Incorporating User Needs and Preferences into the Assessment of Transit-Oriented Development of Urban Areas

Master thesis (7CC40)
40 ECTS

Student
J.T.B.M. (Jon) van Heukelom 1878735

Graduation committee

Chair	Dr. Q. (Qi) Han
Main Supervisor	Dr. ing. P. (Peter) van der Waerden
Secondary Supervisor	Dr. V. (Valeria) Caiati

Eindhoven University of Technology
Department of the Built Environment
MSc. Construction Management and Engineering

Eindhoven, February 20, 2025

Preface

Dear reader,
In front of you lies the finalisation graduation project. This thesis marks the end of my academic journey, and I'm excited to share the final product: *Incorporating User Needs and Preferences into the Assessment of Transit-Oriented Development of Urban Areas*. My journey began at Avans University of Applied Sciences, where I studied the built environment. Over time, I explored different aspects of the field, but it wasn't until my master's program that I found myself drawn to the field of mobility. It quickly became clear that this was where my true interest lay, and I've spent the last part of my studies diving deeper into how user needs and preferences can shape more effective and inclusive urban planning.

I would like to express my sincere gratitude to my supervisors for their support and insightful feedback throughout this research. Their guidance has been crucial in shaping this thesis, and I appreciate the time and effort they dedicated to helping me refine my work. I would also like to extend my gratitude to my family and my girlfriend for their encouragement and belief in me. Their continuous support, especially during challenging times, has been a source of strength and motivation, and I am truly grateful for their presence in this journey.

I hope you will enjoy reading this thesis,

J.T.B.M. (Jon) van Heukelom

Eindhoven, February 20, 2025

Contents

Preface 3

Summary 7

Samenvatting 9

Abstract 11

List of abbreviations 12

List of figures 13

List of tables 14

1. Introduction 15

1.1. Problem definition 15

1.2. Research objective and research questions 16

1.3. Research design 17

1.4. Societal and academic relevance 19

1.5. Reading guide 19

2. Literature review 21

2.1. Transit Oriented Development 21

2.1.1. Historical overview and definition 21

2.1.2. Core principles of TOD 22

2.1.3. TOD indices 22

2.1.4. TOD classifications 25

2.2. Diverse user groups in TOD 26

2.2.1. User-centric TOD 26

2.2.2. Different user groups 27

2.2.3. Demographic factors influencing mode choice 28

2.3. GIS and MCA applications in TOD planning 29

2.4. Conclusion 31

3. Methodology 32

3.1. Introduction 32

3.2. Research approach 32

3.3. User group segmentation 34

3.3.1. Data collection and preparation 35

3.3.2. Decision tree analysis 36

3.4. Assigning weights 41

3.4.1. Data collection and preparation 42

3.4.2. Surveys 42

3.4.3. Weight calculations ... 43
3.5. TOD Index Calculation ... 43
3.5.1. Data collection and preparation ... 43
3.5.2. TOD Index ... 53
3.6. Conclusion ... 54
4. Results ... 56
4.1. User group segmentation results ... 56
4.2. User group weights results ... 58
4.2.1. Weights for criteria ... 60
4.2.2. Weights for indicators ... 61
4.3. TOD Index results ... 63
4.3.1. Preliminary indicator calculations ... 64
4.3.2. Trends across neighbourhoods ... 66
4.3.3. Conclusion ... 68
4.4. Comparison with non-user centred weights ... 68
5. Discussion ... 70
5.1. Key findings ... 70
5.1.1. Segmentation process results ... 70
5.1.2. Weighting process results ... 70
5.1.3. TOD Index results ... 71
5.2. Limitations and methodological reflections ... 71
5.3. Importance of findings ... 72
5.4. Conclusion of discussion ... 72
6. Conclusion ... 73
6.1. Answering of research question ... 73
6.2. Scientific relevance ... 73
6.3. Societal relevance ... 74
6.4. Recommendations ... 75
7. References ... 77
A Appendix – Code for select cases tool SPSS ... 84
B Appendix – Complete Decision Tree ... 85
C Appendix − Survey format ... 86
D Appendix – Ranking of criteria ... 92
E Appendix – Ranking of indicators ... 93
F Appendix − Full tables for TOD values ... 95

G Appendix – Maps of TOD Index 97

Summary

Transit-Oriented Development (TOD) is a planning and development model that promotes sustainable urban growth by encouraging high-density, mixed-use neighbourhoods around public transportation hubs. While TOD principles traditionally focus on optimising land use to support public transit, there is a growing recognition of the importance of aligning TOD planning with the needs and preferences of different user groups. This thesis explores the integration of user needs and preferences into the TOD assessment framework, particularly for urban areas in the Netherlands, with an emphasis on using Geographic Information Systems (GIS) and Multi-Criteria Analysis (MCA) for spatial analysis and decision-making.
The research primarily aims to evaluate whether user needs and preferences can improve TOD assessments and if such integration leads to more effective and inclusive urban planning. By incorporating sociodemographic factors, such as income, ethnicity, age, gender, and other user characteristics, the study aims to develop a methodology that integrates TOD principles with the varying transportation needs and preferences of diverse user groups. The research methodology is structured into three core sections: user group segmentation, the assignment of weights to TOD criteria and indicators, and the calculation of the TOD Index.

User group segmentation is the first step of the methodology, where the study defines different user groups based on their transportation behaviour and sociodemographic characteristics. The segmentation process uses the ODiN dataset, which includes variables such as age, education, employment status, relationship status, income, gender, and ethnicity. A decision tree method in SPSS is employed to segment the population into five distinct groups, based on their mode choice preferences and behaviours:

1. **Group 1 Car & foot oriented**: Car is the dominant mode, followed by walking, cycling, and limited public transport use.
2. **Group 2 Car & bike oriented**: Car is dominant, with cycling being the secondary mode, followed by walking and limited public transport.
3. **Group 3 PT-oriented**: Public transport is the primary mode, followed by cycling and walking, with minimal car use.
4. **Group 4 Bike-oriented**: Cycling is the dominant mode, followed by public transport, car, and walking.
5. **Group 5 Car & mix oriented**: Car remains dominant, but alternative modes like cycling, public transport, or walking are significant in the transportation mix.

By identifying these groups, the research highlights the varying needs and preferences of different population segments, thus offering a more nuanced approach to TOD planning.

Once the user groups are defined, the study focuses on assigning weights to the criteria and indicators used to assess the TOD potential of different neighbourhoods. These criteria are essential factors such as population and commercial density, land use diversity, walkability, cycling facilities, economic development, capacity utilisation of transit, and user-friendliness of the transit system. The weights are determined through a combination of informal consultation with representatives from each user group and survey-based ranking methods. By using the rank-sum method, the study calculates the final weights for each criterion, reflecting the preferences of the user groups. This process allows for the incorporation of subjective user input into the otherwise objective TOD assessment.
The criteria used for evaluating neighbourhoods include:

- **Density**: Population and commercial densities as indicators of transit potential.
- **Land Use Diversity**: The mix of different types of land uses, encouraging shorter trips and multimodal transport.
- **Encouragement of Walking and Cycling**: Accessibility, quality of pedestrian and cycling infrastructure, and the degree of mixed-use areas.
- **Economic Development**: The concentration of business establishments as a driver for public transport usage.
- **Capacity Utilization of Transit**: The load on transit during peak and off-peak hours.
- **User-Friendliness of Transit**: Safety, comfort, and information availability at transit stops.
- **Access to and from the Station**: The frequency of service, interchange options, and the proximity of amenities.
- **Parking Supply at Transit Stations**: The availability of parking for both cars and bicycles.

These criteria, along with their respective weights, allow the study to evaluate the TOD potential of various neighbourhoods in a way that accounts for both physical infrastructure and user preferences.

The final stage of the research involves the calculation of the TOD Index, which combines the criteria scores and the weights assigned to them. The TOD Index serves as a comprehensive measure of a neighbourhood's transit-oriented development potential, considering both physical features and the needs and preferences of different user groups. The results are presented through a comparison of how different neighbourhoods score across the user groups, rather than comparing the neighbourhoods themselves. This approach helps to identify which groups benefit most or least from specific characteristics of each neighbourhood.

In the case study neighbourhoods, Strijp-S and Kronehoef, Strijp-S is expected to score higher due to its innovative, newly developed nature, which is designed with TOD principles in mind. In contrast, Kronehoef, being an older and more traditional neighbourhood, is likely to score lower on certain criteria, especially those related to walkability, cycling, and transit access. However, the analysis highlights that each user group has distinct preferences, with some groups showing a stronger preference for neighbourhoods with high transit capacity, while others prioritise walking and cycling infrastructure or economic development opportunities.

The thesis concludes that integrating user needs and preferences into the TOD assessment process offers valuable insights for urban planners. By acknowledging the different needs and preferences of user groups, planners can better identify areas where TOD can improve transportation outcomes and create more inclusive urban spaces. The study also recommends expanding the user group segmentation to include additional variables like trip purpose, household structure, and cultural background to further refine the analysis. Additionally, it suggests that broader-scale surveys be conducted to capture a more comprehensive view of user preferences, particularly in terms of travel behaviour and mode choice. In terms of practical applications, the research offers a framework for conducting TOD assessments that not only considers physical infrastructure but also aligns with the diverse needs and preferences of urban populations. This can lead to more effective and equitable urban development strategies that promote sustainable, multimodal transport options for all citizens.

Samenvatting

Transit-Oriented Development (TOD) is een plannings- en ontwikkelingsmodel dat duurzaam stedelijk groei bevordert door het stimuleren van hoogbouw en gemengde woonwijken rondom openbaarvervoersknooppunten. Terwijl de principes van TOD traditioneel gericht zijn op het optimaliseren van landgebruik ter ondersteuning van het openbaar vervoer, groeit de erkenning van het belang van het afstemmen van TOD-planning op de behoeften en voorkeuren van verschillende gebruikersgroepen. Dit proefschrift onderzoekt de integratie van gebruikersbehoeften en -voorkeuren in het TOD-beoordelingskader, met een focus op stedelijke gebieden in Nederland, met nadruk op het gebruik van Geographic Information Systems (GIS) en Multi-Criteria Analysis (MCA) voor ruimtelijke analyse en besluitvorming.
Het onderzoek heeft als doel te evalueren of gebruikersbehoeften en -voorkeuren de TOD-gebaseerde herontwikkeling kunnen verbeteren en of deze integratie leidt tot effectievere en inclusievere stedelijke planning. Door sociodemografische factoren, zoals inkomen, etniciteit, leeftijd, geslacht en andere gebruikerskenmerken, te integreren, beoogt het onderzoek een methodologie te ontwikkelen die TOD-principes combineert met de variërende vervoersbehoeften van diverse gebruikersgroepen. De onderzoeksmethodologie is verdeeld in drie kernsecties: gebruikersgroepssegmentatie, het toewijzen van gewichten aan TOD-criteria en indicatoren, en de berekening van de TOD-index.

Gebruikersgroepssegmentatie is de eerste stap van de methodologie, waarbij het onderzoek verschillende gebruikersgroepen definieert op basis van hun vervoersgedrag en sociodemografische kenmerken. Het segmentatieproces maakt gebruik van de ODiN-dataset, die variabelen bevat zoals leeftijd, opleiding, werkstatus, relatie status, inkomen, geslacht en etniciteit. Een beslissingsboomtechniek in SPSS wordt gebruikt om de populatie te segmenteren in vijf verschillende groepen, op basis van hun voorkeuren en gedragingen met betrekking tot vervoermiddelen:

1. **Groep 1 Auto & voet-georiënteerd:** Auto is het dominante vervoermiddel, gevolgd door lopen, fietsen en beperkt gebruik van openbaar vervoer.
2. **Groep 2: Auto & fiets-georiënteerd:** Auto blijft dominant, met fietsen als secundair vervoermiddel, gevolgd door lopen en beperkt openbaar vervoer.
3. **Groep 3: OV-georiënteerd:** Openbaar vervoer is het primaire vervoermiddel, gevolgd door fietsen en lopen, met minimaal gebruik van de auto.
4. **Groep 4: Fiets-georiënteerd:** Fietsen is het dominante vervoermiddel, gevolgd door openbaar vervoer, auto en lopen.
5. **Groep 5: Auto & gemengd georiënteerd:** Auto blijft dominant, maar alternatieve vervoermiddelen zoals fietsen, openbaar vervoer of lopen spelen een belangrijke rol in het vervoersmix.

Door deze groepen te identificeren, benadrukt het onderzoek de variërende behoeften en voorkeuren van verschillende segmenten van de bevolking, waardoor een meer genuanceerde benadering van TOD-planning wordt geboden.

Nadat de gebruikersgroepen zijn gedefinieerd, richt het onderzoek zich op het toewijzen van gewichten aan de criteria en indicatoren die worden gebruikt om het TOD-potentieel van verschillende buurten te beoordelen. Deze criteria omvatten essentiële factoren zoals bevolkings- en commerciële dichtheid, diversiteit in landgebruik, loopbaarheid, fietsinfrastructuur, economische ontwikkeling, capaciteit van het openbaar vervoer, en

gebruikersvriendelijkheid van het openbaar vervoersysteem. De gewichten worden bepaald door een combinatie van informele consultatie met vertegenwoordigers van elke gebruikersgroep en op enquêtes gebaseerde rangmethoden. Door gebruik te maken van de rank-sum methode, berekent het onderzoek de uiteindelijke gewichten voor elk criterium, die de voorkeuren van de gebruikersgroepen weerspiegelen. Dit proces maakt de integratie van subjectieve gebruikersinvoer in de anders objectieve TOD-beoordeling mogelijk.
De criteria die worden gebruikt om buurten te evalueren zijn:

- **Dichtheid**: Bevolkings- en commerciële dichtheden als indicatoren van transitpotentieel.
- **Diversiteit in landgebruik**: De mix van verschillende soorten landgebruik, die kortere reizen en multimodaal vervoer bevordert.
- **Stimulering van lopen en fietsen**: Toegankelijkheid, kwaliteit van de voetgangers- en fietsinfrastructuur, en de mate van gemengd gebruik van gebieden.
- **Economische ontwikkeling**: De concentratie van bedrijfsmatige vestigingen als aandrijver voor het gebruik van openbaar vervoer.
- **Capaciteitsbenutting van openbaar vervoer**: De belasting van openbaar vervoer tijdens piek- en daluren.
- **Gebruikersvriendelijkheid van openbaar vervoer**: Veiligheid, comfort en beschikbaarheid van informatie bij haltes.
- **Toegang tot en van het station**: Frequentie van de dienstregeling, overstapmogelijkheden en nabijheid van voorzieningen.
- **Parkeerfaciliteiten bij stations**: Beschikbaarheid van parkeerplaatsen voor zowel auto's als fietsen.

Deze criteria, samen met de bijbehorende gewichten, stellen het onderzoek in staat om het TOD-potentieel van verschillende buurten te evalueren op een manier die zowel fysieke infrastructuur als gebruikersvoorkeuren in aanmerking neemt.

De laatste fase van het onderzoek betreft de berekening van de TOD-index, die de scores van de criteria combineert met de aan hen toegewezen gewichten. De TOD-index fungeert als een uitgebreide maat voor het TOD-potentieel van een buurt, rekening houdend met zowel fysieke kenmerken als de behoeften van verschillende gebruikersgroepen. De resultaten worden gepresenteerd door te vergelijken hoe verschillende buurten scoren binnen de gebruikersgroepen, in plaats van de buurten zelf met elkaar te vergelijken. Deze benadering helpt te identificeren welke groepen het meest of het minst profiteren van specifieke kenmerken van elke buurt.
In de case study-buurten Strijp-S en Kronehoef wordt verwacht dat Strijp-S hoger scoort vanwege de innovatieve, nieuw ontwikkelde aard, die is ontworpen met TOD-principes in gedachten. In tegenstelling daarmee zal Kronehoef, als een oudere en traditionelere buurt, waarschijnlijk lager scoren op bepaalde criteria, met name die gerelateerd aan loopbaarheid, fietsen en toegang tot openbaar vervoer. De analyse benadrukt echter dat elke gebruikersgroep distinctieve voorkeuren heeft, waarbij sommige groepen een sterkere voorkeur vertonen voor buurten met een hoge transitcapaciteit, terwijl anderen de nadruk leggen op loop- en fietsinfrastructuur of economische ontwikkelingsmogelijkheden.

Abstract

Cities face increasing challenges in designing sustainable and accessible transport networks. Transit-Oriented Development (TOD) promotes compact, mixed-use communities centered around high-quality public transportation. However, traditional TOD evaluations often neglect diverse user needs and preferences. This research investigates how sociodemographic-based user segmentation can enhance the accuracy of TOD assessments.

Using decision tree analysis on the Dutch ODiN dataset, the study segments the population into distinct user groups based on mode choice and demographic characteristics. A Multi-Criteria Analysis (MCA) framework, integrated with Geographic Information Systems (GIS), assigns user-specific weights to TOD indicators. The methodology is applied to case studies in Eindhoven to compare traditional TOD assessments with user-weighted assessments.

Results demonstrate that incorporating user preferences alters TOD rankings, highlighting the importance of diverse mobility needs and preferences in urban planning. The study concludes that integrating user segmentation into TOD frameworks enhances their inclusivity and effectiveness, offering insights for policymakers and urban developers.

Keywords: Transit-Oriented Development (TOD), user segmentation, urban mobility, Multi-Criteria Analysis (MCA), Geographic Information Systems (GIS), decision tree analysis, sustainable urban planning, transport accessibility, sociodemographic factors.

List of abbreviations

GIS – Geographic Information Systems
IPCA – Impedance Pedestrian Catchment Area
MCA – Multi-Criteria Analysis
ODiN – Open Data in the Netherlands (Dataset)
PT – Public Transport
SPSS – Statistical Package for the Social Sciences
TOD – Transit-Oriented Development

List of figures

Figure 1 Research design 18
Figure 2 TOD classifications (De Vos et al., 2014) 25
Figure 3 Case study area (OpenStreetMap Contributors, 2015) 33
Figure 4 Structure of decision tree 37
Figure 5 Decision tree output 40
Figure 6 Land use diversity Kronehoef (OpenStreetMap contributors, 2015) 47
Figure 7 Land use diversity Strijp-S (OpenStreetMap contributors, 2015) 47
Figure 8 IPCA Kronehoef (OpenStreetMap contributors, 2015) 49
Figure 9 IPCA Strijp-S (OpenStreetMap contributors, 2015) 50
Figure 10 Safety of commuters Kronehoef (OpenStreetMap contributors, 2015) 51
Figure 11 Safety of commuters Strijp-S (OpenStreetMap contributors, 2015) 52
Figure 12 Mode choice of user groups 57
Figure 13 Weights per user group 60
Figure 14 Output decision tree analysis full 85
Figure 15 TOD Index group 1 (OpenStreetMap contributors, 2015) 97
Figure 16 TOD Index group 2 (OpenStreetMap contributors, 2015) 97
Figure 17 TOD Index group 3 (OpenStreetMap contributors, 2015) 98
Figure 18 TOD Index group 4 (OpenStreetMap contributors, 2015) 98
Figure 19 TOD Index group 5 (OpenStreetMap contributors, 2015) 99

List of tables

Table 1 Criteria for measuring actual TOD Index (Singh et al., 2017) 23
Table 2 Category grouping of variables 36
Table 3 Data needed and their sources 45
Table 4 Defined user groups 56
Table 5 Weights per user group 59
Table 6 Land use (OpenStreetMap contributors, 2015) 64
Table 7 Passenger load (NS, n.d.-b; 9292, n.d.) 65
Table 8 Criteria and TOD Index scores for both neighbourhoods 67
Table 9 Comparison of TOD Index scores with weights of Singh et al. (2017) 69
Table 10 Ranking of criteria 92
Table 11 Ranking of indicators 93
Table 12 TOD values before normalisation 95
Table 13 TOD values after normalisation 96

1. Introduction

1.1. Problem definition

Cities worldwide face increasing challenges in developing sustainable and efficient transport systems to combat urban congestion, pollution, and climate change. Transit-Oriented Development (TOD) has emerged as a key urban planning strategy to address these issues by promoting compact, mixed-use communities centered around high-quality public transportation. TOD aims to reduce car dependency, encourage active transportation modes like walking and cycling, and enhance land use diversity, fostering vibrant and accessible urban environments (Calthorpe, 1993; Thomas & Bertolini, 2020; Hrelja et al., 2022).

Numerous cities have attempted to implement TOD with varying degrees of success. For example, Copenhagen's "Finger Plan" strategically developed urban corridors along railway routes, ensuring direct access to the city center (Li, 2016). However, while the plan is a landmark TOD strategy, Thomas and Bertolini (2020) argue that inconsistent adherence to TOD policies, inter-municipal competition, and weak site-specific planning tools have limited its effectiveness. Similarly, Vancouver has embraced TOD principles in its urban growth strategies, but political instability at the national and provincial levels has hindered long-term policy consistency. Meanwhile, in Arnhem-Nijmegen, TOD is being used to facilitate a modal shift from cars to public transport, yet challenges arise from a lack of public participation in transportation planning due to rigid governance structures (Thomas & Bertolini, 2020). These examples highlight both the opportunities and challenges associated with TOD implementation.

Despite its strengths, such as reducing car dependency, promoting mixed-use development, and enhancing transit accessibility, TOD also has notable limitations. One major issue is residential self-selection, where individuals prefer to live in areas that align with their existing travel behaviours, potentially limiting TOD's impact on mode shift (Ettema & Nieuwenhuis, 2017; Kamruzzaman et al., 2013). Additionally, TOD can accelerate gentrification and displacement, as rising property values near transit hubs often push out lower-income residents, contradicting TOD's goal of fostering inclusive and accessible communities (Pollack et al., 2010; Dawkins & Moeckel, 2016).

