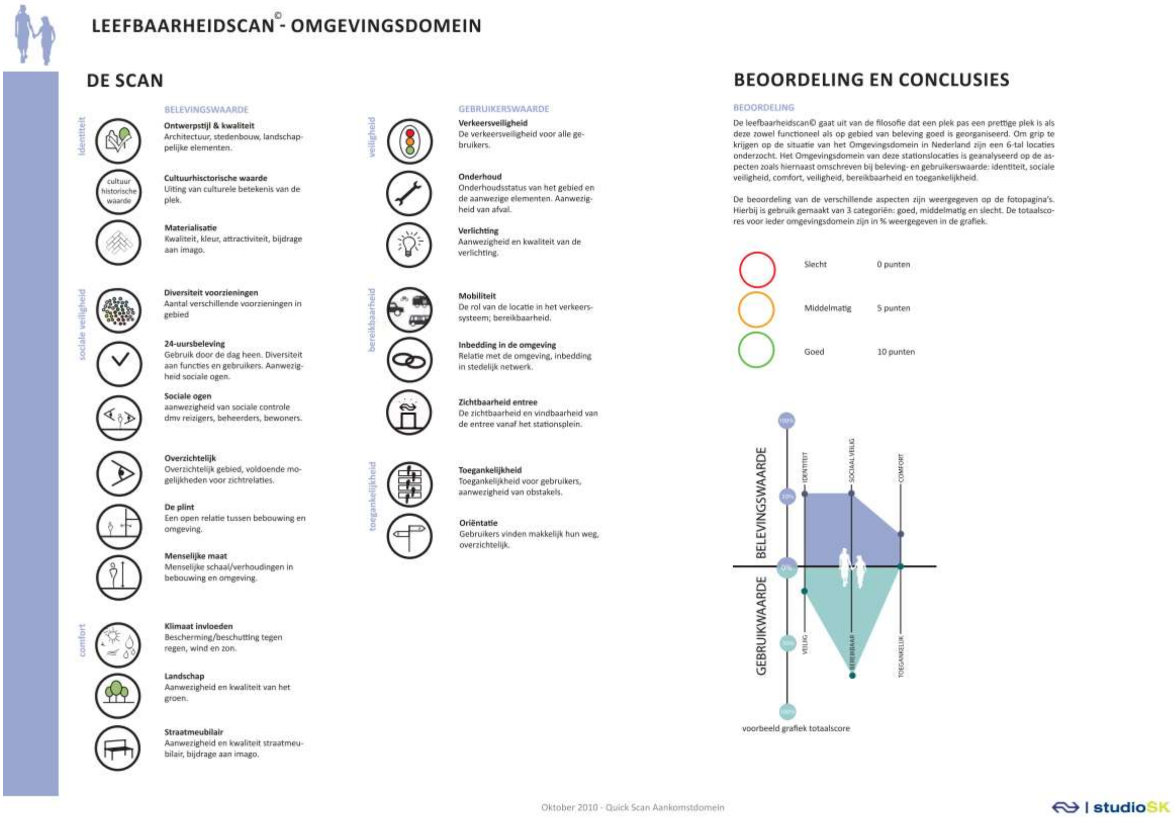
Yang, P. P. J., & Lew, S. H. (2009). An Asian model of TOD: The planning integration in Singapore. *Transit Oriented Development: Making It Happen*, *July*, 91–106.

Zhang, Y., & Guindon, B. (2006). Using satellite remote sensing to survey transport-related urban sustainability. Part 1: Methodologies for indicator quantification. *International Journal of Applied Earth Observation and Geoinformation*, *8*(3), 149–164. https://doi.org/10.1016/j.jag.2005.08.005

Appendices

Appendix I: Measurements of transit areas

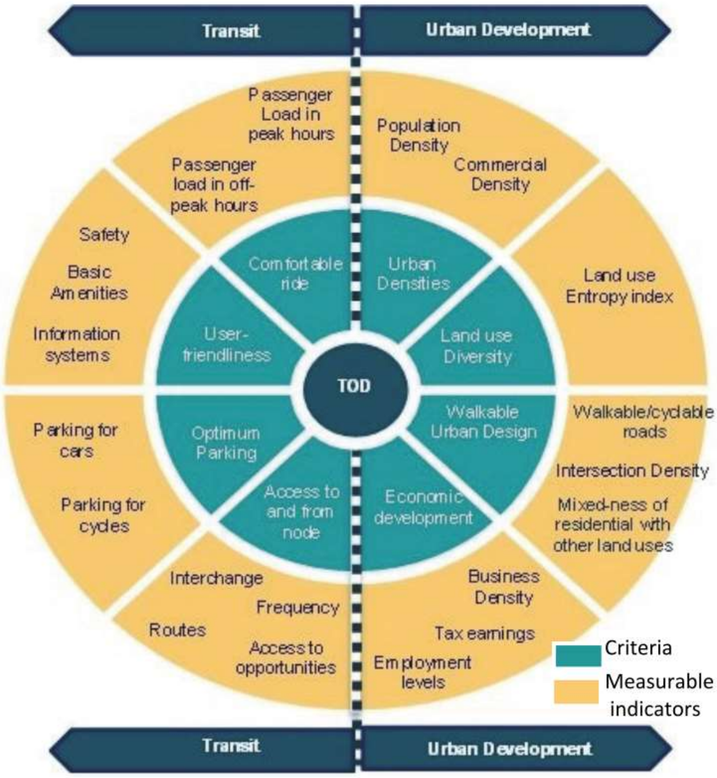
I.I: Criteria of the Quick scan of transit areas, focused on the perception of the surroundings (NS & StudioSK, 2010)



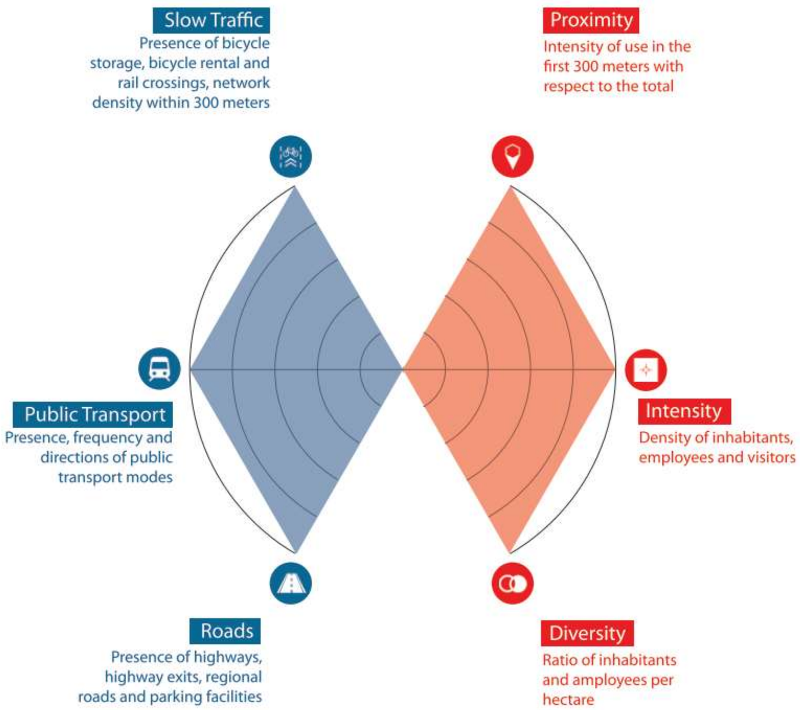
I.II: Criteria for a successful public space (Brouwer, 2011)

1. Liveliness
   a. Mixed Use;
   b. Use along the Day;
   c. Creating an Atmosphere of Watching and Being Watched;
2. Human Scale
   a. Permeability;
   b. Fine Grained Building Blocks;
   c. Walkability;
3. Legibility
   a. Orientation;
   b. Linearity of the Path;
   c. Clarity of the Maps and Signage;
4. Safety & Comfort
   a. Pedestrian Priority;
   b. Eyes on the Street;
   c. Maintenance.