A fundamental limitation in TOD assessment methodologies is the overemphasis on physical and environmental factors, such as density, transit proximity, and land use mix, while overlooking the diverse needs and preferences of urban populations. In this context needs refer to what users must have in a transit-oriented development, like access to transit or safe walkways, while preferences refer to what users prefer or desire, which could be more subjective, such as choosing cycling paths over walking or preferring a certain type of service frequency. TOD frameworks are often designed for the "majority" standard, failing to account for variations in travel behaviour influenced by socioeconomic and demographic factors such as income, age, gender, and ethnicity (Cervero, 2002; Lucas, 2012; Chen et al., 2022). Consequently, existing TOD models may lack inclusivity and fail to effectively address the needs of different user groups, leading to urban developments that are not optimally aligned with the populations they serve (Allen & Farber, 2020).

To address this gap, this research proposes a user-centered TOD evaluation framework, incorporating the needs and preferences of different user groups through a segmentation approach. The Dutch population is classified into distinct user groups based on mode choice and sociodemographic characteristics, and individuals from each group evaluate the importance of different TOD criteria. This method enables a weighted assessment of TOD that seeks to contribute to a more equitable and user-oriented TOD planning process.

1.2. Research objective and research questions

The primary objective of this thesis is to refine the existing methodology for measuring TOD by incorporating the needs and preferences of different user groups. These groups are segmented based on a combination of sociodemographic factors, such as income, ethnicity, age, and gender, to capture variations in transportation behaviour. Rather than focusing on individuals, this research examines user groups to identify patterns in mode choice and assess whether TOD measurements can better reflect diverse mobility needs. The reason for this is further reflected on in Chapter 3.4.
A methodology of measuring TOD through a Multi-Criteria analysis (MCA) using Geographic Information Systems (GIS) software including user-derived weight will be tested to measure the effects. By doing so, this research aims to determine whether incorporating user-group-specific considerations leads to different TOD evaluations. The findings will contribute to improving TOD measurement methodologies, ensuring they are more inclusive and responsive to diverse mobility needs.

To address the central aim of this thesis, the following research question and sub questions will be explored:
"How can sociodemographic-based user segmentation improve the accuracy of TOD assessments?"

This question can be answered using the following sub-questions:
"What is the current process of assessing TOD within urban areas?"
The assessment of TOD typically relies on spatial criteria such as proximity to public transport, land use diversity, and urban density. However, these assessments often overlook user-centric factors that influence how different population groups interact with the built environment. This research reviews existing TOD measurement frameworks, including established TOD Indices, to determine their strengths and limitations. The literature review will highlight how current methodologies account for, or neglect, user preferences and sociodemographic factors, setting the foundation for a more inclusive TOD assessment.

"Which user groups can be identified based on their mode choice and sociodemographic characteristics, and to what extent do these characteristics influence transportation preferences?"
This research aims to classify distinct user groups within the Dutch population by analysing their mode choice patterns and sociodemographic characteristics. Using decision tree segmentation on the ODiN dataset, the study identifies how variables such as age, income, education, and employment status contribute to grouping individuals with similar transportation behaviours. Rather than examining the direct causal effects of these factors on mode choice, the analysis focuses on how they interact to form meaningful user segments. This segmentation provides a structured approach to integrating user preferences into TOD assessment, ensuring that planning strategies reflect the diverse needs of different population groups.

"How can the assessment of TOD be adjusted to reflect the needs and preferences of diverse user groups?"
Traditional TOD assessments are designed around general urban planning principles without explicitly considering the varied needs of different user groups. By incorporating user-derived weightings for TOD criteria, this research explores how TOD assessments can be made more representative of population diversity. Through the use of surveys and rank-sum weighting methods, different user groups express their priorities regarding TOD-related factors such as accessibility, walkability, and transit service quality. This approach ensures that TOD evaluations reflect not only spatial characteristics but also the actual preferences of urban residents.

"What is the effect of sociodemographic-based user segmentation on the current process of measuring TOD?"
Integrating user preferences into TOD assessment introduces a new dimension to evaluating urban environments. This research examines how adjusting TOD measurements based on user-defined weights affects overall TOD scores across different neighbourhoods. The analysis focuses on two case study areas, Kronehoef and Strijp-S, to determine whether user-centered assessments lead to significantly different rankings compared to traditional TOD evaluations. The findings provide insight into whether a more inclusive TOD assessment approach could influence urban planning decisions and policy development.
This research focuses on areas rather than individual stations because a broader spatial context is necessary to capture the full impact of TOD on different user groups. While station-based analyses provide valuable insights, area-based assessments better reflect the complex urban dynamics that influence accessibility, land use diversity, and multimodal transport interactions. This shift aligns with contemporary urban planning approaches that emphasise holistic, neighbourhood-wide improvements rather than isolated station-focused development.

1.3. Research design

This thesis follows a structured, multi-phase research design aimed at exploring how user preferences can be integrated into the assessment of TOD. The research consists of three main phases: a literature review, methodology development, consisting of the user group segmentation and weight assignment, and the TOD Index calculation. This can be seen in Figure 1.

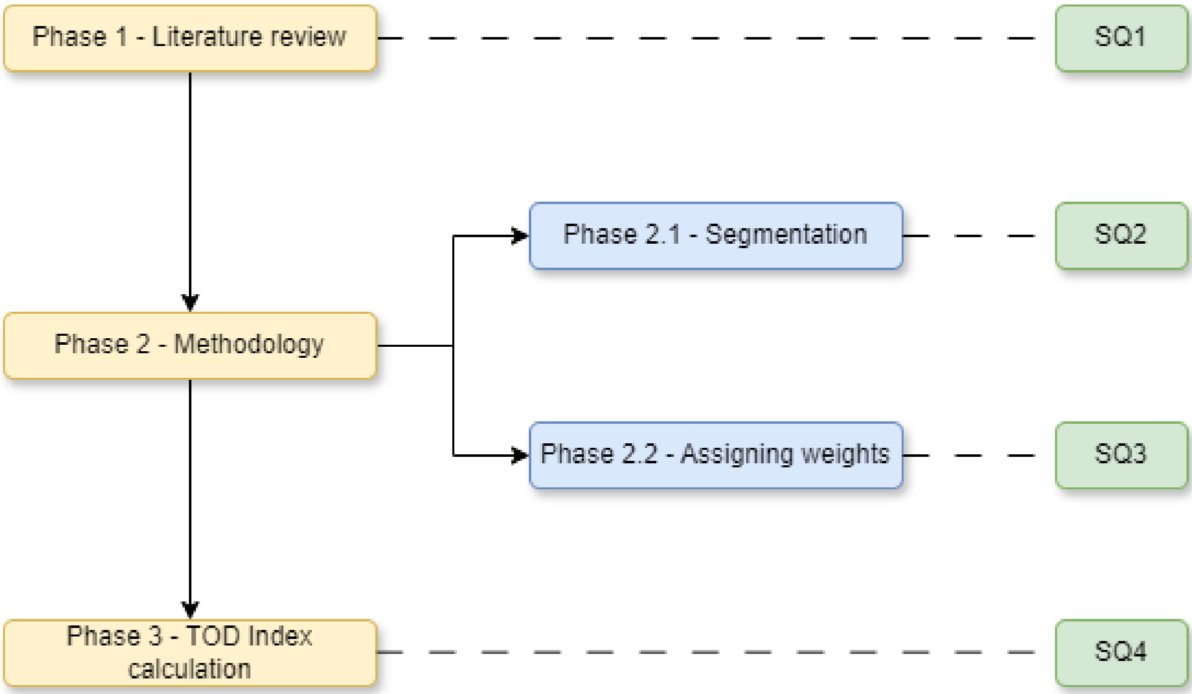

Figure 1 Research design

The first phase addresses the first sub-question by reviewing existing methodologies for assessing TOD. The literature review examines TOD principles, TOD Indices, and methods used to evaluate factors such as transit accessibility, urban density, and land use diversity. Additionally, it explores the influence of socio-demographic factors, such as income, ethnicity, age, and gender, on travel behaviour and mode choice. This phase establishes the theoretical foundation of the research by identifying gaps in current TOD assessment frameworks, particularly regarding their ability to account for user-specific needs and preferences. The review process involved a systematic search of academic sources using databases such as Google Scholar, Scopus, and ScienceDirect, supplemented by relevant policy reports and industry publications. Through backward and forward citation searches, the study ensures a comprehensive overview of existing TOD evaluation approaches and their limitations.

The second phase, forming the core of this research, focuses on the development and implementation of a methodology to integrate user preferences into TOD assessment. This phase directly addresses the second and third sub-questions by first identifying relevant user groups, then determining their priorities regarding TOD criteria, and finally incorporating these insights into the TOD assessment process. To achieve this, a segmentation analysis was conducted to classify distinct user groups based on their transportation mode choice and sociodemographic characteristics. This segmentation process utilised the ODiN dataset, which contains nationwide mobility data. A decision tree analysis, specifically the CHAID method, was applied in SPSS to define user groups based on transportation mode choice and demographic variables such as age, income, and employment status. The result of this analysis produced five user groups with distinct mode-choice preferences.

Following the segmentation process, surveys were conducted to understand how different user groups prioritise TOD-related factors, such as accessibility, density, walkability, and transit service quality. Participants were asked to rank the importance of these criteria, and the rank-sum method was used to assign weights to each factor based on user preferences.

These user-derived weights were then compared to conventional TOD assessment methods to determine how the integration of user preferences affects the overall evaluation process.
The final phase of this research addresses the fifth sub-question by analysing the broader implications of incorporating user preferences into TOD assessment. To assess the impact of these modified TOD weightings, the study applied an MCA to two case study areas: Kronehoef, a traditional urban neighbourhood, and Strijp-S, a redeveloped mixed-use district. The MCA compared the results of a conventional TOD assessment with the user-weighted TOD assessment, highlighting how different user groups perceive the transit-oriented nature of each neighbourhood. This allowed for a comparative analysis of whether integrating user preferences leads to meaningful differences in TOD assessment outcomes.
This phase focuses on comparing TOD scores across user groups to identify which populations benefit most from transit-oriented principles and where gaps remain in current assessment frameworks. By evaluating these results, the research provides insights into the potential for more socially inclusive TOD planning. Additionally, this phase reflects on the limitations of the methodology, including potential data constraints, assumptions in weight calculations, and the generalisability of findings beyond the Netherlands.
By following this three-phase approach, the research systematically integrates user preferences into TOD assessment, offering a nuanced understanding of how different user groups interact with transit-oriented environments. The findings contribute to the ongoing discussion on equitable TOD planning and provide a foundation for future research aimed at refining user-centered approaches to TOD evaluation.

1.4. Societal and academic relevance

This research holds both academic and societal significance. From an academic perspective, it advances the field of TOD assessment by integrating a user-centric framework into traditional evaluation methods. While existing TOD frameworks often focus on physical and infrastructural attributes, this research highlights the role of different user groups in shaping TOD effectiveness. By identifying how different user groups prioritise TOD criteria, such as transit accessibility, walkability, and land use diversity, this study provides a more detailed understanding of how TOD environments cater to different mobility needs and travel behaviours. Furthermore, it bridges the gap between transport planning and social inclusivity, demonstrating how user segmentation can refine existing TOD assessment models. This approach challenges the conventional one-size-fits-all methodology and promotes a more dynamic, user-based planning process.
From a societal perspective, this research underscores the importance of considering diverse user needs in urban planning. Traditional TOD strategies often assume a uniform set of priorities, which may not accurately reflect the varying preferences of different population groups. By incorporating user segmentation into TOD assessment, this study provides insights that can help planners and policymakers develop urban environments that better align with the way people actually interact with transit systems. Ensuring that TOD policies account for a broad range of user perspectives contributes to more effective and responsive urban mobility planning.

1.5. Reading guide

This thesis is structured into six chapters, guiding the reader through the research process and ensuring clarity in the development of research objectives, methodology, and findings.

- Chapter 1 Introduction: This chapter introduces the research topic, defining the problem statement, objectives, and research questions. It outlines the study's societal and academic relevance, emphasising the need for a user-centered approach to TOD assessment. The chapter concludes with an overview of the thesis structure.
- Chapter 2 Literature review: This chapter provides a comprehensive review of existing TOD assessment methodologies, the role of GIS and MCA in urban planning, and how demographic factors influence transit-oriented strategies. It identifies gaps in traditional TOD evaluation methods, particularly the neglect of user diversity, and lays the theoretical foundation for the study's methodology.
- Chapter 3 Methodology: This chapter details the research design, including the segmentation of user groups using decision tree analysis, the process of assigning user-weighted criteria, and the application of MCA and GIS techniques. It explains the data collection process, the statistical techniques used for segmentation, and the integration of user preferences into TOD calculations.
- Chapter 4 Results: This chapter presents the findings of the study, including the decision tree segmentation analysis, user-group-based weight assignments, and the results of the case study applications. It compares traditional TOD assessments with user-weighted TOD evaluations and discusses the observed differences in outcomes across different urban areas.
- Chapter 5 Discussion: This chapter interprets the key findings within the broader context of TOD research, discussing their implications for urban planning and policymaking. It examines methodological limitations, potential biases in the data, and opportunities for refining TOD assessment frameworks in future studies.
- Chapter 6 Conclusion: This chapter summarises the main insights from the research, emphasising the benefits of a user-focused TOD framework. It outlines key takeaways for policymakers and urban planners, offering recommendations for integrating user preferences into TOD strategies. The chapter also suggests directions for further research, particularly in the areas of inclusive transport planning and participatory urban development.

2. Literature review

This chapter provides a comprehensive review of the existing literature related to the integration of user-centered perspectives into TOD assessments, particularly through the use of GIS and MCA. The primary purpose of this chapter is to establish the theoretical foundation for the research by exploring key concepts, methodologies, and studies that inform the evaluation of TOD through a user-specific lens. A critical examination of both traditional and more recent studies in the field reveals the growing importance of considering diverse user needs and preferences when assessing TOD.

The chapter is structured in a way that first presents a detailed explanation of the key concepts related to TOD, including its principles, criteria, and the general approach to its evaluation. This is followed by a review of the methodologies used in TOD assessments, with a particular focus on GIS and MCA as tools for spatial analysis and decision-making. The review also highlights studies that have integrated user segmentation into TOD evaluations, showing the relevance of considering different demographic and socioeconomic groups in shaping TOD outcomes. Finally, the literature is synthesised to identify gaps in existing research and the need for a user-centered approach in TOD evaluations, which this research aims to address.

This structure allows for a clear progression from the broader context of TOD to the specific methodologies and approaches relevant to the research, ensuring that the reader can understand the significance of integrating user needs into TOD planning. The articulation of the literature in this manner is necessary because it not only sets the stage for the research but also clearly demonstrates how previous work has shaped the methodology and focus of this study, which aims to refine TOD assessments by incorporating user group priorities into the GIS-MCA framework.

2.1. Transit Oriented Development

2.1.1. Historical overview and definition

TOD is a concept that has been around for a long time. It can be seen as an urban planning strategy that promotes creating compact, walkable communities centred around high-quality public transportation systems, designed to reduce reliance on cars, enhance accessibility, and encourage sustainable urban growth (Carlton, 2009). The idea that transit might influence urban development and vice versa is not new. Transit as a form of transportation has been a part of the urban landscape since the horse-drawn streetcar was popularised in the mid-1800s. Since then, transit has interacted differently with the built environment to create urban forms. Peter Calthorpe, an American urban designer who is considered the father of TOD, classified the concept of TOD in the late 1980s (Calthorpe, 1993; HDR, n.d.). While others had promoted similar concepts and contributed to the design, TOD became a fixture of modern planning when Calthorpe published “The New American Metropolis” in 1993 (Carlton, 2009).

TOD can be described as "a compact, mixed-use community centred around a transit station, intentionally encouraging residents, workers, and shoppers to minimise car usage and embrace mass transit." (Zaręba et al. 2019, p. 2). TOD communities, designed with pedestrian-friendly and mixed-use features, integrate housing, employment, and retail spaces with a high or medium density (Zaręba et al., 2019).

2.1.2. Core principles of TOD

TOD emphasises the importance of the "five Ds" - density, land use diversity, urban design, destination accessibility and distance to transit highlighting their crucial role in promoting sustainable development (Singh et al., 2014). By focusing on these principles, TOD facilitates the creation of dynamic activity zones along transit lines, which represent continuous areas or corridors of high activity and development that emerge along said transit lines. This sustainable urban transport approach is considered a viable solution for addressing both traffic congestion and environmental challenges linked to transportation (Singh et al., 2014; Zaręba et al., 2019). Compact development is a fundamental principle in sustainable urban development as it reduces sprawl, preserves open space, and promotes efficient land use. Encouraging the densification of existing urban structures is viewed as essential for optimising land utilisation, mitigating urban sprawl, and limiting the consumption of ecologically valuable areas (Schorcht et al., 2023).

In a report set up by the Institute for Transportation and Development Policy (ITDP), called the TOD standard, several core principles are stated (ITDP, 2017). These principles focus on walking, cycling, connecting, transit, mix, densify, compacting, and shifting, showing that TOD not only focuses on transport but also other aspects of urban planning, such as mixed land use and urban density to combat effects such as climate change, urban sprawl and population growth. These are all topics that also correspond to the five Ds.

This claim is further supported by Thomas and Bertolini (2020) who state that a successful TOD is heavily dependent on the five Ds. In their research, they provide the following definition of the five Ds:

- Density is measured as the concentration of a specific variable, such as population, housing units, or employment, within a given area.
- Diversity refers to the variety of land uses within a specific area and the extent to which these uses are represented in terms of land area, floor space, or employment. For example, single-use environments would have low diversity values. Metrics like jobs-to-housing or jobs-to-employment ratios are also used, though less frequently.
- Design refers to the characteristics of the street network, such as block size, the proportion of four-way intersections, and the number of four-way intersections per square mile. Additionally, factors like sidewalk coverage, average building setbacks, and street widths are sometimes considered.
- Destination accessibility is defined as the ease of reaching certain destinations, whether on a regional or local scale. Common measures include the distance to the central business district and the number of jobs accessible within a specified travel time.
- Distance to transit refers to the maximum distance people are willing to walk to reach transit stations. Additionally, Zaręba et al. (2019) state that TOD communities are located within 600 to 800 meters of transit stops.

2.1.3. TOD indices

TOD can be a promising strategy for urban redevelopment, as its various criteria can help identify areas in need of revitalisation. Singh et al. (2014) emphasised the importance of assessing multiple indicators related to the five D's (density, diversity, design, destination, and distance) and incorporating them into a unified index. The index proposed by Singh et al. (2014) stands out because it integrates both spatial and design-related factors, making it applicable to diverse urban contexts. This method was selected for this research due to its established relevance and flexibility in assessing TOD suitability across different locations, with minimal adjustments needed for specific case studies. Singh et al.'s index is still widely referenced in TOD research (Sun et al., 2024; Yi et al., 2024), making it a robust foundation for the analysis of TOD in this study.

The criteria used in the TOD index focus on various aspects of urban development. For example, land use diversity and the encouragement of walking and cycling are measured through factors such as the mix of land uses, the presence of residential areas, the quality of the streetscape for both walking and cycling, and the density of controlled intersections and street crossings. These aspects of urban design are closely aligned with the criteria of land use diversity, as they reflect how mixed and accessible the area is for different types of transportation.

Singh et al. (2014) introduced the concept of the potential TOD Index, which measures TOD potential in areas that may not currently have transit connectivity but possess the necessary characteristics for future TOD development. This index is useful for identifying regions that could benefit from transit infrastructure in the future, even if they lack existing transit services. The potential TOD Index assesses criteria like residential and employment density, land use diversity, and urban design features that support walking and cycling.

In their conclusion they also describe an actual TOD Index. This TOD Index measures existing TOD levels around current transit nodes, focusing on areas within a walkable distance of these nodes. This index evaluates how well urban development around existing transit services aligns with TOD principles, providing a more localised assessment of TOD suitability.

To refine the actual TOD Index, in a follow up study, Singh et al. (2017) introduced additional criteria such as capacity utilisation of transit, user-friendliness of the transit system, access to and from stations, and parking availability at transit stations. These added dimensions have made the actual TOD Index more comprehensive, improving its ability to assess TOD levels in transit-adjacent areas. This methodology remains foundational for TOD assessments and has been applied in numerous studies (Sun et al., 2024; Yi et al., 2024; Ibrahim et al., 2023; Anwar et al., 2024). In these studies, researchers have used Singh et al.'s index as a baseline, making minor adjustments for their specific research contexts. For example, Yi et al. (2024) focused on metro stations, adjusting the criteria to assess TOD levels primarily for metro transit.

In Table 1, the complete set of criteria for measuring actual TOD, as proposed by Singh et al. (2017), is presented.

Table 1 Criteria for measuring actual TOD Index (Singh et al., 2017)

Criteria	Indicators	Measurements
Various densities	Residential density	Number of residential units per square kilometre
	Commercial density	Number of commercial establishments per square kilometre
Land use diversity	Land use diversity	Proportion and variety of different land uses within a given area (entropy index)

Encouragement walking and cycling	Level of mixed-ness of land uses w.r.t. residential land use	Degree to which different land uses (residential, commercial, etc.) are integrated within the same area
	Quality and suitability of streetscape for walking and cycling	Length of walkable/cyclable paths/roads
	Density of controlled intersections/street crossings	Number of traffic lights, pedestrian crossings, and other traffic control measures within a specific area
	Impedance Pedestrian Catchment Areas (IPCA)	area that can be accessed by walking within a specified time from a railway station
Current level of economic development	Number of business establishments	Total number of businesses operating in the area
	Tax earnings of municipality	Analysed through municipal tax records and revenue reports
	Unemployment levels	Employment statistics and labour market surveys
Capacity utilisation of transit	Passenger load at peak hours	Total number of passengers divided by total capacity of the transit system at station
	Passenger load at off-peak hours	
User-friendliness of transit system	Safety of commuters at the transit stop	Number of shops and eating joints
	Information display systems	Presence of static and dynamic information display systems
Access to and from the transit station	Frequency of transit service	Number of transit services per hour from transit station
	Interchange to different routes of same transit	Number of transit routes accessible at each transit station
	Interchange to different transit modes	Number of different transit modes at transit station
	Access to opportunities within walkable distance from transit station	Number of jobs accessible within the area of analysis for each station
Parking supply at the transit station	Parking supply demand for cars/four-wheelers	Number of occupied spaces divided by total number of spaces
	Parking supply demand for cycles	

2.1.4. TOD classifications

De Vos et al. (2014) created a subdivision for TODs based on the initial stage of development. According to this TODs fall into three classifications (see Figure 2): (1) new TODs, established in proximity to recently introduced public transportation services; (2) high-density TODs, where new public transportation services are integrated into pre-existing, compact, mixed-use areas; and (3) low-density TODs, characterised by elevating the density and diversity of existing suburban-style neighbourhoods adjacent to public transportation services (Thomas et al., 2018) (De Vos et al., 2014). This classification is useful to identify how a neighbourhood can be developed as a TOD.

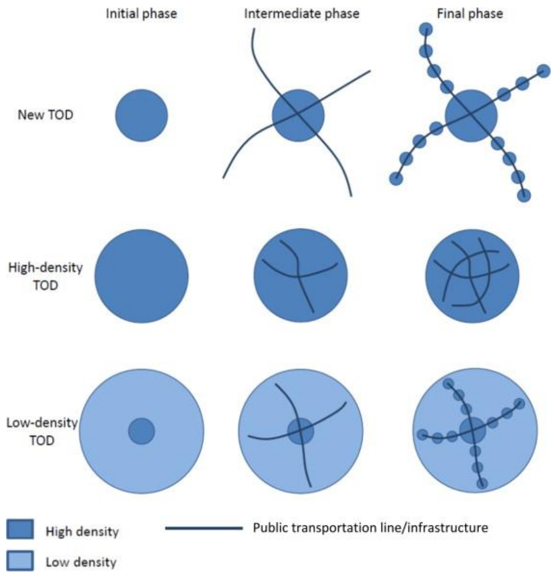

Figure 2 TOD classifications (De Vos et al., 2014)

The first classification focuses on developing new neighbourhoods around public transportation services, focusing on compact, mixed-use areas surrounding transit stations (De Vos et al., 2014). The second classification looks at developing new public transportation services within and between existing compact mixed-use areas (De Vos et al., 2014). The third classification is a combination of the first two, in this classification the aim is to increase the density and diversity of the areas and create new public transportation services within these areas (De Vos et al., 2014).

For the Netherlands, Pojani and Stead (2014) performed research on the resurgence of TOD in Dutch planning policy. In their study, they conducted interviews with over 40 experts, including policy officers from various levels of government, Dutch Railways, the Ministry of Infrastructure and Environment, and independent specialists. From these interviews, they identified the characteristics of what would be considered the ideal TOD model in the Netherlands. Their findings outline key aspects such as the emphasis on visually appealing, midrise, medium-density, mixed-use neighbourhoods, the importance of multifunctionality, where living, working, shopping, and recreation are concentrated around railway stations, and the role of multimodal transportation, integrating walking, cycling, public transport, and cars. They also highlight the balance between accessibility to transport and maintaining a high-quality living environment by screening stations from residential views. Huang et al. (2018) further delved into the different TOD classifications for the Netherlands and called them typologies. For their study, they used the city region of Arnhem-Nijmegen as their study area. In this city region, three distinct types of TOD typologies have been identified, each serving unique roles within the network.

Suburban Residential nodes are characterised by low population, job, and business densities. These areas are primarily residential and function as feeder stations, channelling passengers from suburban locations to core urban areas. They are located farther from employment centres, have limited street connectivity, and offer fewer facilities for walking or cycling.

Urban Residential nodes are somewhat denser, providing moderate job opportunities and slightly better connectivity for pedestrians and cyclists. However, they still lack the diversity

of land uses and accessibility to services seen in more central nodes, making them less multifunctional than core areas.
In the centre of the network are the Urban Mixed Core nodes, which have the highest densities of population and jobs. These nodes feature diverse land uses, ranging from commercial to residential, and benefit from better-designed infrastructure, including highly connected streets and transit options. Located in central business districts, they serve as key hubs within the TOD system, integrating various functions and transport modes to support a vibrant urban environment.
In conclusion, these different TOD typologies provide valuable insights into the varying characteristics and stages of TOD development. By applying these typologies, it becomes easier to identify areas with distinct needs and opportunities for this research. Based on the insights presented in this chapter, Strijp-S and Kronehoef were selected as the case study areas for this research, as they each fall into different typologies of TOD development. Strijp-S aligns more with an Urban Mixed Core node, featuring higher densities and diverse land uses, while Kronehoef corresponds more closely to a Suburban Residential node, with its lower densities and more limited mix of land uses. This contrast between the two areas offers a unique opportunity to explore how different TOD typologies influence user group needs and preferences.

2.2. Diverse user groups in TOD

2.2.1. User-centric TOD

One of the shortcomings in the existing literature and research on TOD concerns stakeholder engagement and community participation. Carlton (2009) states that TOD projects overall lack ambition regarding the impact they can have on users. He states that TODs often fail to address diverse user groups' behavioural and lifestyle preferences. This claim is further supported by Lucas (2012) who states that transportation policies, including TOD, frequently neglect the needs and preferences of socially excluded groups, such as low-income individuals and ethnic minorities. This shows that TOD does not thoroughly look at the interests of different user groups. Besides this, Allen & Farber (2020) found that several researchers have emphasised that reducing the risks of social exclusion and increasing considerations of social equity should be more thoroughly integrated into transport planning practices. These are critical for the success of TOD projects because the preferences and needs of the users will realistically determine part of the implementation outcome. Demographic and socioeconomic variables are crucial factors influencing travel behaviour within the built environment. Studies have consistently shown that these variables significantly affect individuals' mode choices, highlighting their importance in transportation planning and policy.
Few studies on evaluating inequity in TOD with a specific emphasis on demographic and socioeconomic variables have been done. One relevant study is that of Chen et al. (2022), which looked at user age in high-density, public-transport-oriented cities like Tokyo. Their study found significant inequities in TOD service levels based on user age. Specifically, they observed a negative correlation between the average age of users and most TOD indicators. These indicators included passenger load, the number of transfer lines, walkability index, and various accessibility factors such as the number of bicycle parking spots, bus stops, and the density of intersections. Chen et al.'s methodology involved selecting a 500-meter station catchment area to collect data on indicators like footways, cycleways, and public transport infrastructure. They expanded the radius to 1500 meters for indicators like population and

commuter density to ensure a comprehensive analysis. The inclusion of factors such as average land price, housing price, and land use diversity helped better understand the relationship between demographic factors and TOD outcomes in this densely packed environment. They go on to highlight the importance of considering demographic factors in urban planning to address inequities.

Another relevant study is the work of Zhao et al. (2024). They propose a Node-Place-People model, an extension of the traditional Node-Place model, to analyse TOD with a focus on social equity. This model adds the People dimension to assess the vulnerability of residents to gentrification and displacement, factors that the original NP model does not address. Their study area consisted of 133 TOD sites in Austin, Texas. In addition to the traditional indicators of the Node-Place Model, they incorporated the dimension of people/vulnerability (Ethnic minority; Elder; Foreign-born; Low income; Without car). By doing this they identified significant imbalances in TOD performance when considering the people/vulnerability dimension, especially in vulnerable communities. High transportation service (Node) and land-use development (Place) in certain TOD areas coexist with high levels of social vulnerability. These areas are at risk of gentrification and displacement, particularly impacting low-income, minority, and carless households. They explain that while TOD can enhance accessibility and land use, it may also lead to inequities if social vulnerability is not addressed. The integration of the People dimension into TOD planning can help mitigate these issues and foster more equitable TOD development.

Studies like those of Singh et al. (2014), Singh et al. (2017), Ibrahim et al. (2023), Sun et al. (2024), Yi et al. (2024) and Anwar et al. (2024) are examples of studies that do not take demographic and socioeconomic variables of the population of their research area into account when calculating the level of TOD. Ignoring these variables risks producing models that may not account for the diverse needs and preferences of different user groups. Integrating such factors is crucial, as they have been shown to impact travel behaviour, and their omission could result in policies that fail to address social equity concerns in TOD development.

2.2.2. Different user groups

Since this study focuses on the needs and preferences of the users of the urban environment, it is essential to segment the population into user groups based on mode choice. Given that the analysis is based on Dutch data, this segmentation reflects mode choice patterns within the Netherlands. In the context of this research user groups can be seen as segments of the population categorised by their mode choice patterns and socio-demographic characteristics. This importance is stressed because to create a just mobility distribution all user groups need to be looked at independently (van Luven, n.d.). In the study performed by Kattiyapornpong and Miller (2006), they found that variables like family life cycle, age, gender, education, income, marital status and cultural background influence travel behaviour. In their research, they decided to segment their survey respondents into different groups. They did this because segmentation helps understand the unique barriers and opportunities each group faces when making travel decisions. Besides this, segmentation makes the findings more applicable for designing targeted travel services, policies, or marketing strategies. They segmented the group of respondents based on combinations of socio-demographic factors such as age, income, and life stage. Specifically, they utilised these variables to create socio-demographic groups and then compared travel plans and past travel behaviour across these groups. Since they defined socio-demographic groups in advance, every respondent is assigned to one of these groups. However, this approach may overlook individual differences and unique travel behaviours. The segmentation process was not based on the respondents themselves.

Within the existing literature on the influence of demographic and socioeconomic variables on travel behaviour, many studies examine their impact at the individual or household level. For example, Vij et al. (2013) and Ardeshiri and Vij (2019) specifically examined how household characteristics and individual characteristics influence travel mode choices using latent class analysis. These studies are relevant here because they demonstrate how segmentation techniques can capture variations in travel behaviour beyond traditional demographic groupings.

While existing research has explored how socioeconomic and demographic variables influence travel behaviour at the household and individual levels, fewer studies have examined these effects across user groups. Although some research has incorporated segmentation approaches, there remains a gap in understanding whether current methods adequately capture the diversity of travel behaviours within a population. This raises the question of whether a user group-based approach, such as the one adopted in this study, can provide deeper insights into the relationship between demographic and socioeconomic factors and travel behaviour.

Whooz, a data analytics and segmentation company, demonstrates that a population can be categorised into distinct user groups based on socioeconomic and demographic variables (Whooz, n.d.). Their Whize segmentation divides the Dutch population into eleven segments using factors such as age, gender, household type, income, education level, cultural background and norms and values. This segmentation highlights how socio-demographic and behavioural characteristics can be systematically used to classify populations into meaningful groups, an approach that could be relevant across various domains, including transportation research.

2.2.3. Demographic factors influencing mode choice

Several researchers have already answered whether socioeconomic and demographic variables affect travel behaviour (Kattiyapornpong and Miller, 2006; Vij et al., 2013; Ardeshiri and Vij, 2019; Van Acker and Witlox, 2009). The most frequently discussed variables in these researches are age, income, household size, employment, marital status, education, gender and race/ethnicity.

De Witte et al. (2013) performed extensive research on how socio-demographic indicators influence a person's mode choice. In a more recent study performed by Meli (2022), the work by De Witte et al. (2013) was revisited and further explored. Meli (2022) performed research on the influence of socioeconomic variables on mode choice in Switzerland. In both papers, the following relevant variables were researched: age, education, occupation, income and household structure.

Both found that older people may experience decreased ability to use certain transportation modes, such as driving or cycling, due to physical limitations. As a result, older people tend to use public transport more as they age, but the utility of public transport increases more gradually compared to walking or cycling. Besides this, it was concluded that in countries such as the Netherlands, walking and cycling remained important for the elderly.

De Witte et al. (2013) and Meli (2020) also found that education and car usage have a negative correlation. This means that when a person has a higher level of education they tend to prefer public transport or active modes of transportation of the use of a car. This is further supported by Limtanakool et al. (2005) who did a study on mode choice in the Netherlands. They also found that higher-educated people overall make more use of public transport than medium or lower-educated people. In their study, they found that on average highly educated people use public transport 20.7% of the time compared to lower educated people with only 8.1% of the time.

Meli (2020) found that employed people are more likely to use cars as their mode of transport, while unemployed people are more likely to use public transport. Besides this, De Witte et al. (2013) found that full-time workers are more likely to use transit, especially if they have transit travel passes. On the other hand, they found that part-time workers and self-employed individuals are more likely to drive and less likely to walk.

Income is one of the most important factors in determining mode choice (De Witte et al., 2013). Many studies conclude that a higher income is associated with increased car usage over public transport and active modes of transportation (Meli, 2020). This is further supported by Limtanakool et al. (2005) who found that lower-income individuals are far more likely to use public transportation for commuting. Adding on this, Vanoutrive (2018) and Rice (2004) both found that low-income households tend to own fewer cars and spend significantly less on transportation compared to higher-income households. Vanoutrive's study in Vlaams Gewest and Rice's analysis in the U.S. both highlight this pattern, reinforcing the link between income levels and mobility expenditures.

Both De Witte et al. (2013) and Meli (2020) noted that the presence of children in a household positively affects the usage of cars and negatively affects the utility of public transportation. Limtanakool et al. (2005) also found that single-person households are the most frequent users of public transportation at 22.9% and couples without children are the least frequent at 16.4%. Couples with children use public transportation 17.5% of the time, but mostly for leisure activities.

2.3. GIS and MCA applications in TOD planning

The combination of GIS and MCA is not something new. Since 1990 GIS-based MCA has been a growing topic among researchers (Greene et al., 2011). They explain that the primary goal of spatial applications of MCA is to enhance the traditional focus on "what" by also addressing the question of "where." Integrating MCA with GIS significantly enhances traditional decision-making methods (Aminu et al., 2017). GIS-based MCA combines spatial and non-spatial data, transforming them into a comprehensive decision output (Motlagh et al., 2020). This process incorporates geographical data and stakeholder preferences, merging them into single-dimensional values representing alternative decisions. Such integration ensures decisions are well-informed and reflective of stakeholders' needs (Khare et al., 2021).

In a study by Poholka (2011) GIS and MCA were employed to locate optimal affordable housing sites. Their first step was to identify relevant criteria based on their literature review and local context. These included quantitative criteria such as income and rent prices, but also qualitative criteria such as community preferences. After this, they weighted their criteria based on their importance in the decision-making process. This weighting allowed for the prioritisation of certain factors over others, reflecting the specific needs of the community. The selected criteria were then mapped using GIS. The study utilised secondary data from reliable sources, including the City of Kelowna and the Regional District of Central Okanagan (RDCO) GIS departments. This data included demographic statistics, housing prices, and infrastructure locations. The researchers integrated the various data layers into a GIS platform, allowing for spatial analysis of the criteria. This step involved creating maps that visually represented the distribution of factors across the city. After this, the MCA analysis was performed in which each potential location was scored based on how well it met the weighted criteria. Higher scores indicated more favourable conditions for affordable housing development.

In a study conducted by Khare et al. (2021), GIS and MCA were used to measure the TOD of Bhopal in India. GIS software was employed for spatial analysis, allowing the mapping of selected transit stations in Bhopal using data from the municipal corporation and Google Earth. This mapping facilitated the creation of a transit core and neighbourhood around the transit stations, essential for understanding the spatial context of TOD. The study employed MCA techniques to assess the level of TOD. This involved using both spatial and non-spatial performance measures to evaluate the selected criteria. The MCA results provided quantitative values for the performance measures, allowing for the ranking and comparison of different stations. A TOD Index was calculated based on the selected performance measures, which provided a quantitative measurement of the TOD level around the studied transit stations. This index served as a basis for effective planning schemes tailored to the specific land-use types and development patterns of the area. The results of the TOD Index and MCA were analysed to conclude the current levels of TOD in Bhopal. The findings aimed to inform sustainable urban planning and the rapid development of the Bus Rapid Transit System (BRTS) in the city.

A similar study was conducted for the TOD of Alexandria in Egypt by Ibrahim et al. (2023). The research relied on a GIS-SMCA model to assess the TOD potential of different neighbourhoods in Alexandria. The model integrated spatial analysis with multi-criteria decision-making to calculate a TOD Index, allowing planners to rank areas based on their suitability for TOD development. This involved gathering a wide range of data, including population density, land use, transportation networks, and economic activity, from multiple Egyptian government agencies. Once collected, the data was processed into spatial formats such as shapefiles, which could be analysed in GIS software. Indicators for measuring TOD were identified which included residential, commercial, employment, and population density, as well as land-use diversity and mixedness, which captured the degree of integration between residential and non-residential areas. Economic development was also considered through business density measures. Using the SMCA model, these indicators were standardised to ensure they could be compared across different units. They were then weighted according to their relative importance to TOD principles, such as accessibility, density, and mixed land use. After weighting, the indicators were combined to compute a TOD Index for each grid cell. This process helped identify areas with high or low TOD potential across the city. The study applied statistical analyses, such as hotspot detection and Moran's I statistic, to identify clusters of high TOD potential. The results revealed that the highest TOD scores were concentrated in Alexandria’s inner-city areas, which had higher population densities, a mix of land uses, and better economic activity. In contrast, peri-urban zones showed lower TOD potential but were highlighted as areas where future transit infrastructure could be developed to support growth.

While the integration of GIS and MCA has proven to be a valuable tool in urban planning, existing studies primarily focus on identifying optimal locations based on predefined criteria, often emphasising spatial and economic factors. However, these studies tend to overlook the diversity of user groups within the population and how their specific needs and preferences influence TOD outcomes. For example, while studies on affordable housing and TOD effectively map and weigh various criteria, they typically adopt a one-size-fits-all approach that does not account for variations in travel behaviour across different demographic and socioeconomic segments. Additionally, existing research largely emphasises the technical

implementation of GIS-MCA but provides limited insight into how different user groups experience and interact with transit-oriented environments.
This gap underscores the need for a more user-centered approach in GIS-based TOD evaluations. By incorporating user segmentation into the GIS-MCA framework, this research aims to refine TOD assessments by considering how different user groups prioritise criteria such as accessibility, density, and mixed land use. This perspective is particularly relevant for ensuring that TOD planning is not only data-driven but also socially inclusive, ultimately leading to more equitable and effective urban redevelopment strategies.

2.4. Conclusion

TOD stands as a pivotal strategy for advancing sustainable urban planning, advocating for the creation of compact, walkable communities centered around efficient public transportation systems. The core principles of TOD, encapsulated in the "five Ds" (density, diversity, design, destination accessibility, and distance to transit), offer essential criteria for fostering dynamic activity zones along transit corridors (Singh et al., 2014; Thomas & Bertolini, 2020).
Furthermore, the integration of demographic and socioeconomic factors into TOD planning is crucial for ensuring that the diverse needs and preferences of various user groups are met. Research has shown that the preferences and behaviours of different population segments significantly influence travel patterns, underscoring the importance of user-centric approaches in TOD initiatives (Zhao et al., 2024). This is particularly relevant in mitigating social inequalities, such as those arising from gentrification and displacement, ensuring that TOD policies are inclusive and equitable for all urban residents (Pollack et al., 2010; Kamruzzaman et al., 2013).
The application of GIS combined with MCA has proven invaluable in assessing TOD potential across different urban settings. These methodologies allow for the evaluation of both spatial and non-spatial criteria, enabling planners to pinpoint optimal sites for development while ensuring that strategies are tailored to meet the unique needs and preferences of local communities (Khare et al., 2021; Ibrahim et al., 2023). By incorporating diverse data and stakeholder input, GIS and MCA not only enhance the precision of TOD assessments but also contribute to broader goals of sustainable urban growth and social equity.
In conclusion, the literature highlights the multifaceted nature of TOD and its potential to transform urban landscapes by addressing key challenges such as climate change, population growth, and social inclusion. However, as existing research largely overlooks the diversity of user needs and preferences in TOD assessments, this research seeks to fill that gap by offering a more nuanced, user-centered approach. By refining TOD evaluations through the lens of demographic and socioeconomic factors, this study aims to provide valuable insights for planners and policymakers working towards resilient, equitable, and vibrant urban environments. This research is particularly relevant in the context of contemporary urban planning, where there is an increasing need to ensure that TOD strategies are not only effective in environmental and economic terms but also socially inclusive and sensitive to the needs and preferences of all community members.

3. Methodology

3.1. Introduction

This chapter builds upon the findings of the literature review to outline the methodological framework applied in this research. The literature established the critical need to integrate user preferences and demographic diversity into TOD planning, emphasising the significance of tailored approaches to address diverse urban mobility needs and preferences. To bridge the gaps identified in existing methodologies, this study employs a structured framework combining statistical analysis, informal consultation, and spatial data evaluation.