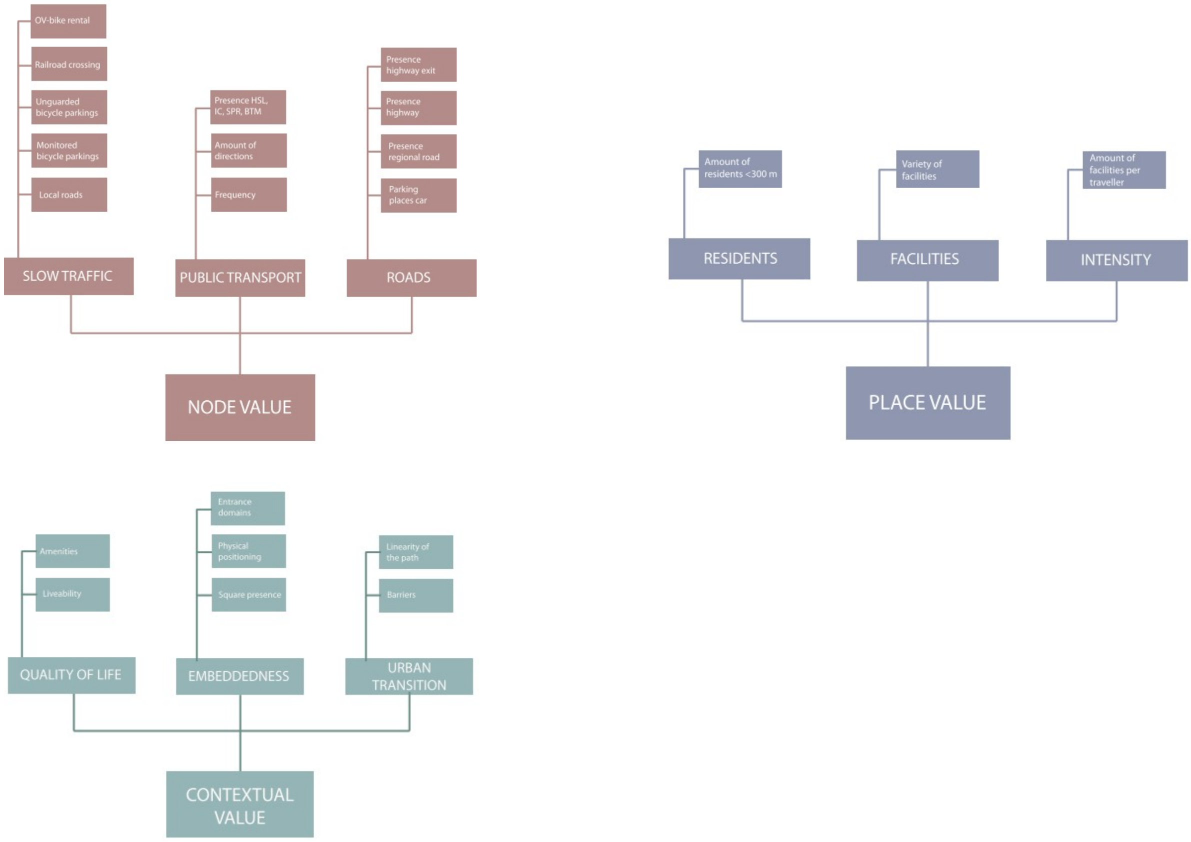
I.III: Criteria and measurable indicators to measure transit areas on the level of TOD-ness (Singh, 2015)



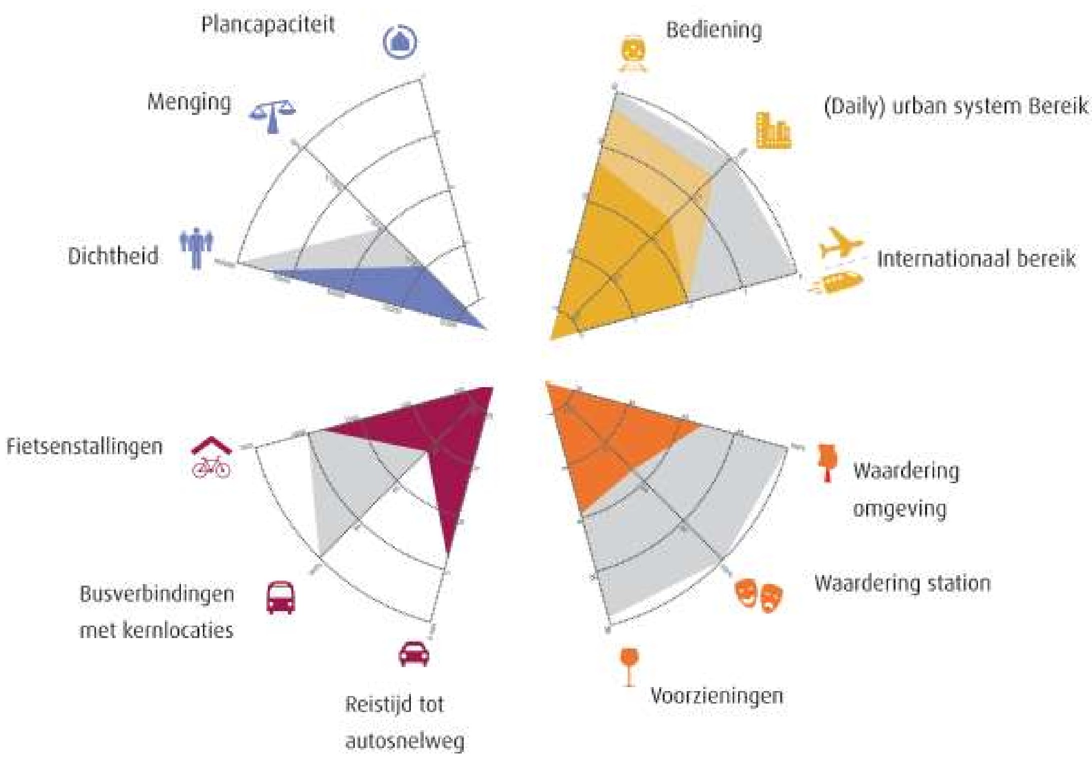
I.IV: Butterfly model to test the transit areas in the province of Noord-Holland (Provincie Noord-Holland & Vereniging Deltametropool, 2013)



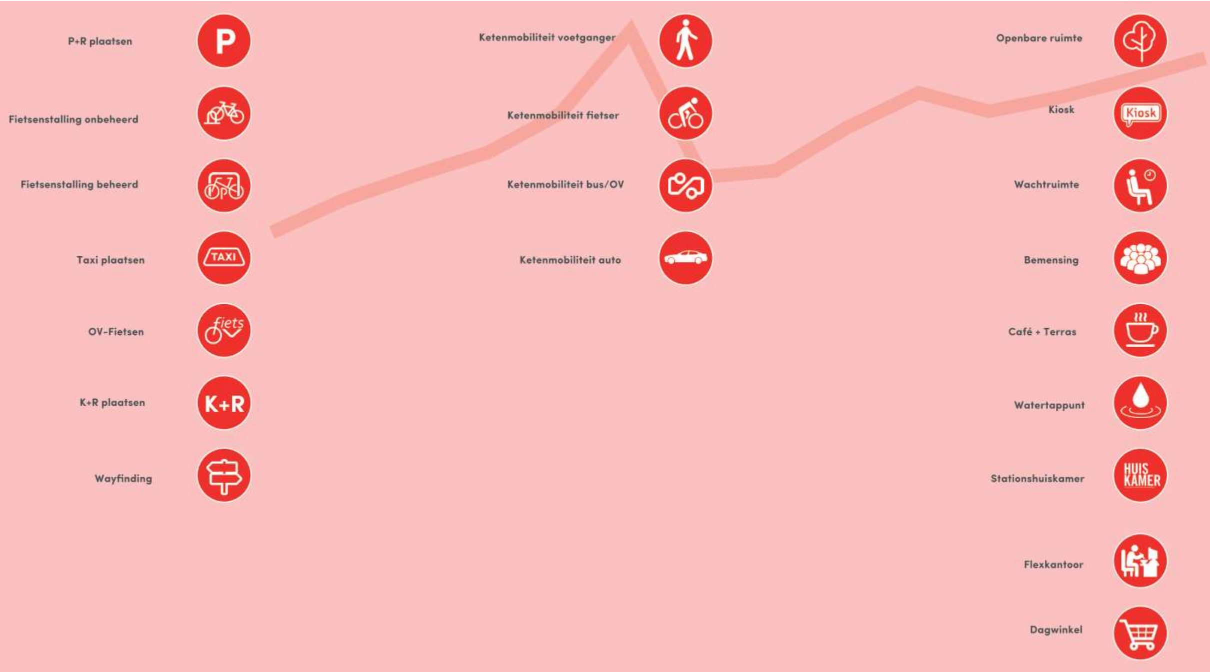
I.V: The three values with accompanying criteria to test the experience at station locations (Simkens, 2020)



I.VI: The four quadrants of the node research in Noord-Brabant (Provincie Noord-Brabant, 2018)

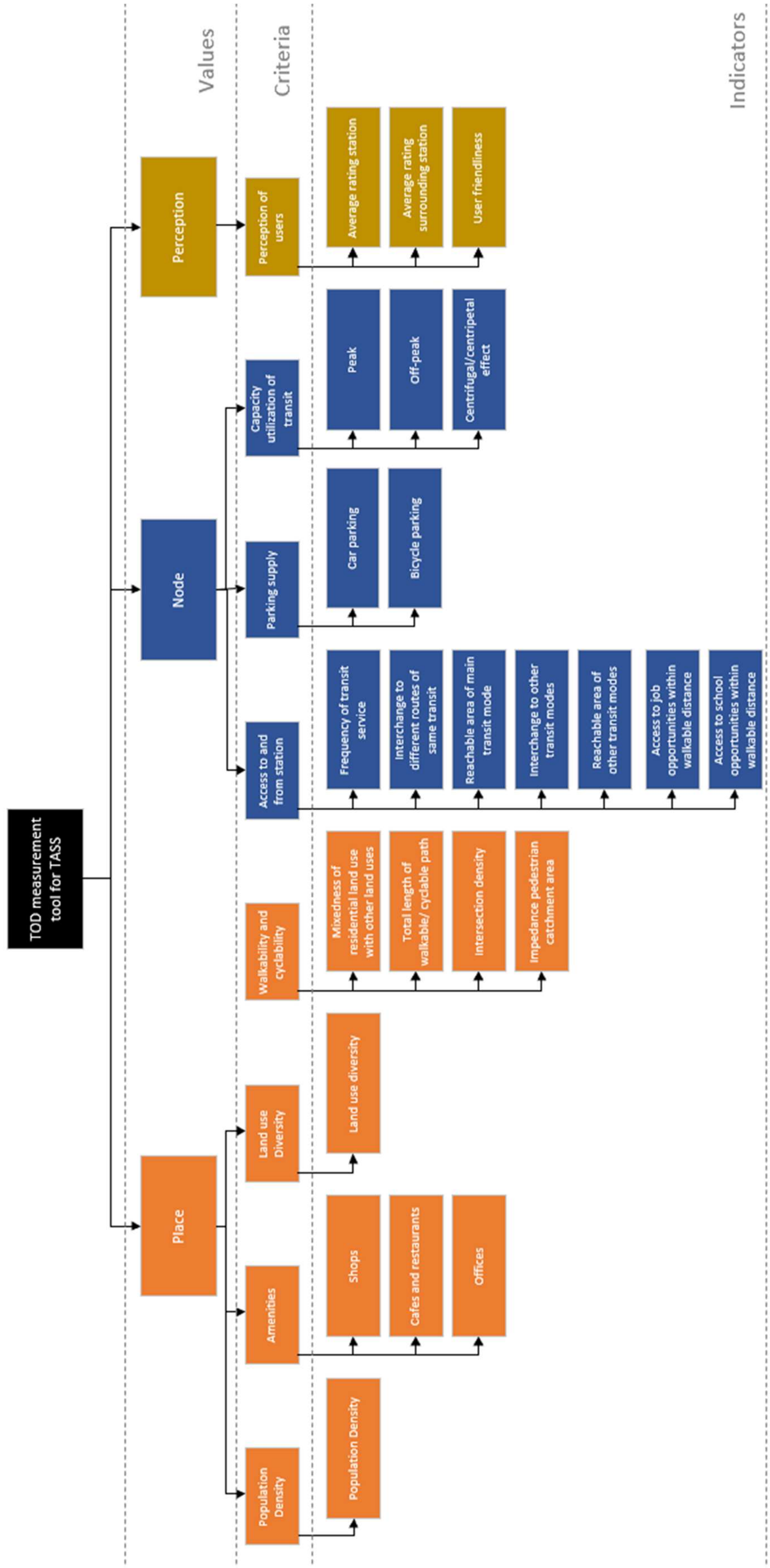


I.VII: The node criteria (left and middle column) and criteria for the perception of users (left column) of the Sprinter frequency research in Zuidoost-Brabant (Movares Nederland B.V., 2019b)



- Place-values (not in the figure)
  - Forecast of production (residents and extra travelers)
  - Forecast of attraction (job facilities, school facilities and extra travelers)
- Node-values
  - P+R places
  - Bicycle parking
  - Taxi stands
  - OV-bikes
  - K+R places
  - Way findings
  - Mobility options pedestrians, cyclists, public transport and cars
- Values for the perception of users
  - Public spaces
  - Kiosks
  - Waiting room
  - Crowdedness
  - Cafes and terraces
  - Water taps
  - Station living room
  - Flex office
  - Daily shop

Appendix II: Conceptual model



Appendix III: Summaries of the information provided by experts of NS

- **Product manager NS -**

The province and the metropolitan region were enthusiastic about the increase of the Sprinter frequency in the area, but the municipalities were less positive. Except for the municipality of Eindhoven, who wanted to invest in the plan.

From the perspective of NS to the increase of Sprinter frequency in Zuidoost-Brabant, the that came up was if it is useful or if it is necessary to increase the number of Sprintertrains in the area. Because the NS does not want to "transport air" with empty trains, the capacity of the trains is reviewed. The NS states that the trains of the current rail program have to be maximize their capacity before extra trains are being used. Besides that, the length of the trains can be extended with extra cars. Also, the NS states that, because of the centrifugal and centripetal effect to and from large cities, the ideal situation is that the transit areas around small stations first investigate in increasing the attractiveness with e.g. amenities. This makes the distribution of the passenger loads better and ensures that less "air" is transported.

- **Expert in travelers' waiting experience in and around train stations, principal consultant NS -**

Focusing on the experience of users of train stations, the Maslow pyramid is very important. the factors in the pyramid can be split in Must and Lust; the must of traveling fast and the lust to travel "relaxed" (see figure i). When the travel time increases, there is more time left for leisure activities in and around stations. For example for shopping or reading.

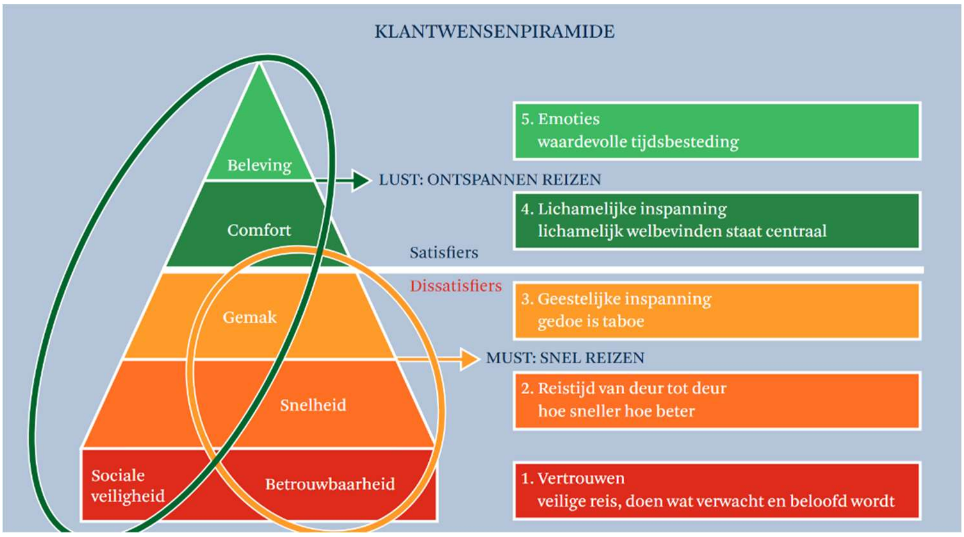


Figure I: User's preferences Maslow pyramid (NS, 2020)

The NS nowadays works with the "four W's"; Wifi, Warm drinks, WC's and Wait at a warm place. This is because waiting time feels three times longer if the waiting is boring, even if the train is fast. Small stations try to cope with these "four W's" by creating a "living room", which ensures a pleasant waiting time.

Measuring the perception of users in and around stations is stated to be very difficult. There is a surveys by NS that measures different aspects of user experience, the "station experience monitor". What stands out in these surveys, is that an increased atmosphere around stations increases the purchasing behavior of users. Also the color, and other environmental stimuli, around stations has a subconscious effect on users. What is also important for the perception of users around train stations, is the integration with the surroundings. An attractive train station in an unfavorable surrounding, and the other way around, does not work positively on the perception of users.

From the user's perspective, the base of the Maslow pyramid is important, but expensive to enhance. The top of the pyramid is relatively cheap to enhance, which could have a lot of impact. A smart integration of "social eyes" could have a big impact. But, this integration of a something in the top of the pyramid has to be congruent with the environment. Especially in the top of the pyramid, the possibilities are endless.

- **Controller of the Station Experience Monitor, Market researcher NS -**

The Station Experience Monitor is used for every train station in the Netherlands, 400 stations in total. This monitor is tested four times a year at stations with more than 5000 users per day and one of two times a year for stations with less users. The benchmark of 7.0 or higher is used. This is done because users that rate the overall score of stations with a 7 or higher are more loyal, while uses that rate the overall score of a station with a score lower than 7 are more uncaring.

In the Station Experience Monitor, seven themes are investigated following the Maslow pyramid; safety, cleanliness, orientation, travel flow, waiting experience, attractiveness and atmosphere.

For the measurement of the waiting experience is done by three statements; I experience sufficient shelter (actually dissatisfier), I can spend time pleasantly and I experience the waiting as comfortable. For measurement of the perception of the surrounding of stations is done by two statements; I can easily get to the station and I experience the direct surroundings as pleasant. What turns out to be most attractive at stations and where NS focusses on are shops at big stations and user friendliness/ information availability for small stations.

Unfortunately, the data cannot be shared because it is private information of the NS, but luckily some information is provided in table i. Here the percentages of the ratings with a mark of 7,0 or higher, the average mark of the station and the rating of the station surrounding versus the benchmark is shown.

Table I: Provided information of the Station Experience Monitor (NS, 2020)

	Rating stations % 7 en >	Rating stations average mark	Rating station surrounding versus benchmark
Best	73,9%	7,0	Equal
Deurne	80,9%	7,2	Higher
Eindhoven Strijp-S	53,7%	6,5	Equal
Geldrop	72,1%	6,9	Slightly higher
Heeze	74,0%	7,1	Much higher
Helmond	84,0%	7,4	Equal
Helmond 't Hout	73,3%	7,0	Much higher
Helmond Brandevoort	80,4%	7,3	Much higher
Helmond Brouwhuis	47,9%	6,3	Slightly lower
Maarheeze	75,6%	7,1	Slightly lower

Appendix IV: Indicator calculations of the TOD measurement tool

In this appendix, an overview of all Excel-sheets of the TOD measurement tool are shown for TASS is shown. Here, a description of the calculations and the tables that are used to calculate the values of the indicators are present.

Explanation

These numbers are extracted from CBS data 100x100m population count. The polygons are transformed into points and the information is counted within the 2200 m buffer around stations. The number of residents within the buffers is divided through the area size. Last, the scores are transformed into a scale between 1 and 0. (Eindhoven Centraal in the picture is used as reference and is not used in the research)

Density Inhabitants

Calculations resident density	Number of residents	Area m2	Area km2	Density	scale 1-0
Best	27895	15195	15,195	1835,8	**0,50**
Deurne	20890	15195	15,195	1374,8	**0,37**
Eindhoven Strijp-s	41795	11385	11,385	3671,1	**1,00**
Geldrop	28210	15012	15,012	1879,2	**0,51**
Heeze	9245	15012	15,012	615,8	**0,17**
Helmond	31555	10541	10,541	2993,5	**0,82**
Helmond 't Hout	17405	8389	8,389	2074,7	**0,57**
Helmond Brandevoort	9235	11218	11,218	823,2	**0,22**
Helmond Brouwhuis	19660	13369	13,369	1470,6	**0,40**
Maarheeze	5155	15195	15,195	339,3	**0,09**
	MIN	0,0			
	MAX	3671,1			
	$(V - \min V)/(\max V - \min V)$				

Explanation

The number of shops is extracted from open street map and counted within the buffer of 800m around the stations. After that, the scores are transformed into a value between 1 and 0. This information was available in points.