The methodology is designed to achieve the research objectives of identifying user groups, incorporating their needs and preferences into TOD criteria, and calculating a comprehensive TOD Index to assess the alignment of neighbourhoods with TOD principles for different user groups, taking into account their unique needs and preferences. Specifically, this chapter is organised into three key components:

1. **User Group Segmentation**: Guided by the literature, this phase identifies distinct population groups based on demographic and socioeconomic characteristics that influence transportation preferences and behaviours. Findings from prior studies inform the segmentation.
2. **Assigning Weights to Criteria and Indicators**: Building on existing frameworks, such as those proposed by Singh et al. (2017), this section integrates an individuals input to assign relative importance to TOD criteria and indicators for each user group.
3. **Calculation of the TOD Index**: Employing a MCA framework, this component quantifies the suitability of neighbourhoods, reflecting both user needs and preferences and TOD principles.

This research systematically addresses the gaps in current TOD methodologies and provides an approach that incorporates demographic diversity and user-centric perspectives, contributing to equitable and effective TOD planning.

This research focuses on areas rather than individual stations because a broader spatial context is necessary to capture the full impact of TOD on different user groups. While station-based analyses provide valuable insights, area-based assessments better reflect the complex urban dynamics that influence accessibility, land use diversity, and multimodal transport interactions. This shift aligns with contemporary urban planning approaches that emphasise holistic, neighbourhood-wide improvements rather than isolated station-focused development.

3.2. Research approach

The literature review described in Chapter 2 provides a foundational overview of the knowledge required to integrate user preferences and demographic diversity into TOD planning. This research aims to develop a methodology that evaluates how different user groups assess TOD by combining user group segmentation, the assignment of user group-derived weights to TOD criteria and indicators based on perceived importance, and the calculation of a TOD Index. The study examines whether incorporating user preferences influences TOD assessments and highlights variations in TOD suitability across different demographic segments. These steps are designed to address gaps in current TOD practices and ensure that diverse user needs and preferences are considered in the planning process.

To demonstrate the application of this methodology, two case study neighbourhoods, Kronehoef and Strijp-S in Eindhoven, are selected for analysis (See figure 3). These neighbourhoods represent contrasting urban environments, providing an opportunity to evaluate the TOD Index methodology across different contexts. Data for the case studies will be collected from publicly available sources, including the ODiN dataset (which samples the entire Dutch population), CBS, OpenStreetMap, Google Maps, and local transit agencies.

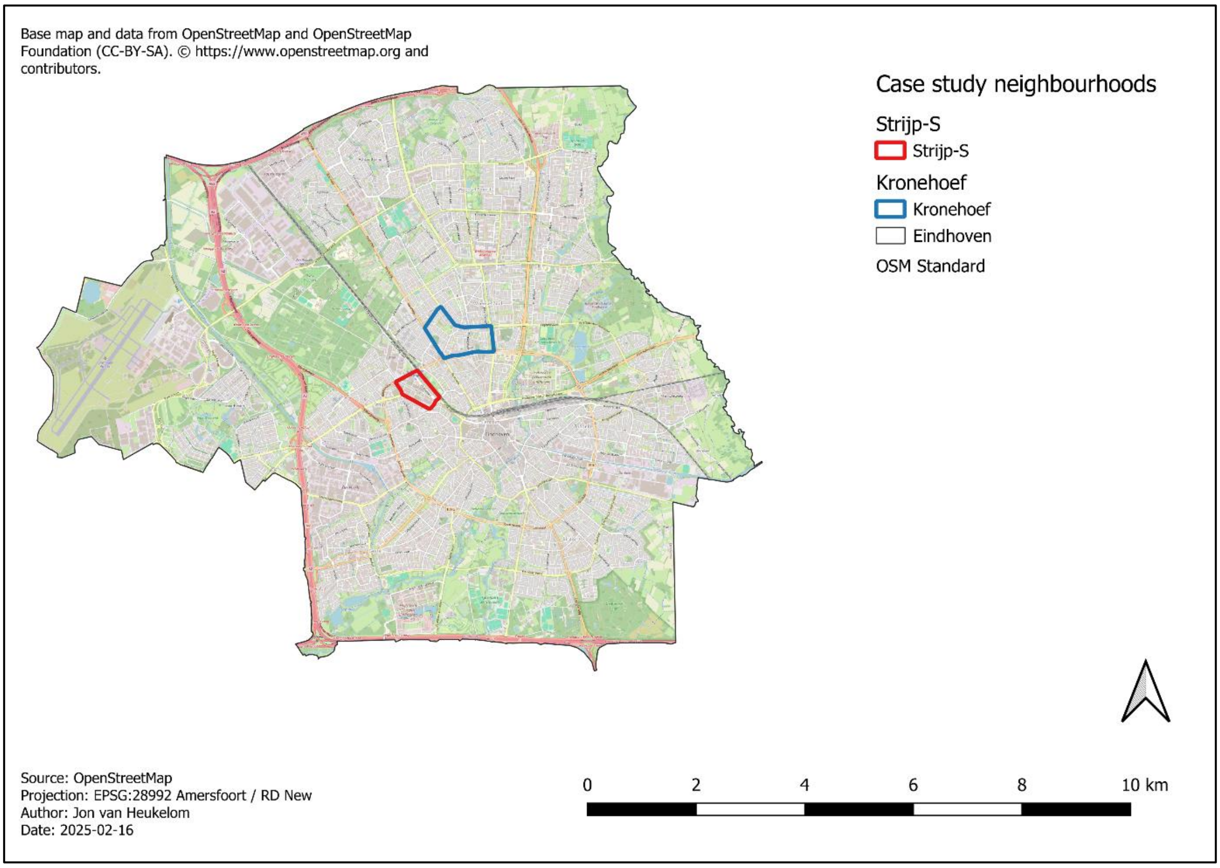

Figure 3 Case study area (OpenStreetMap Contributors, 2015)

The research methodology follows a structured and iterative approach. Starting, user groups are segmented using a decision tree analysis to classify the population based on socioeconomic and demographic characteristics and mode choice. Next, weights for TOD criteria and indicators are calculated through informal consultation, ensuring that the methodology captures the preferences of the identified user groups. Finally, the TOD Index is calculated for both case study neighbourhoods, using normalised and weighted criteria and indicators. The results of these calculations were then used to evaluate how user group based TOD assessments influence the TOD Index calculations.

Throughout the research, continuous testing and reflection are employed to improve the methodology and ensure its applicability. For instance, adjustments were made to the TOD Index calculation based on data availability and the specific characteristics of the neighbourhoods under study. The iterative nature of this process ensured that the final methodology is robust, flexible, and capable of addressing the diverse needs and preferences of urban populations.

This structured approach ensures that the developed methodology can be adapted to other contexts while maintaining its focus on inclusivity and sustainability. Figures illustrating the segmentation process, weight calculation, and TOD Index results for the case studies can be found in subsequent chapters.

3.3. User group segmentation

To develop a comprehensive TOD assessment framework, it is essential to account for the diverse needs and preferences of different user groups. Traditional TOD evaluations often assume a uniform population, failing to consider variations in travel behaviour based on demographic and socioeconomic factors. However, previous research has shown that factors such as age, income, education, employment status, and household composition significantly influence mode choice (De Witte et al., 2013; Meli, 2022). Where there are studies that do include sociodemographic variables in their methodology, they do this on an individual or household basis (Vij et al., 2013; Ardeshiri & Vij, 2019).

This research focuses on user groups rather than individuals because TOD planning requires broad, scalable insights that can guide urban planning at a policy level. While individual travel behaviours vary, analysing user groups allows for identifying patterns and trends that reflect the needs and preferences of larger segments of the population. This approach ensures that TOD criteria and indicators are adjusted to meet the needs and preferences of multiple communities rather than being tailored to highly specific individual cases, which would be impractical in large-scale urban planning. Additionally, user group segmentation helps urban planners prioritise interventions that benefit a wider range of residents, making TOD implementation more inclusive and effective.

This research ensures that TOD suitability assessments reflect the preferences of different travellers by segmenting the population into distinct user groups. This segmentation allows for a more nuanced understanding of which TOD criteria matter most to different groups, enabling more targeted and inclusive planning strategies.

The segmentation process involves analysing data from the ODiN dataset. This dataset, maintained by the Dutch Ministry of Infrastructure and Water Management, is a comprehensive and nationally representative survey capturing detailed information about travel behaviour in the Netherlands (CBS, 2024). This research employs Chi-Square Automatic Interaction Detection (CHAID), a decision tree classification method to segment the population into distinct user groups based on transportation behaviour. The CHAID algorithm is an effective method for rapidly generating meaningful segments based on demographic or other predictive variables, using a categorical dependent variable to define these segments (Magidson & Vermunt, 2005). CHAID is particularly suited for this study because it is designed to work with categorical and ordinal variables, making it an ideal choice for analysing demographic and socioeconomic characteristics that influence travel behaviour. Other fields have already used to method to create market segmentation. For example, Díaz-Pérez and Bethencourt-Cejas (2016) used it to segment the tourism market of La Palma. Another example is Hsu and Kang (2007), who used it to segment inbound travellers to Hong Kong based on travel purpose, age, income, and repeat visit status.

Several alternative decision tree methods were considered, including CRT (Classification and Regression Trees), QUEST (Quick, Unbiased, Efficient Statistical Tree), and Exhaustive CHAID. However, CHAID was selected for the following reasons (IBM, n.d.-b):

- Suitability for Categorical Data: CHAID is a non-binary tree method that allows multiple splits per node, making it more effective in handling categorical variables such as employment status, income groups, and education levels. In contrast, methods like

CRT create binary splits, which can lead to unnecessary complexity when dealing with non-continuous data.

- Chi-Square-Based Splitting: Unlike CRT and QUEST, which rely on measures like the Gini index or entropy, CHAID uses Chi-square tests to determine the best splits. This ensures that the most statistically significant relationships between demographic factors and transportation preferences are captured.
- Reduction of Overfitting: Exhaustive CHAID was considered, as it performs a more detailed search for optimal splits. However, its tendency to overfit made standard CHAID the better choice for ensuring generalisable user group classifications.
- Interpretability for Urban Planning: CHAID produces intuitive decision rules that are easy to interpret, making it more suitable for practical applications in TOD planning. Urban policymakers can readily understand how different user groups emerge based on demographic characteristics, aiding in more effective decision-making.

The segmentation process consists of several stages, including data preparation, decision tree construction, and clustering of terminal nodes to form actionable user groups. Data preparation ensures the dataset is clean and categorised effectively for analysis, while the decision tree algorithm identifies statistically significant splits to maximise the homogeneity within each group. Finally, the clustering phase consolidates terminal nodes into a manageable number of five user groups, each characterised by distinct transportation behaviour patterns. This detailed segmentation allows the TOD framework to integrate user preferences effectively, ensuring that the framework is equitable, user-centred, and aligned with TOD principles. All these steps were performed with the use of SPSS.

3.3.1. Data collection and preparation

The segmentation process begins with the collection and preparation of data from the available ODiN dataset released in 2023. It includes records of trips made by individuals, including variables such as trip modes (e.g., car, bike, public transport, walking), trip purposes, distances, travel durations, and detailed demographic data like age, gender, education, employment status, income, relationship status, and ethnicity. This information made it a valuable resource for analysing transportation preferences and patterns and provided a solid foundation for conducting the user group segmentation. The dataset was available in a structured format compatible with statistical software, facilitating efficient data handling.

The next step in the process was the selection of variables. The selection of variables for segmentation is directly informed by insights from the literature review, which underscores the importance of key demographic and socioeconomic variables in influencing transportation preferences within TOD contexts as described in Chapter 2.2. These variables are chosen to capture the complex relationship between user characteristics and their travel patterns. Demographic factors, such as age, gender, ethnicity, and relationship status, are included to reflect the diverse personal attributes that shape transportation needs. Socioeconomic variables, including education, employment status, and income, are incorporated to account for the economic and occupational factors influencing mobility choices. Additionally, travel behaviour variables in the form of mode choice are selected to provide a comprehensive understanding of how individuals interact with the transportation network. By aligning these variables with the research objectives, the segmentation framework ensures a detailed analysis of user groups tailored to the TOD planning process.

Variable categories are simplified to make the dataset more manageable and easier to interpret. For instance, age is grouped into categories such as <25, 25–40, 41–65, and 65+, while transportation modes are consolidated into broader groups like car users (including both drivers and passengers), cyclists, pedestrians, public transport users, and other modes. This step ensures that the analysis can focus on meaningful patterns without being overwhelmed by excessive detail. This is done in SPSS using the "Recode into Different Variables" tool. This tool transforms or groups data from an existing variable into a new variable while leaving the original variable unchanged. Next, records with incomplete data, such as unknown income, education, relationship status, etc needed to be deleted. The "select cases" tool in SPSS is used for this. Using this tool, it is possible only to select all cases relevant and delete irrelevant cases using a simple code (code can be seen in Appendix A). After doing this, only respondents with known data are left, leaving the category groups seen in Table 2. Doing this brought the number of observations down from 211,992 to 171,157.

Table 2 Category grouping of variables

Category	**Education**	**Employment**	**Age**	**Relationship**	**Income**	**Gender**	**Ethnicity**	**Mode choice**
1	Lower	Employed	<25	Single	Lower	Male	Netherlands	Car
2	Middle	Unemployed	25-40	Couple	Middle	Female	Europe	PT
3	Higher	Student	40-65		Higher		Outside Europe	Bike
4			65+					Foot
5								Other

3.3.2. Decision tree analysis

The segmentation process can start after the variable selection and data preparation performed in the last chapter. The choice was made to use a decision tree to do this. A decision tree can be described as a "non-parametric supervised learning algorithm, which is utilised for both classification and regression tasks." (IBM, n.d.-a). In Figure 4 the structure of a decision tree can be seen.

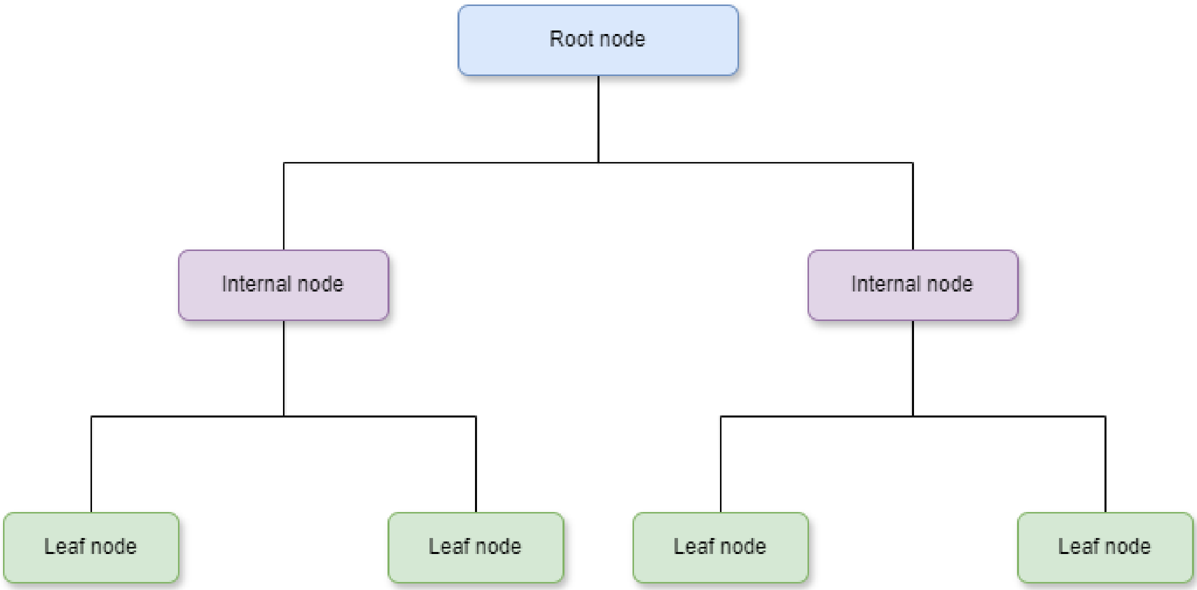

Figure 4 Structure of decision tree

According to Song and Lu (2015), the main components of a decision tree are nodes and branches and the most important steps in building a decision tree are splitting, stopping and pruning. They go on to explain that a decision tree begins with a root node, also called a decision node. From this root node the dataset is split into two or more outgoing branches leading to the internal node, also called chance nodes. These nodes represent one of the available choices at that point in the tree. At the top, it is connected to the parent node, and at the bottom it is connected to the child node. The last type of node is called a leaf node. This node represents the final result of a combination of different decisions made throughout the tree. Branches represent possible outcomes from the root and internal nodes, forming a hierarchical structure. Each path from the root node to a leaf node follows a set of decision rules that determine the final classification. Splitting in a decision tree divides data into child nodes based on input variables that best separate the target variable, using criteria like entropy or the Gini index to maximise purity. This process continues until a stopping condition is met, ensuring the tree effectively classifies new data. Stopping prevents a decision tree from becoming too complex and overfitting the data by setting limits on depth, minimum records per node, or other criteria. Pruning refines an already grown tree by removing less useful branches, either during (pre-pruning) or after (post-pruning) tree construction, to improve accuracy and generalisability. Song and Lu (2015) state that decision trees classify the population into branch-like segments, creating an inverted tree structure with root, internal, and leaf nodes. In this tree, the leaf nodes represent the segmented groups. This segmentation helps simplify complex relationships between input variables and target variables, showing that using decision trees for the segmentation of big datasets can be very useful.

After identifying that decision trees are useful in segmenting big datasets, the segmentation process can start. In this analysis, mode choice was used as the dependent variable and all other variables as the independent ones. An initial analysis was conducted using the standard SPSS settings, which include default parameters such as a minimum of 50 cases per child node, 100 per parent node, a maximum tree depth of 3 levels, 0.05 for splitting nodes, 0.05 for merging categories and 0.05 for cell frequencies. This resulted in more than a hundred final nodes, meaning over a hundred user groups, which Is too many. To address this, further research is conducted on decision tree parameters, referencing SPSS user manuals and academic literature. A first trial run was conducted to evaluate the impact of different settings on the decision tree structure. Several variations were tested, adjusting parameters such as significance thresholds for splitting (e.g., 0.001 vs. 0.0001), category merging (e.g., 0.1 vs. 0.2), minimum cell frequencies, and the number of cases required for parent and child nodes. Some settings led to overly simplified trees with very few final nodes (e.g., Tree 3 with only 3 nodes), while others resulted in incomplete trees with missing branches. By analysing these results, it was concluded that excluding variables can be done if the decision tree still produces meaningful and interpretable groupings, ensuring a balance between complexity and clarity. According to Song and Lu (2015), a decision tree automatically identifies the most relevant variables by evaluating their ability to best split the data. This is based on criteria such as information gain or the Gini index, which measures how well a variable separates the target variable into distinct groups. As a result, the variables appearing first in the tree are the most relevant for predicting the target, while those appearing later contribute less to the overall classification process. This approach is reliable because it ensures that the most informative variables are prioritised, improving the accuracy and interpretability of the model. In line with this, Díaz-Pérez and Bethencourt-Cejas (2016) also found that their first split complied with this idea, reinforcing that the most relevant variable is selected first based on its statistical association with the target variable. Adding on this, each split shows the Chi-squared value of that variable indicating the strength of the relationship between the splitting (or independent) variable and the target (dependent) variable. Larger values indicate a stronger relationship. This brings us to the second trial run in which the tree depth was put to three to identify the most relevant variables.

A second trial run was conducted in which the tree depth was permanently set to 3. The settings for splitting nodes and cell frequencies were decreased and merging categories, parent and child nodes were increased to prune the tree. After this trial, all trees were assessed by ordering the variables based on the tree level at which they appeared. This allowed for identifying the most relevant variables selected by the algorithm. Additionally, for the first two layers of the tree, Chi-squared values were analysed to measure the strength of the relationship between the splitting variable and the target variable. These were the only measures used, as the analysis focused on identifying the first splitting variables and evaluating their significance using chi-squared values.

To improve interpretability and reduce model complexity, the third trial run was conducted with a refined set of variables. Age, education, relationship status, and employment were retained, while less significant variables were excluded. This trial confirmed that age remained the dominant predictor, followed by education and employment. The results also indicated that reducing the number of variables did not substantially impact the segmentation quality.

To further refine the decision tree, adjustments were made to key parameters, including:

- Splitting significance threshold: Increased to allow for a more conservative selection of splitting variables.
- Merging categories threshold: Adjusted to combine similar categories and reduce over-segmentation.
- Minimum parent and child node sizes: Increased to ensure that each node contained a sufficient number of observations for meaningful analysis.

Based on previous results, relationship status was excluded, leaving three key variables: age, employment status, and education level. The final trial run confirmed that these three variables were sufficient for meaningful segmentation, producing a decision tree with 24 terminal nodes. A sample of the final decision tree is presented in Figure 5, with the full version available in Appendix B.