Shops count

	number of shops	scale 1-0
Best	77	**1,00**
Deurne	11	**0,14**
Eindhoven Strijp-s	26	**0,34**
Geldrop	37	**0,48**
Heeze	2	**0,03**
Helmond	33	**0,43**
Helmond 't Hout	21	**0,27**
Helmond Brandevoort	16	**0,21**
Helmond Brouwhuis	9	**0,12**
Maarheeze	0	**0,00**
MIN	0	
MAX	77	
$(V - \min V)/(\max V - \min V)$		

Explanation

from open street map and counted within the buffer of 800m around the stations. After that, the scores are transformed into a value between 1 and 0. This information was available in points.

PCRB count

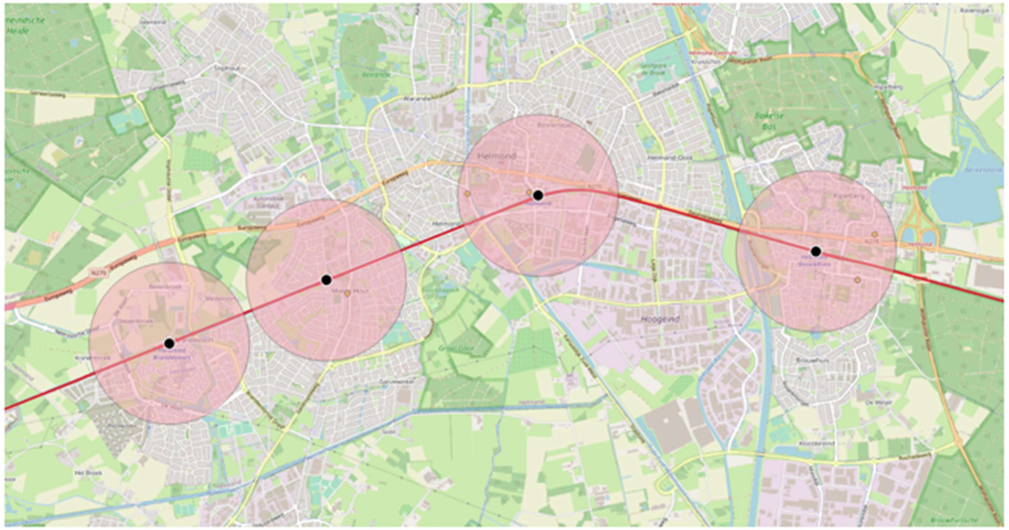
	Number of pubs/cafe's/restaurants and bars	scale 1-0
Best	12	**0,43**
Deurne	1	**0,04**
Eindhoven Strijp-s	28	**1,00**
Geldrop	17	**0,61**
Heeze	0	**0,00**
Helmond	19	**0,68**
Helmond 't Hout	2	**0,07**
Helmond Brandevoort	4	**0,14**
Helmond Brouwhuis	1	**0,04**
Maarheeze	0	**0,00**
MIN	0	
MAX	28	
$(V - \min V)/(\max V - \min V)$		

Explanation

The number of offices is extracted from open street map and counted within the buffer of 800m around the stations. After that, the scores are transformed into a value between 1 and 0. This information was available in points.

Offices count

	Number of offices	scale 1-0
Best	1	**0,08**
Deurne	0	**0,00**
Eindhoven Strijp-s	13	**1,00**
Geldrop	4	**0,31**
Heeze	1	**0,08**
Helmond	2	**0,15**
Helmond 't Hout	1	**0,08**
Helmond Brandevoort	0	**0,00**
Helmond Brouwhuis	3	**0,23**
Maarheeze	0	**0,00**
MIN	0	
MAX	13	
$(V - \min V)/(\max V - \min V)$		



Explanation

The land use mix is calculated by measuring the area of different land uses that are available in open street maps. This information is available in polygons. By using the entropy method, the land use mix is calculated. For now, the area of the buffer is used and not the total area of the buildings. This is counted in the buffers of 800m.

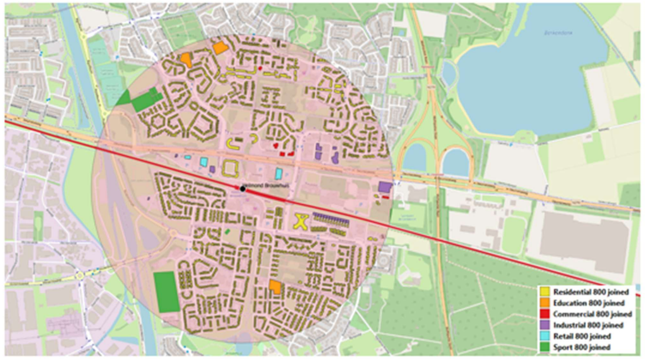
Formula

$$LU_d(i) = \frac{-\sum Q_{lu_i} \times \ln(Q_{lu_i})}{\ln(n)}$$

Where

$$Q_{lui} = \frac{S_{lu_i}}{S_i}$$

lu_i = land uses class (1,2,3,…,n) within the analysis area i
Q_{lui} = Share of specific land use within the analysis area i
S_{lui} = Total area of specific land use within the analysis area i
S_i = Total area of analysis i



Land use diversity

	Total m2	Total building m2	Education	Commercial	Sport	Industrial	Retail	Residential
Best	2008553,00	438658,00	1244,00	5106,00	140,00	1036,00	11168,00	282558,00
Deurne	2008553,00	415685,00	0,10	2119,00	0,10	42692,00	16897,00	214396,00
Eindhoven Strijp-s	2008553,00	483916,00	6881,00	35025,00	5191,00	49819,00	7926,00	230259,00
Geldrop	2008553,00	418263,00	0,10	3969,00	0,10	26921,00	10775,00	246292,00
Heeze	2008553,00	322339,00	7393,00	1068,00	9733,00	2700,00	3054,00	243439,00
Helmond	2008553,00	583759,00	9377,00	14341,00	312,00	76618,00	33801,00	177630,00
Helmond 't Hout	2008553,00	369950,00	0,10	5907,00	2434,00	19746,00	6444,00	236555,00
Helmond Brandevoort	2008553,00	202095,00	27076,00	0,10	5999,00	13755,00	416,00	144388,00
Helmond Brouwhuis	2008553,00	331298,00	10601,00	1985,00	36555,00	10568,00	3739,00	231592,00
Maarheeze	2008553,00	146974,00	0,10	1764,00	0,10	92610,00	0,10	20528,00

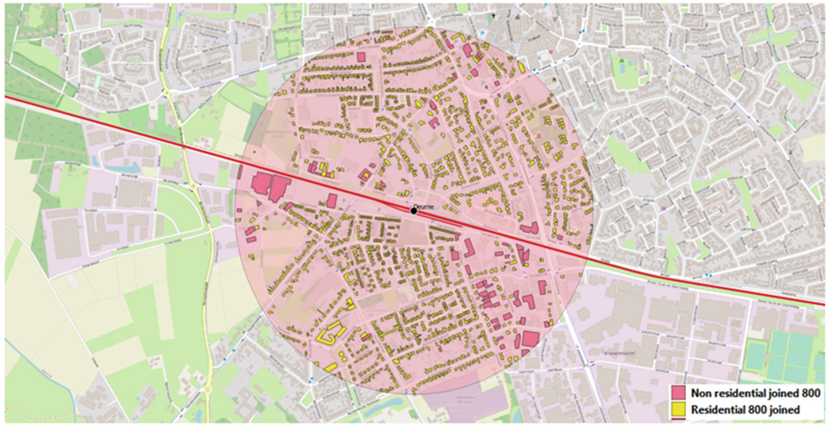
								Score
Best	Qlui	0,00	0,00	0,00	0,00	0,01	0,14	**0,18**
Deurne		0,00	0,00	0,00	0,02	0,01	0,11	**0,21**
Eindhoven Strijp-s		0,00	0,02	0,00	0,02	0,00	0,11	**0,26**
Geldrop		0,00	0,00	0,00	0,01	0,01	0,12	**0,20**
Heeze		0,00	0,00	0,00	0,00	0,00	0,12	**0,18**
Helmond		0,00	0,01	0,00	0,04	0,02	0,09	**0,26**
Helmond 't Hout		0,00	0,00	0,00	0,01	0,00	0,12	**0,19**
Helmond Brandevoort		0,01	0,00	0,00	0,01	0,00	0,07	**0,17**
Helmond Brouwhuis		0,01	0,00	0,02	0,01	0,00	0,12	**0,22**
Maarheeze		0,00	0,00	0,00	0,05	0,00	0,01	**0,11**

Explanation

The mixedness of residential land use is calculated by measuring the area of different land uses that are available in open street maps. The total residential land use is divided through the total non-residential land use. Last. the scores are transformed into a scale between 1 and 0. This scale is created in a way that the mixedness of 0,5 is the highest score. This is counted in the buffers of 800m.

Mixedness of residential with other land uses

	Education	Commercial	Sport	Industri	Residenti	Total non re	Total residential	Mixedness Index	**Scale 1-0 where 0,5 is best**
Best	1244	5106	140	1036	282558	7526	282558	0,03	**0,05**
Deurne	0,1	2119	0,1	42692	214396	44811	214396	0,17	**0,35**
Eindhoven Strijp-s	6881	35025	5191	49819	230259	96916	230259	0,30	**0,59**
Geldrop	0,1	3969	0,1	26921	246292	30890	246292	0,11	**0,22**
Heeze	7393	1068	9733	2700	243439	20894	243439	0,08	**0,16**
Helmond	9377	14341	312	76618	177630	100648	177630	0,36	**0,72**
Helmond 't Hout	0,1	5907	2434	19746	236555	28087	236555	0,11	**0,21**
Helmond Brandevoort	27076	0,1	5999	13755	144388	46830	144388	0,24	**0,49**
Helmond Brouwhuis	10601	1985	36555	10568	231592	59709	231592	0,20	**0,41**
Maarheeze	0,1	1764	0,1	92610	20528	94374	20528	0,82	**0,64**



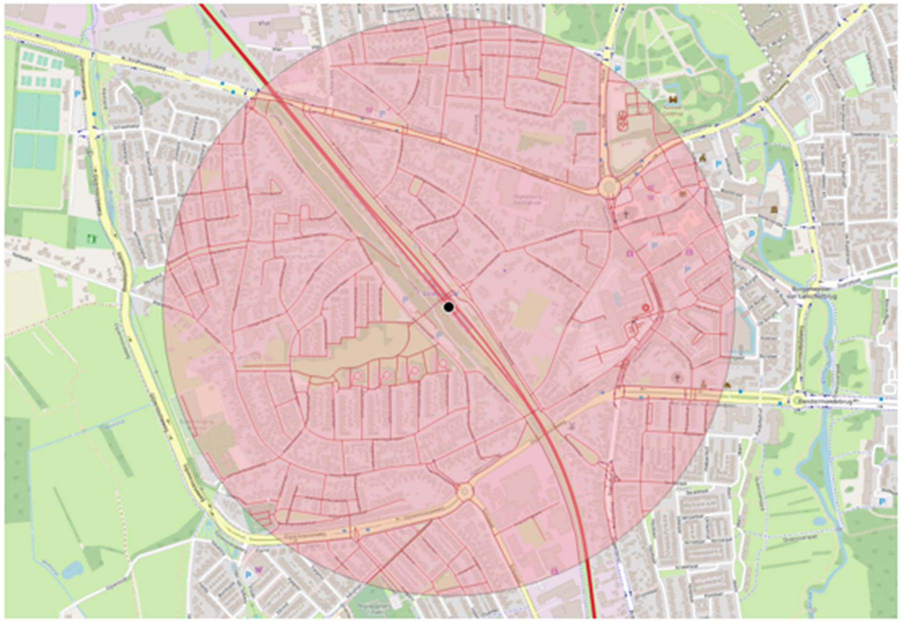
Explanation

The total length of the roads is extracted from open street maps. Several roads that are not walkable or cyclable are kept out of the calculations (see on the right>) by checking google maps and streetview. The total length is counted within the buffer of 800m. Last, the scores are transformed into a score between 1 and 0.

Filtered road types: primary, secondary, service, tertiary and motorway

Road length

	Total length m	scale 1-0
Best	42905	**0,75**
Deurne	31876	**0,56**
Eindhove	56913	**1,00**
Geldrop	44218	**0,78**
Heeze	40382	**0,71**
Helmond	47908	**0,84**
Helmond	43726	**0,77**
Helmond	44678	**0,79**
Helmond	55461	**0,97**
Maarhee:	11995	**0,21**
MIN	0	
MAX	56913	

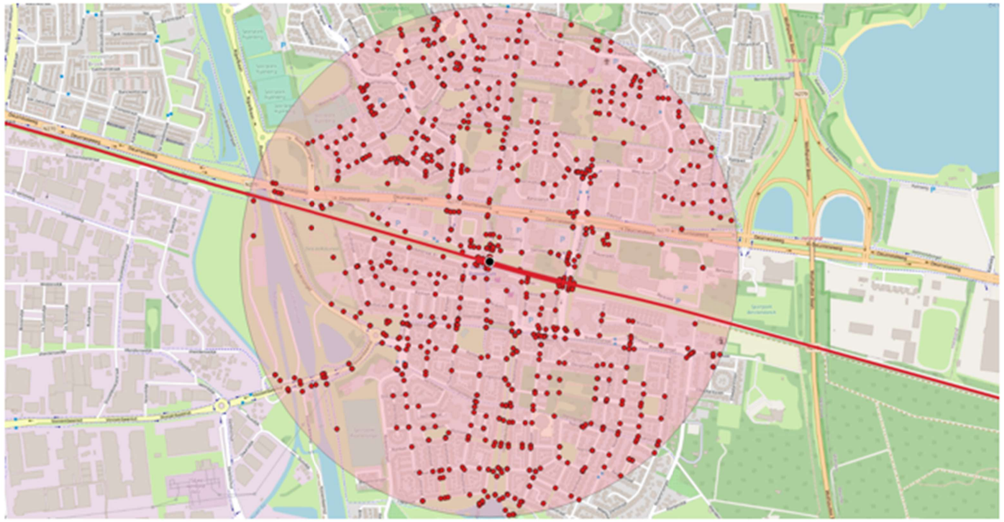


Explanation

The total number of intersections is counted by creating points on the crossings of road lines. The number of points is counted in the buffers of 800m.

Intersection count

	Total crossings	scale 1-0
Best	1702	**0,68**
Deurne	1072	**0,43**
Eindhoven Strijp-s	2500	**1,00**
Geldrop	2106	**0,84**
Heeze	1472	**0,59**
Helmond	2444	**0,98**
Helmond 't Hout	2222	**0,89**
Helmond Brandevoort	2330	**0,93**
Helmond Brouwhuis	2000	**0,80**
Maarheeze	226	**0,09**
MIN	0	
MAX	2500	

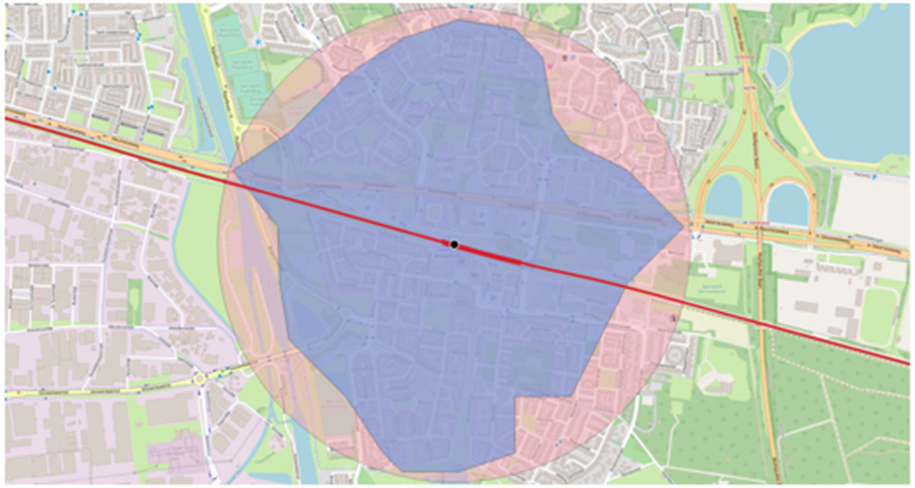


Explanation

The total reachable area by foot in 10 minutes is determined by using the Verbindingswijzer by Movares.

Impedence pedestrian catchment area

	Total m2	Total m2 reachable by foot in 10 min	IPCA
Best	2008553,00	1312233	0,65
Deurne	2008553,00	1353409	0,67
Eindhoven Strijp-s	2008553,00	1303483	0,65
Geldrop	2008553,00	1199848	0,60
Heeze	2008553,00	1304364	0,65
Helmond	2008553,00	1270442	0,63
Helmond 't Hout	2008553,00	1399927	0,70
Helmond Brandevoort	2008553,00	1215614	0,61
Helmond Brouwhuis	2008553,00	1382492	0,69
Maarheeze	2008553,00	983274	0,49



Explanation

The number of trains per hour is extracted from the Knooppuntenboek Brabant. Here the number of sprinters and intercities is counted per station. The total scores are transformed into a scale between 1 and 0.

Frequency of transit

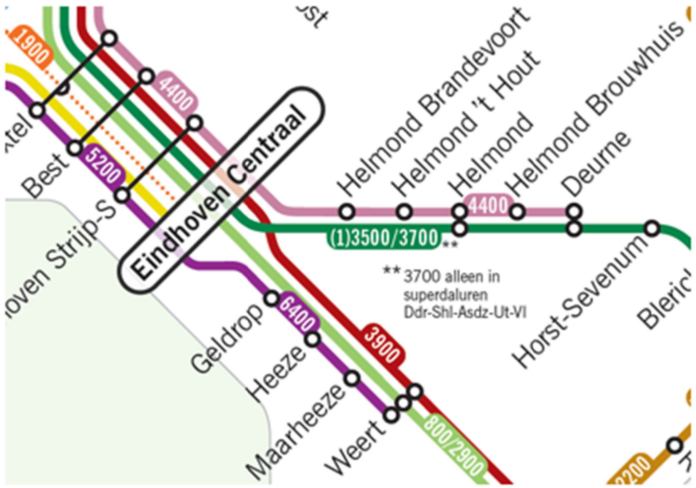
	Sprinters peak hour Score	Intercity peak hour score	Total	scale 1-0
Best	8	0	8	**0,64**
Deurne	2	4	10	**0,82**
Eindhoven Strijp-s	8	0	8	**0,64**
Geldrop	4	0	4	**0,27**
Heeze	4	0	4	**0,27**
Helmond	4	4	12	**1,00**
Helmond 't Hout	4	0	4	**0,27**
Helmond Brandevoort	4	0	4	**0,27**
Helmond Brouwhuis	4	0	4	**0,27**
Maarheeze	4	0	4	**0,27**
			MIN	1
			MAX	12
			$(V - \min V)/(\max V - \min V)$	