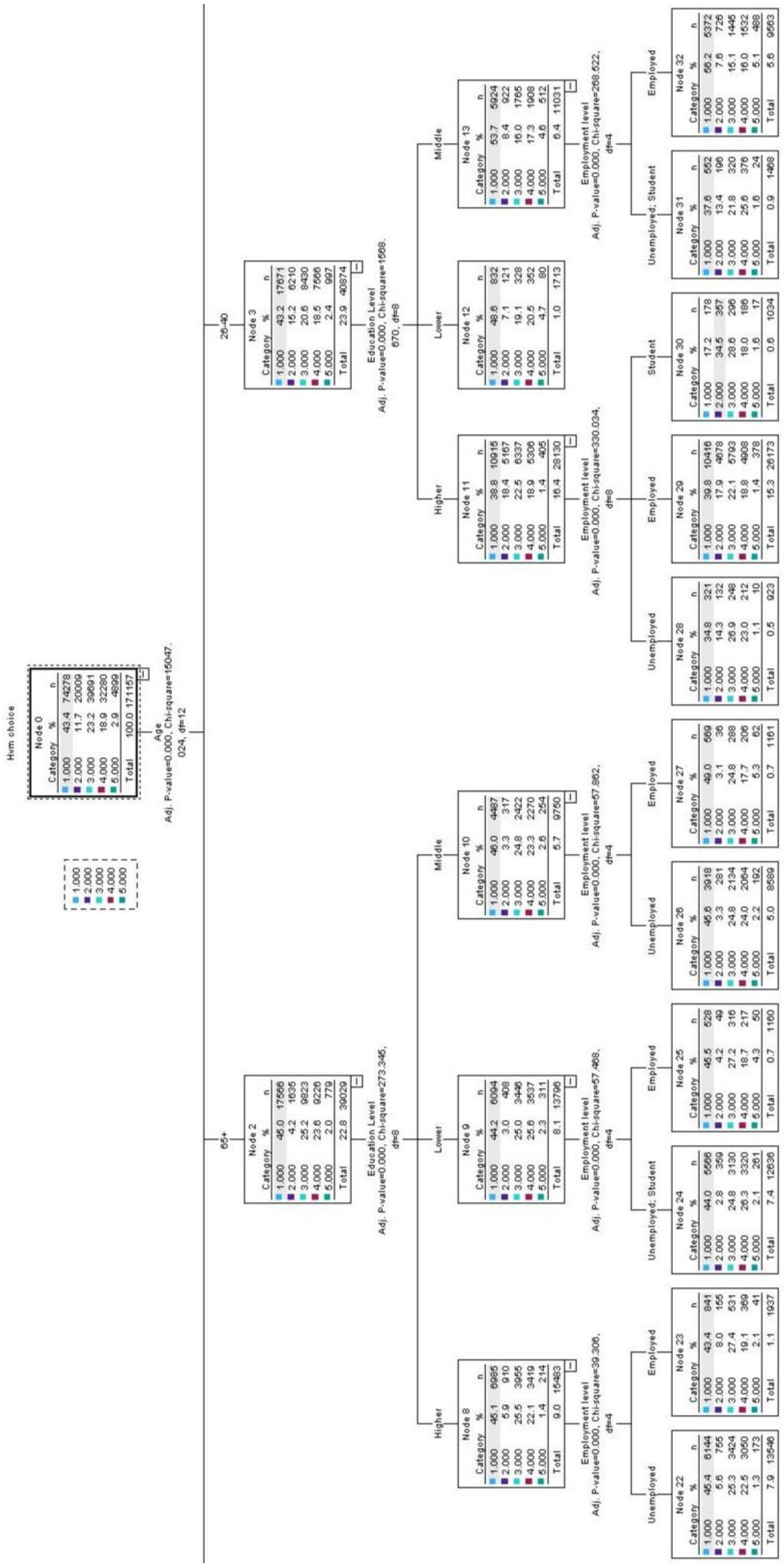

Figure 5 Decision tree output

The final decision tree classified individuals into 24 distinct categories based on their demographic and socioeconomic characteristics. The primary mode of transport for each category is as follows:

- Category 1: Car
- Category 2: Public transport
- Category 3: Bicycle
- Category 4: Walking
- Category 5: Other modes of transport

In the next step, the decision tree was manually reviewed to merge similar nodes, aiming to reduce the number of terminal nodes while preserving meaningful distinctions between travel behaviour patterns. This was done to ensure a more interpretable and generalisable segmentation, as an excessive number of small, highly specific groups could reduce the practical applicability of the findings.

Nodes were grouped based on the dominant mode of transportation (e.g., car, foot, bike, or public transport) within each node, using the percentage distribution of mode choices. After identifying the dominant mode, the remaining modes were ranked in descending order of their percentage shares. Nodes with similar rankings (e.g., Car > Foot > Bike > PT) were merged into the same group to maintain internal consistency. However, nodes were only merged if their mode choice distributions were similar enough to indicate comparable travel behaviour patterns, ensuring that distinct travel behaviours were not artificially combined.

This approach allows for a structured yet flexible classification of user groups while maintaining the integrity of mode choice patterns. However, a key limitation is the subjectivity involved in determining whether two nodes are similar enough to be merged. While percentage distributions provided a guideline, the final decision involved a degree of personal judgment, which could introduce bias. Additionally, merging nodes may lead to a loss of granularity, potentially overlooking subtle differences in travel behaviour that could be relevant for policy or planning purposes. Despite these limitations, this approach was chosen to balance segmentation complexity with practical usability. For example:

- A node with Car: 48%, Foot: 20%, Bike: 19%, PT: 7% is merged with a node having Car: 44%, Foot: 27%, Bike: 24%, PT: 3% because the dominant mode (car) and the ranking of other modes are consistent.

Nodes that exhibited unique or transitional travel behaviour patterns, such as a high reliance on public transport or alternative modes, were kept separate to form distinct groups. One such group is the "Alternative Mode Choice Influenced Nodes," which includes individuals whose travel behaviour does not fit neatly into the primary categories but still shows a dominant mode preference. The definitive user groups can be found in Chapter 4 “Results”.

3.4. Assigning weights

The second phase of this research focuses on assigning weights to TOD criteria and indicators, building on the user group segmentation. This phase aims to integrate the preferences and priorities of different user groups into the TOD framework.

The weighting process follows the approach that Singh et al. (2017) established and combines informal consultation with quantitative methods. To capture user-specific preferences, fifteen individuals participated in a survey in which they first self-identified with one of the predefined user groups. They were then asked to rank TOD criteria based on their perceived importance. The individual rankings were aggregated to generate a uniform ranking for each

user group. The Borda Count and rank-sum method was applied to calculate the final weights for each criterion.
This chapter details the methodological steps involved, including participant selection, survey design, ranking procedures, and the mathematical calculations used to normalise and finalise the weights for each user group.

3.4.1. Data collection and preparation

The criteria and indicators used in this study are adapted from Singh et al. (2017) and adjusted to incorporate the unique preferences of the identified user groups. These criteria and indicators can be seen in Table 1 in Chapter 2.1.3, they include:

- Residential and commercial densities: Indicators of urban intensity.
- Land use diversity: Measured through entropy to assess mixed land uses.
- Walkability and cyclability: Evaluated through streetscape quality, intersection density, and pedestrian catchment areas.
- Economic development: Measured through the number of business establishments in the area.
- Capacity utilisation of transit: Measured through passenger load in peak hours and off peak hours
- Access to and from transit stations: Based on proximity and multimodal connectivity.
- User-friendliness of transit systems: Including safety and accessibility.
- Parking at station: measured through the utilisation of parking spaces for four-wheelers/bikes.

For the context of the thesis, criteria can be seen as broad, overarching categories that represent key aspects or goals of your analysis. They are used to evaluate and compare the performance of different options (e.g., neighbourhoods or stations) in a structured manner. Indicators are measurable, specific variables used to quantify or assess the performance of a criterion. They are the "building blocks" of criteria and provide the data needed for evaluation.

3.4.2. Surveys

This analysis will use the user groups identified in the decision tree segmentation process to assign weights to the criteria. Each group's unique transportation preferences and priorities will shape how the criteria are weighted, ensuring that the TOD Index calculation reflects these groups' diverse needs and preferences. Based on this ranks need to be given to each criterion for every group. These ranks will be aggregated using the Borda Count method. This method is also used by Singh et al. (2017) in their analysis. They describe it as “a method of ‘election by order of merit’ and can be used to arrive at a combined rank for each of the ‘candidates’”. They go on to explain that in this method, the n candidates, which are the criteria and indicators, are first ranked from highest to lowest. Each group's rankings will then be converted into scores, with the most preferred candidate receiving n points, the second choice getting n-1 points, and so on, down to 1 point for the least preferred option. After converting the ranks of all respondents into scores for each candidate, the scores are aggregated. The candidate with the highest total score receives the highest rank, while the candidate with the lowest total score receives the lowest rank.
To ensure that the criteria and indicators reflected the perspectives of diverse user groups, individuals were invited to participate in a structured survey. Each participant first identified the user group they most closely aligned with before ranking the TOD criteria and indicators

on a numerical scale based on their personal preferences. Their responses were then aggregated to derive a uniform ranking for each user group. Participants were recruited from the researcher's network. This approach ensured that the weighting process reflected the perspectives of individuals who aligned with the identified user groups. No personal data was collected, as the survey focused solely on determining the relative importance of TOD criteria. The survey was designed to collect user group rankings of TOD criteria and indicators. Participants were asked to rank criteria and indicators in order of importance, reflecting their transportation priorities. Each survey question included definitions and real-world examples of the criteria to ensure clarity. Surveys were administered both online and in person to maximise accessibility and participation. In total, 15 responses were collected, and distributed as follows: Group 1 (2 respondents), Group 2 (4 respondents), Group 3 (2 respondents), Group 4 (5 respondents), and Group 5 (2 respondents). The survey itself can be seen in Appendix C and the rankings given to the criteria and indicators can be seen in Appendices D and E.

3.4.3. Weight calculations

The first step in calculating the weights was to aggregate them, using the aforementioned Borda Count method.

For the next step, the rank-sum method was used. This research follows the approach that Singh et al. (2017) used, who applied the rank-sum method to weigh different TOD criteria. This method was chosen because, as Odu (2019) explains, it is one of the simpler and more transparent approaches for weighting criteria. The rank-sum method involves ranking the criteria from worst to best, normalising each rank, and then dividing it by the total sum of all ranks to derive the final weights. This approach ensures a straightforward and replicable weighting process while maintaining consistency with existing TOD research. To do this, the following formula is used:

$$w_j(RS) = \frac{n - p_j + 1}{\sum_{k=1}^{n} n - p_k + 1}$$

In this formula:

- p_j is the rank of the *j-th* criterion, j = 1, 2, n.
- p_k is the rank of all criteria summed for normalisation
- n is the total number of criteria

Using this formula the normalised weights were calculated separately for each user group to reflect the distinct preferences of different segments. This process ensured that the importance of TOD criteria varied according to the needs and preferences of the user groups.

3.5. TOD Index Calculation

3.5.1. Data collection and preparation

To perform an MCA with the weights found in the section before this, data on all criteria and indicators will be needed to measure them. Singh et al.'s (2017) paper describes their data collection methods. The same methods will be used for this analysis, albeit with some adjustments because of data availability. The required data will be collected from sources such as the Eindhoven database, CBS, the transit service's website, and Open Street Map (OSM).

While many TOD studies assess development potential at the transit station level, this research evaluates TOD suitability at the neighbourhood level. The decision to shift the unit

of analysis ensures a more comprehensive assessment by incorporating factors beyond immediate station accessibility and making it more practical for municipalities to use.
The selection of neighbourhoods instead of transit stations was implemented as follows:

- Defining neighbourhood boundaries – Instead of using fixed station catchment areas (e.g., 800m buffer zones), predefined administrative neighbourhood boundaries were used to better align with demographic and socioeconomic data. This ensures that user groups are matched with real-world living environments rather than abstract station radii.
- Assigning TOD criteria to neighbourhoods – TOD indicators traditionally measured at transit stations (e.g., transit accessibility, frequency, and modal integration) were recalculated at the neighbourhood level. Individual scores of transit stations in the neighbourhood were aggregated to show the overall score the transit network has in that neighbourhood.
- Incorporating user group needs and preferences – Since user groups were segmented based on demographic and socioeconomic factors, assigning TOD scores at the neighbourhood level allows for a more direct integration of their needs and preferences. This approach prevents potential mismatches that could arise from station-based assessments that ignore where users live.

This methodological adaptation ensures that the TOD Index is not only a measure of transit accessibility but also a reflection of neighbourhood-level urban characteristics and user needs and preferences. The final TOD Index scores are therefore more aligned with the research objective of incorporating user group preferences into TOD evaluation. Kronehoef and Strijp-S were chosen as the focus areas for this thesis due to their contrasting urban characteristics and relevance to TOD principles.
Strijp-S is a vibrant and redeveloped neighbourhood known for its mixed-use character, proximity to a major train station, and emphasis on sustainable mobility. It serves as an example of a high-density, well-connected urban area with significant transit infrastructure. Analysing Strijp-S allows for evaluating TOD principles in a modern, planned environment where redevelopment has already aligned with TOD objectives.
Kronehoef, on the other hand, is a more residential neighbourhood with a lower-density urban form and less developed transit infrastructure. This area represents a typical suburban environment that contrasts with Strijp-S, offering the opportunity to examine how TOD principles can be applied to areas with different demographic and spatial dynamics.
These two neighbourhoods provide a valuable comparison, highlighting how TOD principles perform in areas with varying levels of density, accessibility, and land use diversity. The selection ensures a comprehensive analysis of how TOD strategies can be adapted to different urban contexts in Eindhoven. Due to the unavailability of data, the indicators 'tax earnings' and 'employment levels' were excluded from the analysis. Additionally, the indicator 'basic amenities' was removed, as all stations were found to have essential facilities, including waiting rooms, seating, and accessibility features for individuals with disabilities. As a result, this indicator did not allow for meaningful differentiation across transit areas. Consequently, a total of 18 indicators were measured for 2 neighbourhoods. However, this does not impact the TOD Index calculations, as each criterion remains represented by at least one measurable indicator.

Table 3 Data needed and their sources

Indicator	Data needed	Source
Residential density	Population count per neighbourhood	(Eindhoven Open Data, n.d.)
Commercial density	Number of commercial establishments per neighbourhood	(Eindhoven Open Data, n.d.)
Land use diversity	Land use classifications (residential, commercial, industrial, etc.) and their spatial distribution	(OpenStreetMap contributors, 2015)
Level of mixed-ness of land uses w.r.t. residential land use	Areas classified as residential versus other uses	(OpenStreetMap contributors, 2015)
Quality and suitability of streetscape for walking	Road network with classifications for pedestrian suitability	(Eindhoven Open Data, n.d.), (PDOK & Rijkswaterstaat, n.d.)
Quality and suitability of streetscape for cycling	Road network with classifications for cycling suitability	(PDOK & Rijkswaterstaat, n.d.)
Density of controlled intersections/street crossings	Number and location of intersections	(OpenStreetMap contributors, 2015)
Impedance Pedestrian Catchment Areas (IPCA)	Pedestrian-accessible areas within an 800m walking distance	(PDOK & Rijkswaterstaat, n.d.)
Number of business establishments	Number of businesses and their spatial distribution	(Eindhoven Open Data, n.d.)
Passenger load at peak hours	Number of passengers and train/bus capacities during peak hours	(NS, n.d.-a), (NS, n.d.-b), (9292, n.d.)
Passenger load at off-peak hours	Number of passengers and train/bus capacities during off-peak hours	(NS, n.d.-a), (NS, n.d.-b), (9292, n.d.)
Safety of commuters at the transit stop	Number of shops, eateries, and other services near the station	(OpenStreetMap contributors, 2015)
Information display systems	Presence of static and digital information displays	(Google, n.d.)
Frequency of transit service	Number of trains or buses per hour	(Hermes, n.d.-b)
Interchange to different routes of same transit	Number of routes accessible at the station	(University of Groningen Geodienst, 2022), (Hermes, n.d.-a)

Interchange to different transit modes	Presence of bus, tram, or other modes at the station	(University of Groningen Geodienst, 2022), (Hermes, n.d.-a)
Access to opportunities within walkable distance from transit station	Number of jobs and services within the catchment area	(Eindhoven Open Data, n.d.)
Parking supply demand for cars/four-wheelers	Number of parking spaces available and used	(Google, n.d.)
Parking supply demand for cycles	Number of parking spaces available and used	(Google, n.d.)

3.5.1.1. Population and commercial density

The population and commercial density data were available at the neighbourhood level on the Eindhoven Open Data website. The data was imported into QGIS, and the population per square kilometre was recalculated using the attribute table. Commercial density represents retail and service while business represents establishments such as architectural firms. This is done to avoid double counting. The population and commercial density of Eindhoven can be seen in Figures 4 and 5.

3.5.1.2. Land use diversity

Land use diversity is an important concept within TOD. As Singh et al. (2017) state, it creates a sense of place within an area and improves transit outside peak moments, such as off-peak hours and weekends. Singh et al. (2017) used entropy to measure the land use diversity, which is often used when measuring levels of diversity. They used the following formula:

$$LU_d(i) = \frac{-\sum_i Q_{lu_i} * \ln(Q_{lu_i})}{\ln n}$$

Where,

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

$LU_d(i)$ = land use diversity in analysis area i

lu_i = land use class (1,2,……,n) within analysis area i

Q_{lu_i} = Share of specific land use within analysis area i

S_{lu_i} = Total area of the specific land use within the analysis area i

S_i = Total area of analysis i

Higher levels of entropy relate to higher levels of land use diversity leading to a higher TOD score. The land use categories considered for this indicator include residential, industrial, commercial, office complexes, healthcare, educational facilities, sports, and other miscellaneous uses (Singh et al., 2017). All data needed for this indicator was retrieved using OSM. How this looks in OSM can be seen in Figures 6 and 7 The calculation of this can be found in Chapter 4 "Results".

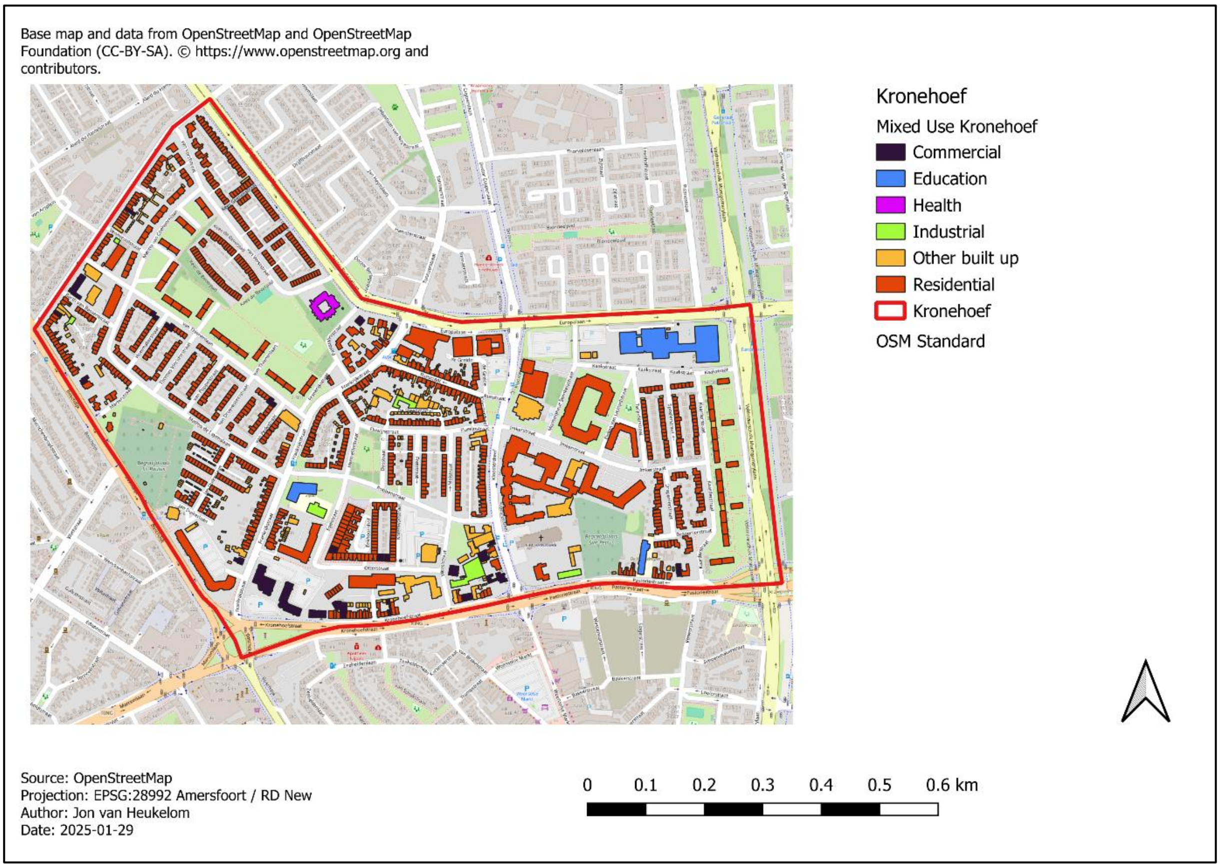

Figure 6 Land use diversity Kronehoef (OpenStreetMap contributors, 2015)