Explanation

The number of interchanges of trains at a stations is counted by checking the Spoorkaart Nederland 2020. Here, the different routes and train lines are presented to see the interchange possibilities by train. The scores are transformed into a scale

Interchange by train

		scale 1-0
Best	4	**1,00**
Deurne	3	**0,67**
Eindhoven Strijp-s	4	**1,00**
Geldrop	2	**0,33**
Heeze	2	**0,33**
Helmond	4	**1,00**
Helmond 't Hout	2	**0,33**
Helmond Brandevoort	2	**0,33**
Helmond Brouwhuis	2	**0,33**
Maarheeze	2	**0,33**
MIN	1	
MAX	4	
(V - min V)/(max V - min V)		



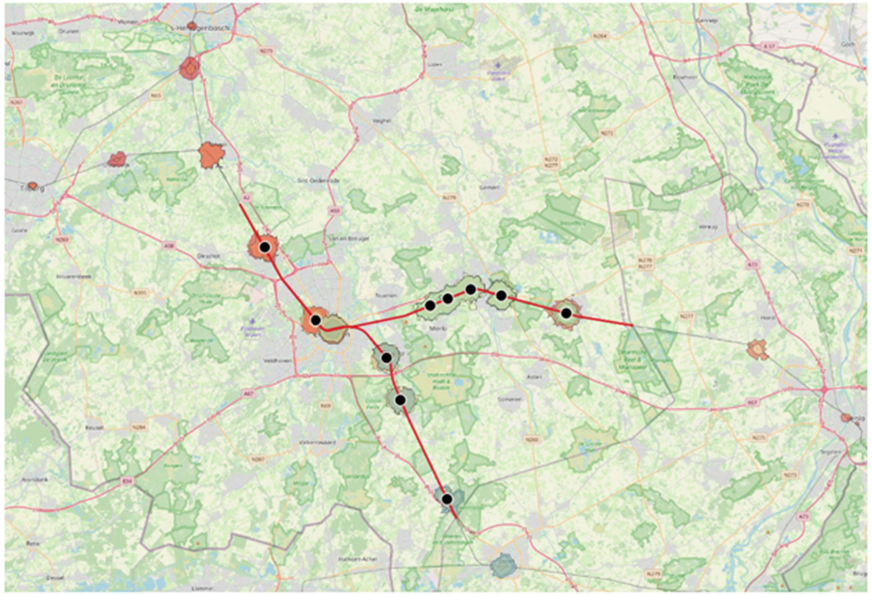
Explanation

The total reachable area by foot and train in 45 minutes is determined by using the Verbindingswijzer by Movares. The total scores are transformed into a scale between 1 and 0.

Measured in Verbindingswijzer 07:00 - 09:00 30-01-2020

Reachable area by train

	Total m2 reachable by foot and train in 45 min	Score 1-0
Best	24017984	0,77
Deurne	26816796	0,86
Eindhoven Strijp-s	21919543	0,70
Geldrop	18550209	0,59
Heeze	21480624	0,69
Helmond	31350674	1,00
Helmond 't Hout	25328706	0,81
Helmond Brandevoort	25082669	0,80
Helmond Brouwhuis	23263333	0,74
Maarheeze	19132236	0,61
	MIN	0
	MAX	31350674
	$(V - \min V)/(\max V - \min V)$	



Explanation

The number of interchanges of trains at a stations is counted by checking the Lijnnetkaart of the busses in the area. The number of bus line possibilities that are reachable within the 800m buffer are counted, if there is a bus stop. The scores are transformed into a scale between 1 and 0.

Interchange by other transport modes (bus)

	Bus	scale 1-0	nummers							
Best	7	**0,88**	9	20	101	141	142	204	260	
Deurne	5	**0,63**	28	80	262	266	268			
Eindhoven Strijp-s	8	**1,00**	8	10	103	401	402	403	608	610
Geldrop	6	**0,75**	24	320	257	260	266	324		
Heeze	4	**0,50**	257	258	266	657				
Helmond	7	**0,88**	23	24	25	26	51	150	320	
Helmond 't Hout	1	**0,13**	150							
Helmond Brandevoort	0	**0,00**								
Helmond Brouwhuis	0	**0,00**								
Maarheeze	4	**0,50**	11	255	256	258				
MIN	0									
MAX	8									

$(V - \min V)/(\max V - \min V)$

Explanation

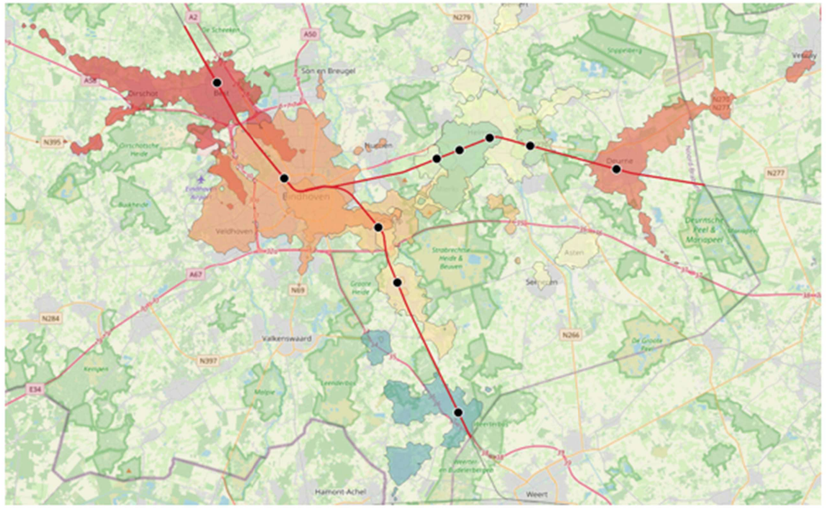
The total reachable area by foot and train in 45 minutes is determined by using the Verbindingswijzer by Movares. The total scores are transformed into a scale between 1 and 0.

Measured in Verbindingswijzer 07:00 - 09:00 30-01-2020

Reachable area by bus

	Total m2 reachable by foot and train in 45 min	Score 1-0
Best	46703444	0,57
Deurne	28672202	0,35
Eindhoven Strijp-s	81832032	1,00
Geldrop	38667613	0,47
Heeze	16062843	0,20
Helmond	54393729	0,66
Helmond 't Hout	17051080	0,21
Helmond Brandevoort	4952084	0,06
Helmond Brouwhuis	5531607	0,07
Maarheeze	25268105	0,31

MIN	0
MAX	81832032
$(V - \min V)/(\max V - \min V)$	



Explanation

The number of job opportunities is extracted from the calculation model of Ruimte voor de Sprinter by Movares. The number of job opportunities is calculated within a buffer of 1000m. The relation between the 800m buffer and 1000m buffer is calculated. The scores are transformed into a scale beteen 1 and 0.

Job opportunities

	Job opportunities 1000m	Relation buffer 800m/1000m	Job opportunities 800m	scale 1-0
Best	3311	0,64	2119	**0,39**
Deurne	3719	0,64	2380	**0,44**
Eindhoven Strijp-s	8464	0,64	5417	**1,00**
Geldrop	5064	0,64	3241	**0,60**
Heeze	1659	0,64	1062	**0,20**
Helmond	8046	0,64	5149	**0,95**
Helmond 't Hout	3412	0,64	2184	**0,40**
Helmond Brandevoort	1881	0,64	1204	**0,22**
Helmond Brouwhuis	2725	0,64	1744	**0,32**
Maarheeze	996	0,64	637	**0,12**
MIN			0	
MAX			5417	
$(V - \min V)/(\max V - \min V)$				

Explanation

The number of school opportunities is extracted from the calculation model of Ruimte voor de Sprinter by Movares. The number of school opportunities is calculated within a buffer of 1000m. The relation between the 800m buffer and 1000m buffer is calculated. The scores are transformed into a score between 1 and 0.

school opportunities

	Leerlingplaatsen	Relation buffer 800m/1000m	Job opportunities 800m	scale 1-0
Best	1860	0,64	1190	**0,47**
Deurne	526	0,64	337	**0,13**
Eindhoven Strijp-s	3946	0,64	2525	**1,00**
Geldrop	0	0,64	0	**0,00**
Heeze	0	0,64	0	**0,00**
Helmond	2108	0,64	1349	**0,53**
Helmond 't Hout	231	0,64	148	**0,06**
Helmond Brandevoort	1184	0,64	758	**0,30**
Helmond Brouwhuis	1174	0,64	751	**0,30**
Maarheeze	0	0,64	0	**0,00**
MIN			0	
MAX			2525	
$(V - \min V)/(\max V - \min V)$				

Explanation

The number of car parkings is extracted from the Knooppuntenboek Brabant. Here, the number of parking spaces is divided by the average number of users that takes the car to the train station, with a small margin.

Parking facilities car

	Car parkings	IN UIT 2018	15% by car	Car parking/user
Best	200	6027	904,05	0,22
Deurne	300	4486	672,9	0,45
Eindhoven Strijp-s	0	3184	477,6	0,00
Geldrop	40	1511	226,65	0,18
Heeze	75	1628	244,2	0,31
Helmond	162	7419	1112,85	0,15
Helmond 't Hout	0	1344	201,6	0,00
Helmond Brandevoort	20	1493	223,95	0,09
Helmond Brouwhuis	30	1766	264,9	0,11
Maarheeze	174	1347	202,05	0,86

Explanation

The number of bike parkings is extracted from the Knooppuntenboek Brabant. Here, the number of parking spaces is divided by the average number of users that take the bike to the train station, with a small margin.

Parking facilities bike

	Bike parkings	IN UIT 2018	65% by bike	Bike parkings/ users
Best	1300	6027	3918	0,33
Deurne	1320	4486	2916	0,45
Eindhoven Strijp-s	212	3184	2070	0,10
Geldrop	388	1511	982	0,40
Heeze	448	1628	1058	0,42
Helmond	2000	7419	4822	0,41
Helmond 't Hout	400	1344	874	0,46
Helmond Brandevoort	424	1493	970	0,44
Helmond Brouwhuis	392	1766	1148	0,34
Maarheeze	272	1347	876	0,31

Explanation

The only thing that is known per station is the busiest morning peak train and the average percentage per train is known. The morning peaks are used from that information and the evening peak is approached by looking at the difference between the average peaks. The two morning peaks, the two evening peaks and the two off-peaks get a score of 1 when the capacity is between 10% and 90%. The centrifugal/centripetal effect is calculated by looking at the differences within morning peaks and within evening peaks; the average is the score. The bigger the difference, the lower the score. All are transformed into a score between 1 and 0.

Capacity utilization (1)

Busiest morning peaks

RAIL LINE	Den Bosch - Eindhoven	Tilburg - Eindhoven	Deurne - Eindhoven	Weert - Eindhoven	Eindhoven - Den Bosch	Eidhoven - Tilburg	Eindhoven Deurne	Weert - Eindhoven
Best	113,60%	106,70%			99,50%	94,60%		
Deurne			101,30%				34,90%	
Eindhoven Strijp-s	110,30%	104,30%			96,20%	93%		
Geldrop				81,20%				15,20%
Heeze				78,50%				15,50%
Helmond			107%				33,10%	
Helmond 't Hout			109,10%				33,90%	
Helmond Brandevoort			112,60%				34,90%	
Helmond Brouwhuis			103,50%				32,80%	
Maarheeze				76,10%				15,80%

	morning to Eindhoven	evening peak % compared to m	**evening to eindhoven**	**morning from eindho**	evening peak % compared to	**evening from eindhoven**
Best	**110,15**	-19,45	**90,70**	**97,05**	-8,20	**88,85**
Deurne	**101,30**	-72,00	**29,30**	**34,90**	59,40	**94,30**
Eindhoven Strijp-s	**107,30**	-19,45	**87,85**	**94,90**	-8,20	**86,70**
Geldrop	**81,20**	-68,80	**12,40**	**15,20**	85,70	**100,90**
Heeze	**78,50**	-68,80	**9,70**	**15,50**	85,70	**101,20**
Helmond	**107,00**	-72,00	**35,00**	**33,10**	59,40	**92,50**
Helmond 't Hout	**109,10**	-72,00	**37,10**	**33,90**	59,40	**93,30**
Helmond Brandevoort	**112,60**	-72,00	**40,60**	**34,90**	59,40	**94,30**
Helmond Brouwhuis	**103,50**	-72,00	**31,50**	**32,80**	59,40	**92,20**
Maarheeze	**76,10**	-68,80	**7,30**	**15,80**	85,70	**101,50**

					SCORE PEAK
Best	**0,00**	**0,00**	**0,00**	**1,00**	**0,25**
Deurne	**0,00**	**1,00**	**1,00**	**0,00**	**0,50**
Eindhoven Strijp-s	**0,00**	**1,00**	**0,00**	**1,00**	**0,50**
Geldrop	**1,00**	**1,00**	**1,00**	**0,00**	**0,75**
Heeze	**1,00**	**0,00**	**1,00**	**0,00**	**0,50**
Helmond	**0,00**	**1,00**	**1,00**	**0,00**	**0,50**
Helmond 't Hout	**0,00**	**1,00**	**1,00**	**0,00**	**0,50**
Helmond Brandevoort	**0,00**	**1,00**	**1,00**	**0,00**	**0,50**
Helmond Brouwhuis	**0,00**	**1,00**	**1,00**	**0,00**	**0,50**
Maarheeze	**1,00**	**0,00**	**1,00**	**0,00**	**0,50**

Capacity utilization (2)

	average % off peak to eindhoven		average % off peak from eindhoven		SCORE OFF PEAK
Best	40,00	1	30,00	1	1
Deurne	30,00	1	20,00	1	1
Eindhoven Strijp-s	40,00	1	30,00	1	1
Geldrop	18,00	1	15,00	1	1
Heeze	18,00	1	15,00	1	1
Helmond	30,00	1	20,00	1	1
Helmond 't Hout	30,00	1	20,00	1	1
Helmond Brandevoort	30,00	1	20,00	1	1
Helmond Brouwhuis	30,00	1	20,00	1	1
Maarheeze	18,00	1	15,00	1	1

	Centrifugal effect morning	Centrifugal effect evening		SCORE centripetal/ centrifugal effect
Best	13,10	-1,85	5,625	**0,94**
Deurne	66,40	65,00	65,7	**0,34**
Eindhoven Strijp-s	12,40	-1,15	5,625	**0,94**
Geldrop	66,00	88,50	77,25	**0,23**
Heeze	63,00	91,50	77,25	**0,23**
Helmond	73,90	57,50	65,7	**0,34**
Helmond 't Hout	75,20	56,20	65,7	**0,34**
Helmond Brandevoort	77,70	53,70	65,7	**0,34**
Helmond Brouwhuis	70,70	60,70	65,7	**0,34**
Maarheeze	60,30	94,20	77,25	**0,23**

Explanation

The average rating of users is received from NS, who owns the numbers of reizigers beoordelingen. Finally, the score are transformed into a scale between 1 and

Rating stations by users

	Average rating users	scale 1-0
Best	7	**0,67**
Deurne	7,2	**0,69**
Eindhoven Strijp-s	6,5	**0,61**
Geldrop	6,9	**0,66**
Heeze	7,1	**0,68**
Helmond	7,4	**0,71**
Helmond 't Hout	7	**0,67**
Helmond Brandevoort	7,3	**0,70**
Helmond Brouwhuis	6,3	**0,59**
Maarheeze	7,1	**0,68**
MIN	1	
MAX	10	

$(V - \min V)/(\max V - \min V)$

Explanation

The average rating of users is received from NS, who owns the numbers of reizigers beoordelingen. (s) stays for significant difference. Finally, the score are transformed into a scale between 1 and 0.

Rating station surroundings by users

	Average rating user compared to benchmark (same station type)	in scale 1-7 (from much lower to much higher)	**scale 1-0**
Best	Same	4	**0,50**
Deurne	Higher (s)	6	**0,83**
Eindhoven Strijp-s	Same	4	**0,50**
Geldrop	Slightly higer	5	**0,67**
Heeze	Much higher (s)	7	**1,00**
Helmond	Same	4	**0,50**
Helmond 't Hout	Much higher (s)	7	**1,00**
Helmond Brandevoort	Much higher (s)	7	**1,00**
Helmond Brouwhuis	slightly lower	3	**0,33**
Maarheeze	slightly lower	3	**0,33**
MIN		1	
MAX		7	

$(V - \min V)/(\max V - \min V)$

Explanation

The number of facilities is counted per station. The higher the number of basic facilities, the higher the score. Finally, the score are transformed into a scale between 1 and 0.

User friendliness and facilities

	WC	Service- en alarmzuil	Kiosk	Wachtruir	Watertappunt	Dagwinkel	TOTAL	scale 1-0
Best	1	1		1	1		4	**0,67**
Deurne	1	1		1	1	1	5	**0,83**
Eindhoven Strijp-s		1					1	**0,17**
Geldrop	1	1			1		3	**0,50**
Heeze		1					1	**0,17**
Helmond	1	1	1	1	1	1	6	**1,00**
Helmond 't Hout	1	1			1		3	**0,50**
Helmond Brandevoort		1			1		2	**0,33**
Helmond Brouwhuis	1	1		1	1	1	5	**0,83**
Maarheeze		1					1	**0,17**
						Min	0	
						Max	6	

$(V - \min V)/(\max V - \min V)$

Appendix V: Overall TOD scores

TOD measurement tool for TASS	Place				Node			Perception	TOD Score
	1. Population density (Weight: 0,1)	2. Amenities (Weight: 0,25)	3. Land use diversity (Weight: 0,05)	4. Walkability/ Cyclability (Weight: 0,15)	5. Accessibility to and from station (Weight: 0,15)	6. Parking supply (Weight: 0,05)	7. Capacity of utilization of transit (Weight: 0,1)	8. Perception of users (Weight: 0,15)	
TOD area	Score	Score	Score	Score	Score	Score	Score	Score	Total
Best	0,50	0,42	0,18	0,64	0,68	0,28	0,57	0,61	0,53
Deurne	0,37	0,05	0,21	0,55	0,62	0,45	0,27	0,77	0,40
Eindhoven Strijp-s	1,00	0,80	0,26	0,85	0,85	0,05	0,57	0,48	0,70
Geldrop	0,51	0,42	0,20	0,68	0,44	0,29	0,21	0,63	0,46
Heeze	0,17	0,05	0,18	0,61	0,36	0,37	0,21	0,69	0,33
Helmond	0,82	0,34	0,26	0,79	0,89	0,28	0,27	0,70	0,58
Helmond 't Hout	0,57	0,13	0,19	0,72	0,38	0,23	0,27	0,75	0,42
Helmond Brandevoort	0,22	0,09	0,17	0,73	0,35	0,26	0,27	0,73	0,37
Helmond Brouwhuis	0,40	0,16	0,22	0,80	0,35	0,23	0,27	0,55	0,38
Maarheeze	0,09	0,00	0,11	0,31	0,35	0,59	0,21	0,46	0,23