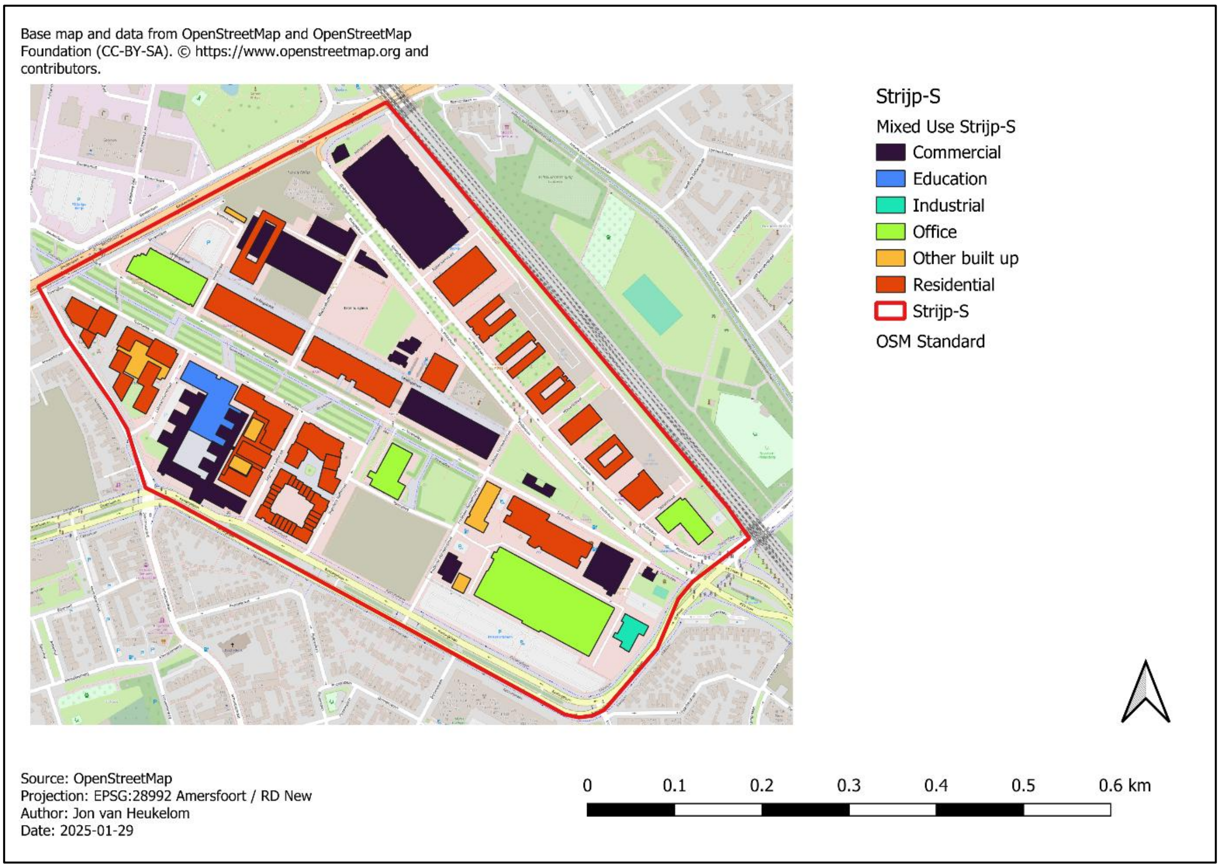

Figure 7 Land use diversity Strijp-S (OpenStreetMap contributors, 2015)

3.5.1.3. Mixedness of residential land use

The mixedness of residential land use is calculated to assess the walkability and cyclability of the area of analysis. It is different from the land use diversity indicator because it assesses the mixedness of residential land use with other land uses within the area. This is measured using the following formula also used by Singh et al. (2017):

$$MI(i) = \frac{\sum_{\cap i} S_c}{\sum_{\cap i}(S_c + S_r)}$$

Where,
$MI(i)$ = Mixedness Index for the area of analysis i
S_c = sum of the total area under non-residential urban land uses within i
S_r = sum of the total area under residential land use within i
The value of the MI (Mixedness Index) ranges from 0 to 1, with a value of 0.5 representing a balanced mix of land uses, indicating an equal proportion of residential land use compared to other land use types (Singh et al., 2017). All data needed for this indicator was retrieved using OSM. The calculation of this can be found in Chapter 4 "Results".

3.5.1.4. Total length of walkable/cyclable paths

This indicator measures the total length of roads accessible to pedestrians and cyclists within the specified neighbourhood, expressed in meters. The road network was reclassified to prioritise roads likely to be used for slow traffic. The dataset was retrieved from the Rijkswaterstaat database (PDOK & Rijkswaterstaat, n.d.), as no single dataset fully captured the desired road network. Roads designated for fast traffic, such as motorways where walking and cycling are prohibited, were excluded. Singh et al. (2017) applied a similar approach to refining the road network for TOD analysis. While OSM and Eindhoven Open Data were considered, they contained inaccuracies, such as missing roads and the inclusion of roads unsuitable for slow traffic.

3.5.1.5. Intersection density

Intersections are important to make an area more walkable or cyclable since they allow pedestrians and cyclists to cross a street more easily and safely. Singh et al. (2017) state that a higher density of intersections relates to higher walkability and cyclability. The intersection density is represented by the number of intersections per square kilometre within the area of analysis. The same road network as the total length of walkable/cyclable roads criterion was used in QGIS to calculate this (PDOK & Rijkswaterstaat, n.d.).

3.5.1.6. Impedance Pedestrian Catchment Areas (IPCA)

Pedestrian Catchment Areas, or "Ped-Sheds," represent the areas within walking distance of a transit station (Singh et al., 2017). The Index of Pedestrian Catchment Area (IPCA) is calculated by measuring the walkable area within an 800-meter radius of the transit station, following the road network in both directions. This calculation was performed using the network analysis tool in QGIS, which allowed for the precise measurement of walkable paths while considering the actual road network.

To ensure that only pedestrian-friendly routes were considered, roads designated for fast traffic, such as motorways, were excluded from the analysis. This was done by reclassifying the road network to prioritise roads suitable for slow traffic, as described earlier. The resulting IPCA values range from 0 to 1, where 0 indicates the lowest level of pedestrian accessibility (i.e., no catchment area within walking distance) and 1 indicates the highest level (i.e., full catchment within walking distance). This method provides a clear and consistent measure of how accessible a transit station is to pedestrians within the specified walking distance. The IPCA of the case study areas can be seen in Figures 8 and 9.

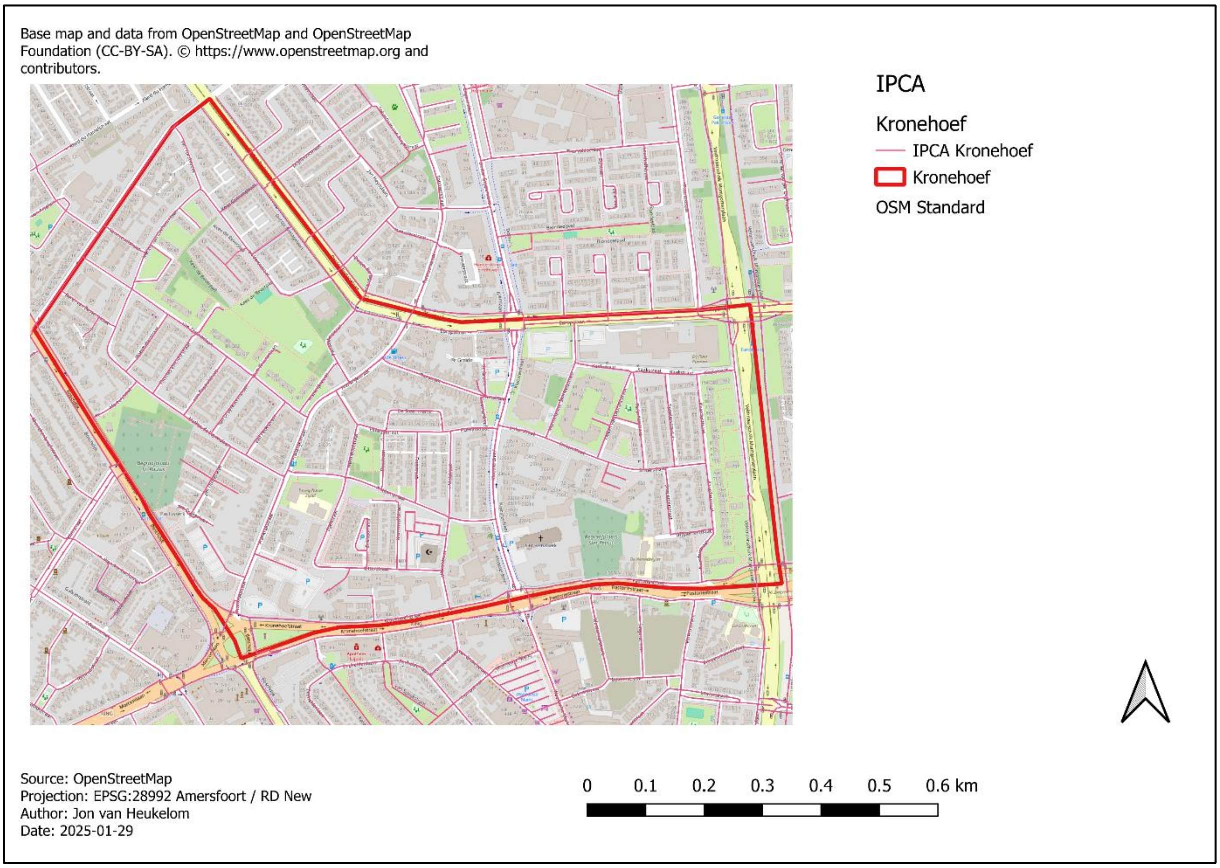

Figure 8 IPCA Kronehoef (OpenStreetMap contributors, 2015)

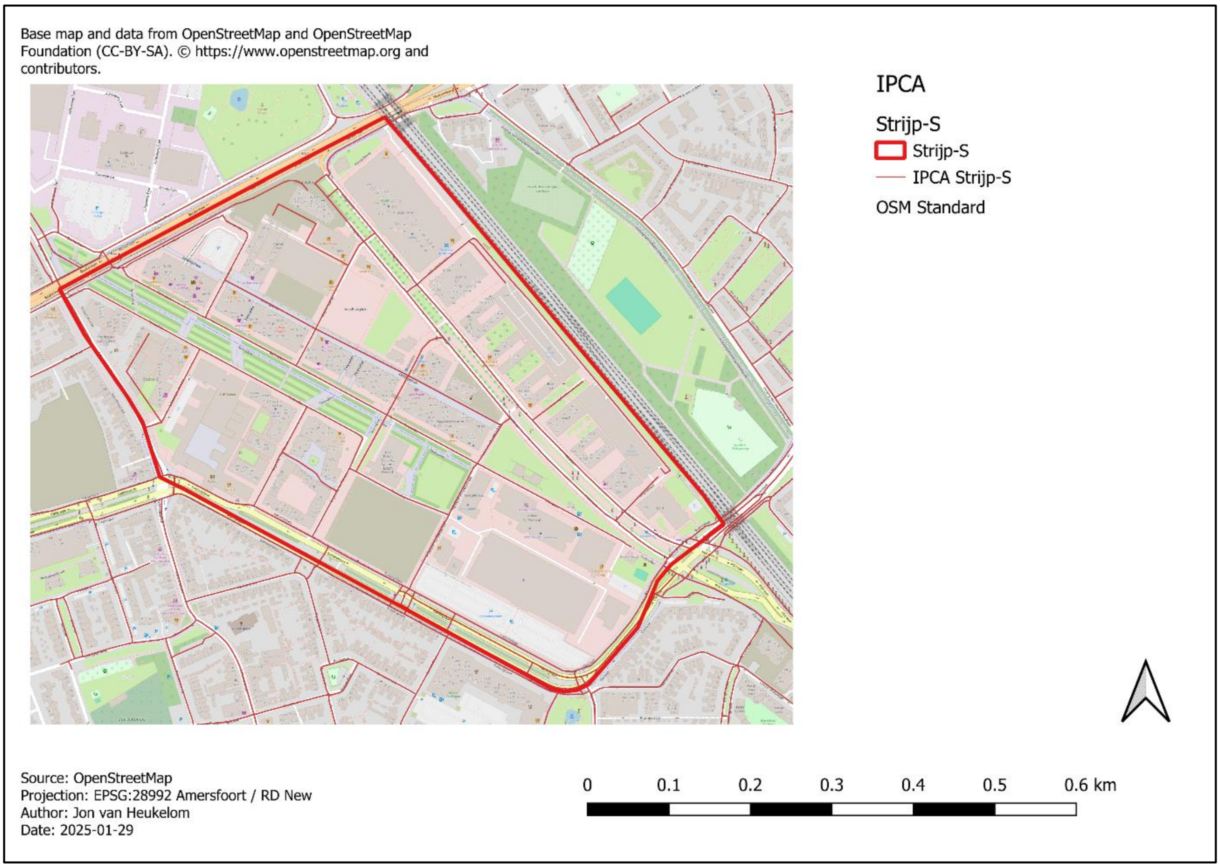

Figure 9 IPCA Strijp-S (OpenStreetMap contributors, 2015)

3.5.1.7. Passenger load

Passenger load is a key indicator for assessing TOD as it reflects how efficiently transit capacity is utilised. A higher passenger load indicates better utilisation and contributes to a higher TOD Index score. However, passenger loads above 90% are considered overcrowded, reducing comfort and potentially steering away from transit use in favour of cars (Singh et al. The calculation of passenger load in this thesis follows the same approach and uses the assumptions of Singh et al. (2017). Daily ridership data per station was divided into 75% for peak hours and 25% for off-peak hours. Capacity was calculated based on service frequency during these periods and the total capacity of transit vehicles. For real-world conditions, a 40% baseline occupancy was assumed for transit vehicles arriving at non-terminus stations. Passenger load for peak and off-peak hours was calculated as the ratio of the number of passengers to the total capacity during each period. While data limitations required certain assumptions, these were consistent with the methodology outlined by Singh et al. (2017) and are reasonable for this analysis. Another method was used to estimate the passenger load for the bus stops. Since there is no readily available data on the number of travellers per bus or bus route, some assumptions had to be made. Local travelling apps were utilised to gather data on bus occupancy levels during different times of the day. These apps typically provide real-time information on bus schedules, including how crowded a bus is at specific times, based on user input or sensor data. By analysing this data, an estimation of the bus's occupancy was made, which reflected how busy the bus could be during particular time slots. This estimation helped assess the capacity utilisation of public transport in the area, offering insights into peak usage times and providing a more accurate measure of transit accessibility and demand. The calculation of this can be found in Chapter 4 "Results".

3.5.1.8. Safety of commuters at the transit stop

Safety is a key factor influencing public transit usage, yet it remains one of the most challenging aspects to quantify. Ideally, station safety can be assessed based on the presence of other people, the layout and design ensuring good visibility, and adequate lighting during both day and night (Singh et al. 2017). A preliminary assessment confirmed that all transit stations in the study area had sufficient lighting. Since direct data on the number of people at transit stations was unavailable, safety was measured using the number of shops and eating establishments within the station's service area, as commercial activity attracts people and contributes to a more active and surveyed environment. This approach follows the same assumptions used by Singh et al. (2017), where the presence of shops was considered a proxy for station activity and perceived safety.

To quantify this, the number of shops was counted within a 100-meter buffer around each station. However, due to the inability to precisely define building entrances, a weighted approach was used: if, for example, half of a building's footprint fell within the buffer zone, it was counted as 0.5 rather than a full shop. To help visualise this, see Figures 10 and 11.

This method aligns with the findings of Singh et al. (2017), who emphasise that mixed land uses contribute to a more vibrant and safer transit environment by increasing station activity and human presence. In transit settings, the presence of commercial establishments encourages people to remain in the area beyond the immediate act of travelling, fostering a sense of security. In contrast, stations without such amenities tend to have lower lingering activity, as passengers typically arrive shortly before departure and leave immediately upon arrival.

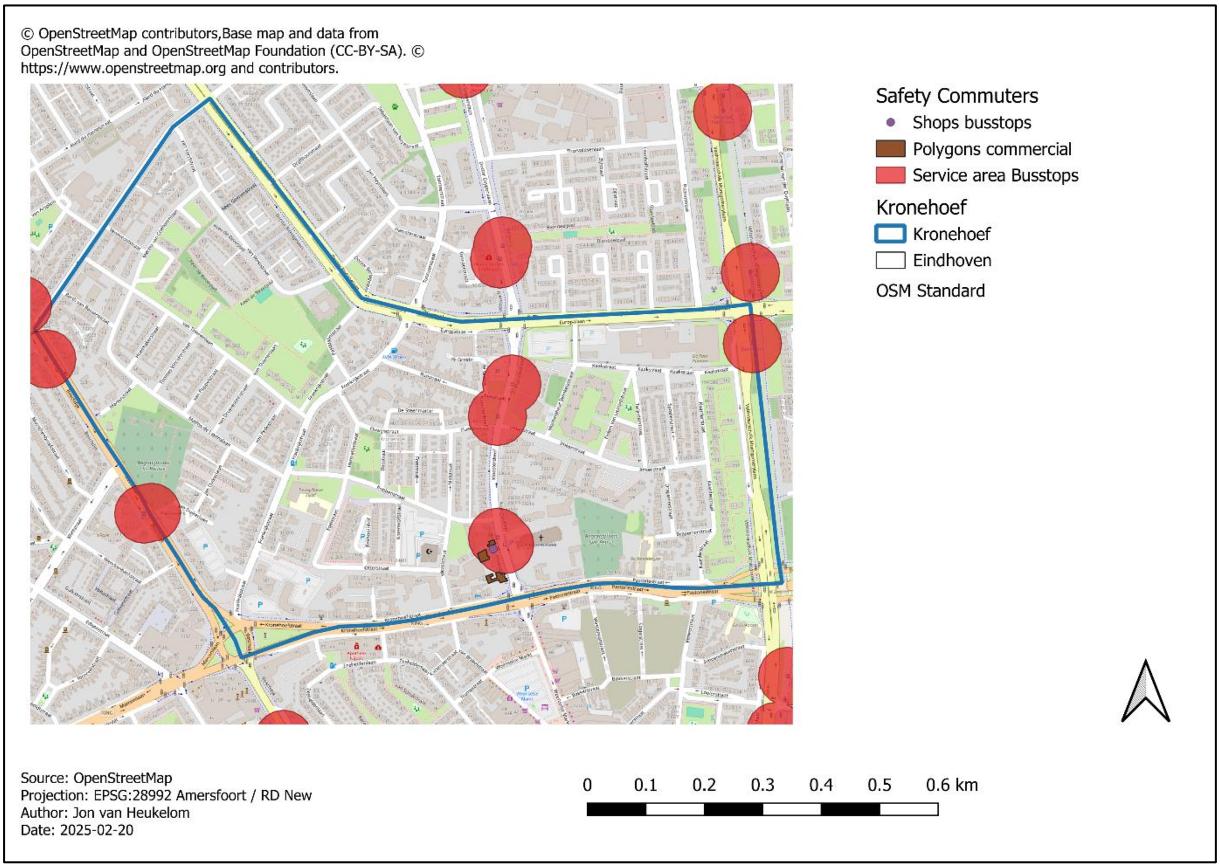

Figure 10 Safety of commuters Kronehoef (OpenStreetMap contributors, 2015)

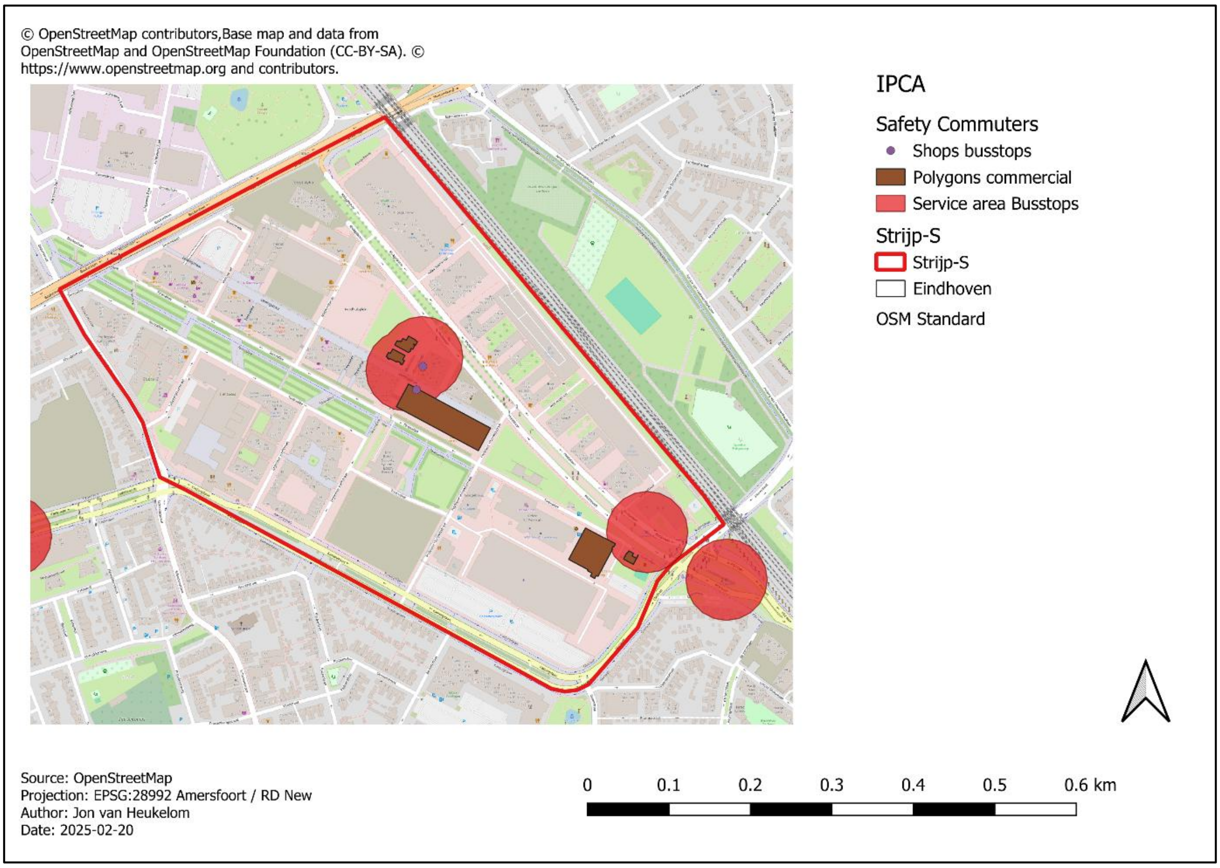

Figure 11 Safety of commuters Strijp-S (OpenStreetMap contributors, 2015)

3.5.1.9. Information display systems

Information display systems can be divided into two types: static and dynamic. Static information displays are fixed, non-changing displays that provide general, permanent information about transit services. Dynamic information displays are electronic or digital displays that provide real-time or regularly updated information. To assess the types of information display systems, Google Street View was used to check whether the neighbourhoods featured static, dynamic, or both types of displays (Google, n.d.). Static displays provide permanent information, while dynamic displays offer real-time or frequently updated information about transit services.