Appendix VI: Criteria calculations of the TOD measurement tool

1. Density	Population density (Indicator weight: 1,00)	Total
	Score	total
Best	0,50	0,50
Deurne	0,37	0,37
Eindhoven Strijp-s	1,00	1,00
Geldrop	0,51	0,51
Heeze	0,17	0,17
Helmond	0,82	0,82
Helmond 't Hout	0,57	0,57
Helmond Brandevoort	0,22	0,22
Helmond Brouwhuis	0,40	0,40
Maarheeze	0,09	0,09

2. Amenities	Leisure		Work	Total
	Shops (Indicator weight: 0,3)	PubCafeBarRestaurant (Indicator weight: 0,2)	Offices (Indicator weight: 0,5)	
	Score	Score	Score	total
Best	1,00	0,43	0,08	0,42
Deurne	0,14	0,04	0,00	0,05
Eindhoven Strijp-s	0,34	1,00	1,00	0,80
Geldrop	0,48	0,61	0,31	0,42
Heeze	0,03	0,00	0,08	0,05
Helmond	0,43	0,68	0,15	0,34
Helmond 't Hout	0,27	0,07	0,08	0,13
Helmond Brandevoort	0,21	0,14	0,00	0,09
Helmond Brouwhuis	0,12	0,04	0,23	0,16
Maarheeze	0,00	0,00	0,00	0,00

3. Land use diversity	Entropy (Indicator weight: 1,0)	Total
	Score	total
Best	0,18	0,18
Deurne	0,21	0,21
Eindhoven Strijp-s	0,26	0,26
Geldrop	0,20	0,20
Heeze	0,18	0,18
Helmond	0,26	0,26
Helmond 't Hout	0,19	0,19
Helmond Brandevoort	0,17	0,17
Helmond Brouwhuis	0,22	0,22
Maarheeze	0,11	0,11

4. Wakability and cyclability	Mixedness of residential land use with other land uses	Total length of walkable/ cyclable path	Intersection density	Impedance pedestrian catchment area	Total
	Mixedness (Indicator weight: 0,1)	Length (Indicator weight: 0,4)	Intersections (Indicator weight: 0,2)	Area (Indicator weight: 0,3)	
	Score	Score	Score	Score	total
Best	0,05	0,75	0,68	0,65	0,64
Deurne	0,35	0,56	0,43	0,67	0,55
Eindhoven Strijp-s	0,59	1,00	1,00	0,65	0,85
Geldrop	0,22	0,78	0,84	0,60	0,68
Heeze	0,16	0,71	0,59	0,65	0,61
Helmond	0,72	0,84	0,98	0,63	0,79
Helmond 't Hout	0,21	0,77	0,89	0,70	0,72
Helmond Brandevoort	0,49	0,79	0,93	0,61	0,73
Helmond Brouwhuis	0,41	0,97	0,80	0,69	0,80
Maarheeze	0,64	0,21	0,09	0,49	0,31

	5. Access to and from station							
	Frequency of transit service	Connectivity of main transit mode		Connectivity of other transit modes (bus)		Access to opportunities within walkable distance from train station		Total
	Frequency (Indicator weight: 0,2)	Interchange options (Indicator weight: 0,1)	Reachable area train (Indicator weight: 0,25)	Interchange options other transit modes (Indicator weight: 0,1)	Reachable area other modes (Indicator weight: 0,15)	Job opportunities (Indicator weight: 0,1)	School opportunities (Indicator weight: 0,1)	
	Score	Score	Score	Score	Score	Score	Score	total
Best	0,64	1,00	0,77	0,88	0,57	0,39	0,47	**0,68**
Deurne	0,82	0,67	0,86	0,63	0,35	0,44	0,13	**0,62**
Eindhoven Strijp-s	0,64	1,00	0,70	1,00	1,00	1,00	1,00	**0,85**
Geldrop	0,27	0,33	0,59	0,75	0,47	0,60	0,00	**0,44**
Heeze	0,27	0,33	0,69	0,50	0,20	0,20	0,00	**0,36**
Helmond	1,00	1,00	1,00	0,88	0,66	0,95	0,53	**0,89**
Helmond 't Hout	0,27	0,33	0,81	0,13	0,21	0,40	0,06	**0,38**
Helmond Brandevoort	0,27	0,33	0,80	0,00	0,06	0,22	0,30	**0,35**
Helmond Brouwhuis	0,27	0,33	0,74	0,00	0,07	0,32	0,30	**0,35**
Maarheeze	0,27	0,33	0,61	0,50	0,31	0,12	0,00	**0,35**

	6. Parking supply		
	Car	Bikes	Total
	Car (Indicator weight: 0,5)	Bikes (Indicator weight: 0,5)	
	Score	Score	total
Best	0,22	0,33	**0,28**
Deurne	0,45	0,45	**0,45**
Eindhoven Strijp-s	0,00	0,10	**0,05**
Geldrop	0,18	0,40	**0,29**
Heeze	0,31	0,42	**0,37**
Helmond	0,15	0,41	**0,28**
Helmond 't Hout	0,00	0,46	**0,23**
Helmond Brandevoort	0,09	0,44	**0,26**
Helmond Brouwhuis	0,11	0,34	**0,23**
Maarheeze	0,86	0,31	**0,59**

	7. Capacity utilization of transit			
	Capacity		Centrifugal effect	Total
	Peak (0,4)	Off Peak (Indicator weight: 0,1)	Centrifugal effect (Indicator weight: 0,5)	
	Score	Score	Score	total
Best	0,25	1,00	0,94	**0,57**
Deurne	0,50	1,00	0,34	**0,27**
Eindhoven Strijp-s	0,50	1,00	0,94	**0,57**
Geldrop	0,75	1,00	0,23	**0,21**
Heeze	0,50	1,00	0,23	**0,21**
Helmond	0,50	1,00	0,34	**0,27**
Helmond 't Hout	0,50	1,00	0,34	**0,27**
Helmond Brandevoort	0,50	1,00	0,34	**0,27**
Helmond Brouwhuis	0,50	1,00	0,34	**0,27**
Maarheeze	0,50	1,00	0,23	**0,21**

	8. Perception of users			
	User ratings stations		User friendliness	Total
	Average rating station (Indicator weight: 0,45)	Average rating surrounding (Indicator weight: 0,35)	User friendliness (Indicator weight: 0,2)	
	Score	Score	Score	total
Best	0,67	0,50	0,67	**0,61**
Deurne	0,69	0,83	0,83	**0,77**
Eindhoven Strijp-s	0,61	0,50	0,17	**0,48**
Geldrop	0,66	0,67	0,50	**0,63**
Heeze	0,68	1,00	0,17	**0,69**
Helmond	0,71	0,50	1,00	**0,70**
Helmond 't Hout	0,67	1,00	0,50	**0,75**
Helmond Brandevoort	0,70	1,00	0,33	**0,73**
Helmond Brouwhuis	0,59	0,33	0,83	**0,55**
Maarheeze	0,68	0,33	0,17	**0,46**

Appendix VII: Sensitivity analysis

	Sensitivity Analysis																
	Original score	Population Density +5%	Population Density -5%	Amenities +5%	Amenities - 5%	Land use diversity +5%	Land use diversity - 5%	Walkability/ Cyclability +5%	Walkability/ Cyclability - 5%	Accessibility to and from station +5%	Accessibility to and from station -5%	Parking supply +5%	Parking supply -5%	Capacity utilization +5%	Capacity utilization - 5%	Perception of users +5%	Perception of users -5%
Eindhoven Strijp-s	***0,702***	0,724	0,679	0,712	0,691	0,682	0,721	0,715	0,688	0,715	0,688	0,670	0,733	0,699	0,704	0,694	0,709
Helmond	***0,577***	0,593	0,562	0,566	0,589	0,561	0,593	0,592	0,563	0,597	0,558	0,562	0,592	0,562	0,593	0,586	0,569
Best	***0,525***	0,526	0,524	0,522	0,529	0,508	0,542	0,534	0,516	0,536	0,514	0,513	0,537	0,530	0,520	0,532	0,518
Geldrop	***0,464***	0,469	0,459	0,464	0,464	0,451	0,477	0,479	0,449	0,465	0,463	0,456	0,472	0,452	0,476	0,476	0,452
Helmond 't Hout	***0,415***	0,424	0,406	0,400	0,430	0,403	0,427	0,433	0,397	0,414	0,416	0,405	0,425	0,407	0,423	0,435	0,395
Deurne	***0,400***	0,397	0,402	0,379	0,420	0,388	0,411	0,407	0,392	0,411	0,388	0,402	0,397	0,392	0,407	0,420	0,379
Helmond Brouwhuis	***0,383***	0,384	0,381	0,370	0,395	0,374	0,391	0,407	0,358	0,381	0,384	0,374	0,391	0,377	0,388	0,393	0,373
Helmond Brandevoort	***0,366***	0,358	0,373	0,351	0,381	0,355	0,376	0,387	0,344	0,365	0,366	0,360	0,371	0,361	0,370	0,387	0,344
Heeze	***0,326***	0,317	0,335	0,310	0,342	0,317	0,334	0,342	0,310	0,328	0,324	0,328	0,324	0,319	0,332	0,346	0,305
Maarheeze	***0,233***	0,223	0,243	0,218	0,248	0,224	0,242	0,236	0,230	0,238	0,228	0,251	0,215	0,230	0,236	0,244	0,222

Appendix VIII: Radar graphs of scores of the transit areas