3.5.1.10. Frequency of service

Access to transit is influenced by the frequency of service, which was calculated based on the number of public transit vehicles, such as trains, buses, and trams, operating per hour at each station or stop (Singh et al. 2017). For this calculation, data from a local travel agency, Hermes, was used to determine service frequencies at specific stations and stops (Hermes, n.d.-b).

3.5.1.11. Interchange to different routes of same transit

This indicator measures the number of public transit routes of the same transit, including trains, buses, and trams, accessible at each station or stop (Singh et al. 2017). A higher number of routes and connections to various destinations increases the likelihood of people choosing transit over cars. Again for this calculation, data from a local travel agency, Hermes, and the University of Groningen, were used to determine different routes available at specific stations and stops (Hermes, n.d.-a; University of Groningen Geodienst, 2022).

3.5.1.12. Interchange to other transit modes

Singh et al (2017) describe that a high-quality transit system not only provides access to more destinations but also facilitates interchanges between different transit modes. In Eindhoven, where both train and bus systems operate, the interchange possibilities at each transit station to the other transit modes were measured. A value of 0 indicates no interchange is possible and a value of 1 represents an interchange to an alternative mode.

3.5.1.13. Access to opportunities within the area

According to Singh et al. (2017), this indicator measures the number of jobs accessible within the area of analysis around each station. This approach aligns with what is commonly referred to as the 'Cumulative Opportunity Measure' or 'Contour Measure'. Singh et al. utilised data on jobs categorised by sectors, such as industry and commerce, at the municipal level. Since data on job availability in the specific neighbourhoods was not readily available, an alternative method was employed to estimate the number of jobs within these areas.
The first step was to gather data on the total number of jobs in the city. Next, the total number of businesses operating within the city was collected. Using this information, the number of businesses in the neighbourhoods of Strijp-S and Kronehoef was identified.
To estimate the job availability in each neighbourhood, the number of businesses in each area was used to determine its share of the total number of businesses in the city. This share was then applied to the total number of jobs in the city, under the assumption that the distribution of businesses could be used as a proxy for the distribution of jobs. The calculation of this can be found in Chapter 4 "Results".

3.5.1.14. Parking utilisation

Parking utilisation at bus stops and train stations was assessed using Google Maps to evaluate the efficiency of parking spaces and their alignment with TOD. Satellite imagery and street views were analysed at different times and dates to estimate the occupancy levels of parking facilities at transit hubs. High parking utilisation indicated efficient use of space, reflecting well-integrated park-and-ride facilities. In contrast, low utilisation highlighted inefficiencies, such as oversupply relative to demand, which could encourage unnecessary car dependency or result in underutilised land. These findings inform TOD planning by emphasising the need to balance parking supply with demand. Oversized lots can promote excessive driving, while insufficient spaces may deter park-and-ride users. Stations with low utilisation present opportunities to repurpose excess parking for uses such as bicycle parking, retail spaces, or green areas, better supporting sustainable and multimodal transit goals. By linking parking supply to actual demand, this analysis identifies ways to optimise transit hubs, reducing car dependency while promoting efficient land use and user-centred urban development.

3.5.2. TOD Index

The TOD Index was calculated using a structured approach to assess how well the neighbourhoods align with user needs and preferences, based on the TOD framework. This method, which follows the approach used by Singh et al. (2017), was employed to determine if incorporating these user preferences impacts the TOD scores of neighbourhoods for different user groups. The steps are detailed below:

Step 1: Normalisation of Indicator Values

To ensure comparability across different indicators, all values were normalised to a scale of 0 to 1 using the following formula:

$$Normalised\ value = \frac{Actual\ value}{Maximum\ value}$$

This step adjusted raw data values to eliminate differences in measurement units and scales, allowing for meaningful aggregation in subsequent steps.

Step 2: Weight Adjustment for Indicators
Each normalised indicator value was adjusted according to its assigned weight, reflecting its relative importance within the TOD framework. The formula used was:

$$TOD\ value = Normalised\ value * Weight$$

This calculation ensured that more critical indicators had a proportionally greater impact on the final TOD Index.

Step 3: Neighbourhood Aggregation
To analyse results at the neighbourhood level, the TOD values of individual bus stops and train stations were averaged. For this study, values for each indicator were aggregated separately for the neighbourhoods of Kronehoef and Strijp-S, providing neighbourhood-specific insights into TOD performance.

Step 4: Criteria-Level TOD Scores
The TOD scores for each criterion were calculated by summing the weighted indicator values that corresponded to the criterion. For example, indicators related to walkability and accessibility were summed to produce a TOD score for the "Encouragement walking and cycling" criterion.

Step 5: Total TOD Score Calculation
The total TOD score for each neighbourhood was calculated by aggregating the criteria-level TOD scores. This involved summing the scores for all criteria, with each criterion further weighted by its relative importance. The formula was:

$$Total\ TOD\ Score\ (Neighbourhood) = \sum (Criterion\ score * Criterion\ weight)$$

This final step produced a total TOD score for each neighbourhood (Kronehoef and Strijp-S) and for each user group, providing a comprehensive measure of TOD scores that accounted for the needs and preferences of the different user groups.
These scores reflect both the quantitative performance of transit and non-transit related criteria and indicators and the weighted preferences of identified user groups, ensuring that the analysis is inclusive and aligned with TOD principles.

3.6. Conclusion

This methodology provides a comprehensive framework for integrating user preferences into TOD planning. The process began with user group segmentation, using a decision tree to classify the population into distinct user groups based on socioeconomic and demographic characteristics that influence transportation behaviour. This segmentation laid the foundation for addressing diverse needs and preferences in the TOD framework.

Building on this, informal consultation was used to determine the relative importance of TOD criteria and indicators. By incorporating the perspectives of representative individuals through surveys, the study ensured that the weighting process captured the unique preferences of each user group. This approach enhanced the framework's inclusivity and relevance.

Finally, the calculation of the TOD Index combined normalised data, weighted criteria, and spatial aggregation to produce neighbourhood-level scores. This robust, data-driven approach allowed for a nuanced evaluation of TOD suitability, reflecting both quantitative performance and user group needs and preferences. By integrating these components, the methodology offers a balanced, user-centred tool for identifying neighbourhoods best suited for TOD interventions.

4. Results

This chapter presents the results of the research, detailing the key findings related to user group segmentation, the influence of demographic and socioeconomic variables on travel behaviour, the weight distribution of TOD criteria across different groups, and the calculated TOD Index for the study areas. The results aim to provide a comprehensive understanding of how different user groups interact with the built environment and transit infrastructure in Strijp-S and Kronehoef. By employing a combination of quantitative and spatial analyses, this chapter highlights both expected and unexpected findings, emphasising significant trends, disparities, and structural patterns within the data.

Visual representations such as graphs, tables, and maps are incorporated to support the interpretation of the results. Special attention is given to the influence of various TOD criteria on different user groups, as well as a sensitivity analysis comparing the results to the weighting methodology used by Singh et al. The findings discussed in this chapter serve as the foundation for the subsequent discussion on the implications of TOD planning and policy recommendations.

The decision to analyse user groups rather than individuals is based on the need for scalable and policy-relevant insights. Individual travel behaviours vary significantly, which makes large-scale urban planning difficult if based on individual-level data. Segmenting populations into user groups allows for identifying broad patterns in mode choice while still capturing the diversity of urban residents. This approach ensures that TOD planning remains practical and applicable for policymakers.

4.1. User group segmentation results

The user group segmentation identified five distinct travel behaviour groups with unique modal preferences and demographic characteristics. The segmentation was derived using a CHAID decision tree analysis described in Chapter 3 (see Figure 5: Decision tree output).

The decision tree revealed clear distinctions between user groups, with the first major split occurring based on age, followed by further refinements based on education and employment status. This structured approach ensured that the segmentation captured statistically significant differences in travel behaviour rather than relying on arbitrary groupings. Table X below provides a more detailed description of each user group along with their socioeconomic and demographic characteristics.

Table 4 Defined user groups

Group No.	Primary mode	Secondary modes	Key characteristics
1	Car	Walking > Cycling	High car dependency but frequent walking. Diverse education levels and age groups, high unemployment.
2	Car	Cycling > Walking	Car remains dominant, but cycling is a strong secondary mode. Including both employed and unemployed individuals, mostly middle-aged or older, all ages included.

3	PT	Bicycle > Walking/car	Public transport is the dominant mode. Consists of younger, highly educated individuals, mostly students.
4	Bike	PT > Car	Primarily bike users with significant public transport use. Includes lower-educated students under 25.
5	Car	PT/Cycling/Walking	Car-dominant but more openness to alternative modes; includes younger and middle-aged individuals across employment and education levels.

To further illustrate the modal split within each user group, Figure 12 presents pie charts showing the percentage distribution of car, bike, walking, and public transport usage. These visuals highlight distinct differences between groups, such as the predominance of cycling in Group 4 and the transitional nature of Group 5, where car dependency is lower but still significant. The charts also reinforce key findings from the decision tree analysis, demonstrating how demographic and socioeconomic factors influence travel behaviour.

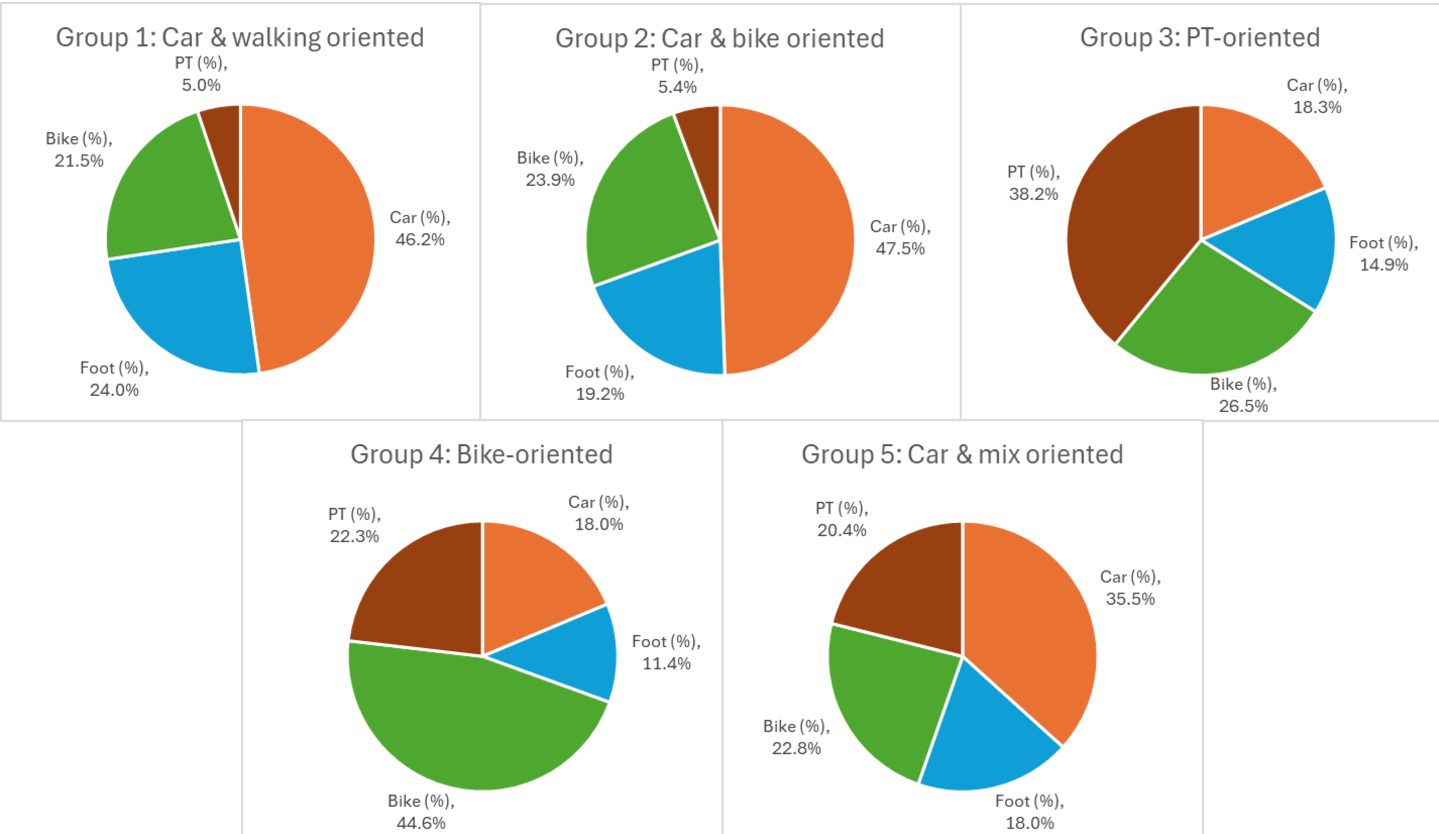

Figure 12 Mode choice of user groups

In analysing the relationship between demographic factors and mode choice, several trends emerged across the different user groups identified in the study.

Regarding age distribution, middle-aged and older individuals in Groups 1 and 2 demonstrated a higher dependency on cars. This suggests that car ownership and habitual driving behaviours tend to increase with age. In contrast, younger and middle-aged individuals in Groups 3, 4, and 5 exhibited greater use of public transport and bicycles, indicating a higher degree of multimodal flexibility. This shift could be attributed to factors such as lower car ownership rates and the preference for more sustainable or cost-effective travel options. Group 5, which includes a combination of younger and middle-aged individuals, is considered a transitional group. This group reflects a willingness among younger generations to explore alternative modes of transport, though they may still rely on cars when necessary.

When considering education levels, those with higher levels of education were more likely to use public transport, as seen in Group 3. This finding is consistent with prior research discussed in Chapter 2, which suggests that individuals such as students and highly educated professionals are more inclined to use sustainable modes of transportation, potentially due to factors like proximity to universities, urban living, and heightened environmental awareness. On the other hand, individuals with lower education levels were more likely to rely on bicycles, as seen in Group 4. This may reflect the role of cost-effectiveness in transportation choices, with cycling being a more affordable mode for those with limited financial resources. Interestingly, car-reliant groups (Groups 1, 2, and 5) exhibited mixed education levels, indicating that car ownership and usage are not related to education levels.

The analysis of employment status further reveals distinct patterns in mode choice. In Groups 1 and 2, which are car-dominant, both employed and unemployed individuals were present, although Group 1 had a notably high unemployment rate. This suggests that car dependency is not always directly linked to financial stability. Group 3, consisting primarily of public transport users, was largely composed of students, reinforcing the connection between education, affordability, and transit use. For Group 4, which favoured bicycles, most individuals were lower-educated students under the age of 25. This indicates that cycling is a preferred mode of transportation for younger individuals with limited financial resources. Finally, Group 5, which represents mixed-mode travellers, included both employed and unemployed individuals, showing that employment status alone does not solely determine transportation preferences. This group's transportation behaviour suggests a more flexible approach to mobility, where different factors, including lifestyle choices and external conditions, influence mode selection.

These findings reinforce the need for a more nuanced approach to TOD measurements, one that considers variations in travel behaviour rather than assuming a uniform user base. By segmenting users based on demographic and socioeconomic characteristics, this research provides a foundation for integrating user-specific TOD assessments into the evaluation process. This step is essential for improving the accuracy of TOD assessments, ensuring that these assessments align with the actual needs and preferences of diverse user groups. In the following sections, these segmentation results will be used to refine the weighting of TOD indicators, further tailoring the TOD Index to reflect real-world travel behaviour.

4.2. User group weights results

The weight assignment process was conducted to determine the relative importance of various TOD criteria and indicators for different user groups in relation to the TOD Index as developed in the paper by Singh et al. (2017). To achieve this, a structured approach was employed, combining direct input from individuals within each group and the rank-sum method to ensure a balanced representation of needs and preferences. By incorporating perspectives from diverse travel behaviour groups, this approach provided a nuanced understanding of how different users value various aspects of TOD. The five user groups, as identified through decision tree segmentation, served as a foundation for analysing the differences in user needs and preferences. This process ultimately informed the evaluation framework, ensuring that the TOD Index reflects the varied needs and preferences of the user groups. In Table x the results of this process can be seen in the form of the different weights per user groups for the criteria and indicators.

Table 5 Weights per user group

<table>
<tr><th>Criteria</th><th colspan="5">Groups and weights</th><th>Indicators</th><th colspan="5">Groups and weights</th></tr>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td rowspan="2">Various densities</td><td rowspan="2">0.194</td><td rowspan="2">0.139</td><td rowspan="2">0.083</td><td rowspan="2">0.028</td><td rowspan="2">0.139</td><td>Residential density</td><td>0.33</td><td>0.33</td><td>0.33</td><td>0.33</td><td>0.5</td></tr>
<tr><td>Commercial density</td><td>0.67</td><td>0.67</td><td>0.67</td><td>0.67</td><td>0.5</td></tr>
<tr><td>Land use diversity</td><td>0.222</td><td>0.222</td><td>0.111</td><td>0.111</td><td>0.222</td><td>Land use diversity</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="4">Encouragement walking and cycling</td><td rowspan="4">0.167</td><td rowspan="4">0.111</td><td rowspan="4">0.167</td><td rowspan="4">0.222</td><td rowspan="4">0.194</td><td>Level of mixed-ness of land uses w.r.t. residential land use</td><td>0.263</td><td>0.187</td><td>0.294</td><td>0.067</td><td>0.263</td></tr>
<tr><td>Quality and suitability of streetscape for walking/cycling</td><td>0.237</td><td>0.282</td><td>0.206</td><td>0.300</td><td>0.237</td></tr>
<tr><td>Density of controlled intersections/street crossings</td><td>0.158</td><td>0.125</td><td>0.177</td><td>0.133</td><td>0.158</td></tr>
<tr><td>Impedance Pedestrian Catchment Areas (IPCA)</td><td>0.105</td><td>0.125</td><td>0.117</td><td>0.2</td><td>0.105</td></tr>
<tr><td>Current level of economic development</td><td>0.139</td><td>0.194</td><td>0.056</td><td>0.056</td><td>0.056</td><td>Number of business establishments</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">Capacity utilisation of transit</td><td rowspan="2">0.056</td><td rowspan="2">0.056</td><td rowspan="2">0.194</td><td rowspan="2">0.167</td><td rowspan="2">0.111</td><td>Passenger load at peak hours</td><td>0.67</td><td>0.67</td><td>0.67</td><td>0.67</td><td>0.5</td></tr>
<tr><td>Passenger load at off-peak hours</td><td>0.33</td><td>0.33</td><td>0.33</td><td>0.33</td><td>0.5</td></tr>
<tr><td rowspan="2">User-friendliness of transit system</td><td rowspan="2">0.083</td><td rowspan="2">0.167</td><td rowspan="2">0.139</td><td rowspan="2">0.139</td><td rowspan="2">0.083</td><td>Safety of commuters at the transit stop</td><td>0.67</td><td>0.67</td><td>0.67</td><td>0.5</td><td>0.67</td></tr>
<tr><td>Information display systems</td><td>0.33</td><td>0.33</td><td>0.33</td><td>0.5</td><td>0.33</td></tr>
<tr><td rowspan="3">Access to and from the transit station</td><td rowspan="3">0.111</td><td rowspan="3">0.083</td><td rowspan="3">0.222</td><td rowspan="3">0.194</td><td rowspan="3">0.167</td><td>Frequency of transit service</td><td>0.364</td><td>0.4</td><td>0.308</td><td>0.364</td><td>0.364</td></tr>
<tr><td>Interchange to different routes of same transit</td><td>0.272</td><td>0.2</td><td>0.308</td><td>0.272</td><td>0.272</td></tr>
<tr><td>Interchange to different transit modes</td><td>0.182</td><td>0.1</td><td>0.230</td><td>0.182</td><td>0.182</td></tr>
</table>

						Access to opportunities within walkable distance from transit station	0.182	0.3	0.154	0.182	0.182
Parking supply at the transit station	0.028	0.028	0.028	0.083	0.028	Parking supply demand for cars/four-wheelers	0.33	0.33	0.33	0.33	0.5
						Parking supply demand for cycles	0.67	0.67	0.67	0.67	0.5

4.2.1. Weights for criteria

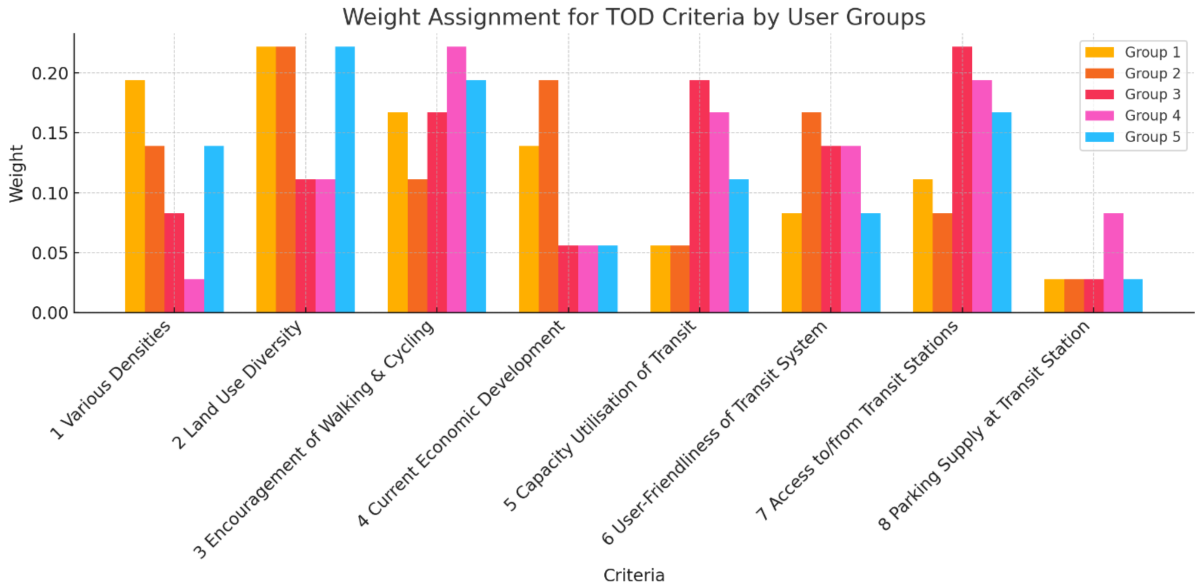

Figure 13 Weights per user group

For criterion 1, "Various densities," the weights vary between the user groups. Group 1 assigns the highest weight (0.194), suggesting that users in this group place a strong emphasis on density, which may correlate with their car dependency and preference for high-density environments. Groups 3 and 4, on the other hand, assign the lowest weight (0.028 and 0.083), indicating that for users in these groups, density is less of a priority when considering TOD. This could be due to differences in travel preferences or lifestyle. For example, Group 3, which prioritises public transport over other modes, may place more emphasis on factors like access to transit and frequency of service rather than densities. Similarly, Group 4, which favours cycling, might prioritise walkability and cycling infrastructure over various densities. In contrast, Groups 2 and 5 assign moderate weights, reflecting a more balanced view of the importance of density in TOD decision-making, possibly due to a broader mix of transportation modes influencing their needs.

For criterion 2, "Land use diversity," all groups assign similar weights (ranging from 0.111 to 0.222), with Group 3 and Group 4 giving the lowest weights. This suggests that while all groups recognise the importance of diverse land use, it may not be the primary driver for TOD suitability, particularly for younger or less car-dependent groups. Group 1 and Group 2, with their higher weights, may reflect the demand for mixed-use areas that support car-dependent lifestyles.

For criterion 3, "Encouragement of walking and cycling," the importance varied across groups. Group 4 places the highest weight (0.222), indicating a strong preference for sustainable

modes of transport like cycling and walking. Group 2, with a weight of 0.111, shows a more moderate interest in promoting walking and cycling, aligning with their car-oriented transportation mode choices.
For criterion 4, "Economic development," the weights assigned are highest for Groups 1 and 2 (0.139-0.194) and lowest for Groups 3, 4, and 5 (0.056). This aligns with the fact that economically developed areas are likely to cater to dominant car-dependent groups who probably prioritise access to services and employment opportunities.
For criterion 5, "Transit capacity utilisation," Groups 1 and 2 assign the lowest scores (0.056), relying more on cars as their main mode of transport, indicating that public transport plays a minimal role in their mobility. Group 3, scoring the highest (0.194), uses public transport the most, reflecting a strong dependence on transit for daily travel. Group 4 (0.167), although primarily focused on cycling, still shows a significant use of public transit, suggesting that while biking is dominant, transit is an important secondary mode. Group 5 (0.111), with moderate transit capacity utilisation, uses a mix of transportation options, indicating a more flexible approach to mobility that incorporates both car use and public transport when needed.
For criterion 6, "User-friendliness of transit systems," Groups 1 and 5, with the lowest scores (0.083), show a limited emphasis on public transport, suggesting that these groups may not prioritise ease of use or may not rely on transit frequently. Group 2, scoring the highest (0.167), places more importance on user-friendliness, which suggests that although they don't rely on public transport frequently, they still value the user-friendliness of it immensely. Groups 3 and 4, with similar scores (0.139), both show a moderate concern for the user-friendliness of transit. While Group 3 primarily depends on public transport, Group 4, which favours cycling, still values transit accessibility and comfort, indicating that ease of use is a consideration for those who combine cycling with public transport.
For criterion 7, "Access to and from transit stations," Group 3, with the highest score (0.222), places significant importance on the convenience of reaching transit stations, reflecting their primary reliance on public transport. Group 4, which also scores relatively high (0.194), values easy access to transit stations, likely due to their combination of cycling and transit use. Group 5, with a moderate score (0.167), shows that while access to transit stations is important, it is not as crucial as for Groups 3 and 4, reflecting their more flexible mobility patterns. Group 1, with a score of 0.111, indicates that while access to transit is less important for this car-dominant group, it still holds some relevance. Group 2, scoring the lowest (0.083), suggests that access to transit stations is of minimal concern, likely due to their preference for car and bike use over public transport.
For criterion 8, "Parking supply at transit stations," Groups 1, 2, 3, and 5 all score the same (0.028), indicating that parking availability is not a major concern for these groups, as their reliance on public transport is either minimal (Groups 1, 2, and 5) or they do not prioritise parking at transit stations. Group 4, with a higher score of 0.083, shows a greater emphasis on parking, likely reflecting the needs and preferences of those who combine cycling with public transport, as they might require parking for their bikes or the occasional use of cars for longer trips. This suggests that while parking at transit stations is not a priority for most groups, Group 4 places some value on it for multimodal integration.

4.2.2. Weights for indicators

For this part of the research, the indicators will be analysed within the criteria they fall under. This approach allows for an assessment of how different groups weigh these categories, with conclusions drawn based on their varying priorities. By grouping similar indicators, the analysis is streamlined, offering clearer insights into the preferences and transportation behaviour of the different groups.

Criteria 2 (Land use diversity) and 4 (Current level of economic development) are not included since they each contain only one indicator. As a result, their weight assignment remains fixed at 1 across all user groups, leaving no variation to analyse.

1. Various Densities:

- Commercial and residential density: All groups value these indicators equally, with a weight of 0.67 for commercial density and 0.33 for residential density. However, Group 5 places slightly more emphasis on residential density (0.5) while scoring lower on commercial density. This suggests that Group 5 prioritises residential areas with less commercial activity.

2. Encouragement of Walking and Cycling:

- Level of mixed-ness of land uses: Group 3 assigns the highest weight (0.294), followed by Groups 1 and 5 (both at 0.263), and Group 2 (0.187). This indicates that public transport users prioritise mixed land uses near residential areas, though car-oriented groups also find it important. Group 4 scores the lowest (0.067), suggesting a preference for areas with more specialised zoning that supports cycling infrastructure.
- Quality and suitability of streetscape for walking/cycling: Group 4 places the highest emphasis on streetscape quality (0.3), which aligns with their preference for biking and public transport. Group 2 follows closely (0.282), indicating the importance of cycling infrastructure for those who primarily drive but also bike. Groups 1 and 5 score slightly lower (0.237), indicating that while they value walking/cycling infrastructure, they do not prioritise it as much as Groups 2 and 4.
- Density of controlled intersections/street crossings: Group 3 scores the highest (0.177), showing that safe pedestrian and cyclist crossings are important for public transport users. Groups 1 and 5 score 0.158, reflecting a balanced approach between walking/cycling and car use. Groups 2 and 4 score the lowest (0.125 and 0.133), suggesting that they emphasise other aspects of cycling infrastructure over pedestrian crossings.
- Impedance Pedestrian Catchment Areas (IPCA): Group 4 scores the highest (0.2), emphasising the importance of pedestrian-friendly catchment areas for cycling-oriented users. Group 2 places the least importance on this (0.125), aligning with their car-oriented travel patterns. Group 3 scores 0.117, suggesting that while pedestrian catchment areas matter to public transport users, other factors are more important

3. Capacity Utilisation of Transit:

- Passenger load at peak and off-peak hours: Groups 1 to 4 score similarly (0.67) for peak hours, indicating a shared concern for handling peak demand. For off-peak hours, these same groups score lower (0.33), suggesting a reduced focus on off-peak capacity. Group 5, in contrast, scores 0.5 for both peak and off-peak hours, indicating that their more flexible transportation options make them less concerned with transit crowding at specific times.

4. User-Friendliness of Transit System:

- Safety of commuters at the transit stop: Most groups (except Group 4) prioritise safety at transit stops, assigning it a weight of 0.67. Group 4, however, scores it slightly lower (0.5), placing more emphasis on information display systems, which they rate higher

(0.5). All other groups assign a weight of 0.33 to information displays, indicating that for most, safety is a greater priority than transit information.

5. Access to and from the Transit Station:

- Frequency of transit service: Group 2 values frequent transit service the most (0.4), followed by Groups 1, 4, and 5 (each at 0.364). Group 3 scores the lowest (0.308), though still relatively high, indicating that transit frequency remains an important factor across all groups.
- Interchange to different routes of same transit: Group 3 scores the highest (0.308), reflecting a preference for flexible transit connections. Groups 1, 4, and 5 score similarly (0.272), suggesting a moderate interest in interchange options. Group 2 places the least importance on this factor (0.2), likely because they rely more on cycling.
- Interchange to different transit modes: Group 3 again places the highest value on this (0.230), indicating that multi-modal connectivity is important for public transport users. Groups 1, 4, and 5 score equally (0.182), suggesting that while mode interchanges are considered, they are not a top priority. Group 2 scores the lowest (0.1), likely due to their reliance on fewer modes of transportation.
- Access to opportunities within walkable distance: Group 2 assigns the highest weight to this indicator (0.3), emphasising the importance of having accessible destinations near transit. Groups 1, 4, and 5 score equally (0.182), suggesting that while walkability is relevant, it is not a primary concern for these groups. Group 3 scores the lowest (0.154), reinforcing that public transport users prioritise other factors over walkable access.

6. Parking Supply at the Transit Station:

- Parking supply demand for cars/four-wheelers and cycles: All groups except Group 5 assign a higher weight to cycle parking (0.67) than to car parking, reflecting the importance of cycling infrastructure. Group 5 scores both equally at 0.5, indicating that they consider car and cycle parking similarly important.

These results highlight differences in user needs and preferences, reinforcing the importance of incorporating diverse transportation needs and preferences into TOD assessments. The weight differences suggest that TOD indices should be tailored to accommodate varying mode-choice behaviours.

4.3. TOD Index results

In this part, the results of the TOD Index calculations are presented, focusing on the differences in how each user group scores within the selected case study areas: Strijp-S and Kronehoef. Since Strijp-S is a newly developed, innovative neighbourhood and Kronehoef is an older, more traditional area, it is expected that Strijp-S will generally achieve higher TOD scores. However, rather than comparing the neighbourhoods directly, the primary goal of this analysis is to understand how the different user groups experience each neighbourhood.

The first section presents the necessary calculations for key indicators that were not readily available, including land use diversity, mixedness of residential land use, passenger load, and access to opportunities within the area. These calculations were essential to ensure the TOD Index accurately reflects the characteristics of both neighbourhoods.

Following this, the TOD Index scores for each user group are analysed within each neighbourhood separately, starting with Strijp-S and then Kronehoef. This approach allows for a clearer understanding of how user groups interact with the urban environment. Finally, an overall comparison of the groups is conducted to identify which groups score highest in each neighbourhood and what this implies for TOD assessments.

4.3.1. Preliminary indicator calculations

Before calculating the final TOD Index, several key indicators had to be determined, as the necessary data was not readily available. The indicators that required calculation include:

- Land use diversity
- Mixedness of residential land use
- Passenger load
- Access to opportunities within the area

The calculation of these indicators involved combining spatial analysis, assumptions based on the research of Singh et al. (2017), and detailed data processing. These steps were essential to ensure the TOD Index reflects the unique characteristics and transit dynamics of the selected case study areas, Strijp-S and Kronehoef.

4.3.1.1. Land use diversity

Table 6 presents the land use distribution for both neighbourhoods based on OpenStreetMap data.

Table 6 Land use (OpenStreetMap contributors, 2015)

Total m^2					
Kronehoef	**Area m^2**	**Land Use Diversity**	**Strijp-S**	**Area m^2**	**Land Use Diversity**
Tot residential	102847.362	0.729	Tot residential	38546.835	0.441
Tot commercial	6375.045	0.045	Tot commercial	25243.479	0.289
Tot education	8436.625	0.060	Tot education	3154.129	0.036
Tot health	1291.807	0.009	Tot office	15721.6	0.180
Tot industrial	2915.738	0.021	Tot industrial	847.195	0.010
Tot other built up	19304.163	0.137	Tot other built up	3898.212	0.045
Total area m2	141170.74		Total area m2	87411.45	

4.3.1.2. Mixedness of residential land use

Table 6 was used for this calculation.

Kronehoef:

$$S_c = 6{,}375.045 + 8{,}436.625 + 1{,}291.807 + 2{,}915.738 + 19{,}304.163 = 38{,}323.378\ m^2$$

$$MI(i) = \frac{38{,}323.378}{38{,}323.378 + 102{,}847.362} = 0.271$$

Strijp-S:

$$S_c = 25{,}243.479 + 3{,}154.129 + 15{,}721.6 + 847.195 + 3{,}898.212 = 48{,}864.615\ m^2$$

$$MI(i) = \frac{48{,}864.615}{48{,}864.615 + 38{,}546.835} = 0.559$$

4.3.1.3. Passenger load train/bus

To assess train occupancy levels during peak and off-peak hours, a series of calculations were conducted based on passenger distribution, train frequency, and capacity assumptions.

According to NS data (n.d.-b), an estimated 3,887 passengers use the station daily. Of this total, 75% (approximately 2,915 passengers) travel during peak hours, while the remaining 25% (around 972 passengers) travel during off-peak hours. Train services operate at a consistent frequency of nine trains per hour throughout the day. The peak period is assumed to last six hours (e.g., 07:00–10:00 and 16:00–19:00), whereas off-peak hours extend over ten hours. Each train has a maximum capacity of 400 passengers, with an estimated 40% occupancy upon arrival (equivalent to 160 passengers).

During peak hours, a total of 54 trains operate. With 2,915 passengers travelling during this period, the average passenger load per train amounts to approximately 54 additional passengers, bringing the total occupancy per train to 214 passengers. This results in a Passenger Load Ratio (PLR) of 53.5%, indicating that just over half of each train's seating capacity is utilised.

In contrast, off-peak hours see 90 trains in operation, accommodating approximately 972 passengers over the ten hours. With an average of 11 additional passengers per train, the total occupancy per train reaches 171 passengers, leading to a PLR of 42.7%.

These findings suggest that while train utilisation is higher during peak hours, significant capacity remains available throughout the day. Even at peak times, nearly half of the train seats remain unoccupied, while off-peak services experience even lower demand. This indicates that there is room to accommodate additional passengers without exceeding capacity, which may inform future transportation planning and service adjustments.

For the passenger load of buses, another method was adopted. Since there is no data readily available on the number of travellers per bus or bus route some assumptions had to be made. Using local travelling apps it was possible to see how busy a bus could be at a certain time. By looking at this an estimation could be made of how many people will be in that bus.

Table 7 Passenger load (NS, n.d.-b; 9292, n.d.)

Bus stop	Time	Expected load NS	Expected load 9292
Strijp-S	Peak	33%	33%
	Off-peak	33%	33%
Glaspoort	Peak	33%	33%
	Off-peak	33%	33%
Kloosterdreef	Peak	33%	33%
	Off-peak	33%	33%
Europalaan	Peak	50%	50%
	Off-peak	33%	33%
Wattstraat	Peak	33%	33%
	Off-peak	33%	33%
Sint Petruskerk	Peak	33%	33%
	Off-peak	33%	33%

4.3.1.1. *Access to opportunities within the area*

First of all, the number of jobs available in Eindhoven was collected, according to Klerks (2024) which is 192,000. Next, the total number of businesses operating in Eindhoven was collected. In Eindhoven, 25,593 businesses are operating (Eindhoven Open Data, n.d.). After this the number of businesses for the two neighbourhoods needed to be identified. Strijp-S has 897 businesses and Kronehoef has 304. Using this information it was possible to assume the amount of jobs available within each neighbourhood.

Job-to-business ratio = 192,000/25,593 ≈ 7.5

Jobs in Strijp-S = 897×7.5 ≈ 6,728 jobs available

Jobs in Kronehoef = 304×7.5 ≈ 2,280 jobs available

4.3.2. Trends across neighbourhoods

After completing these calculations and collecting all the data needed to perform the calculation, the TOD Index calculations were done. The results of the calculations can be seen in Table 7 where the final scores for each criterion can be seen as well as the final TOD Index score per neighbourhood per user group. This section analyses how different user groups score within Strijp-S and Kronehoef. The goal is to identify patterns in how different groups evaluate the transit-oriented characteristics of each area and what this reveals about their needs and preferences. The scores of the indicators can be found in Appendix F.

Table 8 Criteria and TOD Index scores for both neighbourhoods

Group 1: Car & walking oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.84	0.39	0.60	0.74	0.62	1.00	1.00	0.67	1.00
Kronehoef	0.42	0.36	0.18	0.31	0.27	0.29	0.78	0.54	0.15

Group 2: Car & bike oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.83	0.39	0.60	0.77	0.62	1.00	1.00	0.61	1.00
Kronehoef	0.39	0.36	0.18	0.33	0.27	0.29	0.78	0.56	0.15

Group 3: PT-oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.71	0.39	0.60	0.73	0.62	1.00	1.00	0.72	1.00
Kronehoef	0.38	0.36	0.18	0.29	0.27	0.29	0.78	0.55	0.15

Group 4: Bike-oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.68	0.39	0.70	0.74	0.62	1.00	1.00	0.59	1.00
Kronehoef	0.40	0.36	0.20	0.31	0.27	0.29	0.78	0.60	0.15

Group 5: Car & mix oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.78	0.38	0.60	0.74	0.61	1.00	1.00	0.67	1.00
Kronehoef	0.45	0.35	0.18	0.31	0.29	0.39	0.78	0.54	0.15

The TOD Index results offer valuable insights into how well Strijp-S and Kronehoef align with TOD principles for various user groups. Rather than directly comparing the two neighbourhoods, the focus is on examining how each user group scores within these areas, emphasising how the user group needs and preferences influence the overall TOD Index. The differences observed in the final scores are primarily driven by the weights assigned to criteria, since the raw scores for individual criteria are relatively consistent across groups. This highlights the significance of individual needs and preferences in shaping TOD outcomes.

In Strijp-S, the neighbourhood generally performs well across all user groups, thanks to its modern infrastructure, economic opportunities, and strong commercial presence. However, variations emerge due to the different weightings applied by each group. Group 1 scores the highest due to its focus on economic development and density, both of which are prominent in Strijp-S. The group places less emphasis on transit capacity utilisation, making the neighbourhood an ideal fit for their needs and preferences. On the other hand, Group 4 receives the lowest score, despite Strijp-S offering robust cycling infrastructure. This group's lower score can be attributed to their greater emphasis on pedestrian-friendly design and station access, factors that were not weighted as highly in the final assessment.

Kronehoef, with its more traditional urban structure, presents a different set of strengths and challenges based on group-specific preferences. Group 5 achieves the highest score in Kronehoef, as this group values mixed-use environments and walkability, which are relatively stronger in the neighbourhood. In contrast, Group 2 scores the lowest in Kronehoef, primarily due to the lower availability of parking and commercial density, two factors that are highly valued by this group.

The variations in TOD Index scores are primarily influenced by how user groups assigned weights to the criteria rather than by differences in the raw scores themselves. Key patterns include: car-dominant groups (Groups 1 & 2) benefiting from Strijp-S due to their focus on economic development and commercial density, both of which are prominent in this area. These groups' relatively lower emphasis on transit accessibility results in lower scores for Kronehoef. Group 3 achieves moderate scores in both neighbourhoods, with their balanced weighting of transit quality and walkability. However, their lower emphasis on commercial density and economic development prevents them from scoring as highly as car-reliant groups in Strijp-S. Group 4 scores lower across both neighbourhoods, despite the availability of supportive infrastructure. Their focus on pedestrian accessibility and controlled intersections leads to a lower TOD Index compared to groups that prioritise economic and commercial factors. Finally, Group 5 ranks highest in Kronehoef due to their balanced weighting across TOD elements, with Kronehoef's mixed-use environment offering a well-rounded TOD experience.

Maps showcasing the TOD Index score for Kronehoef and Strijp-S for all user groups can be found in Appendix G.

4.3.3. Conclusion

In conclusion, as expected Strijp-S consistently offers a more integrated, supportive environment for a range of user groups, from car-dominant to public transport- and cycling-focused groups. Its higher density, diversity, economic development, and access to transit stations make it a more suitable choice for a broad spectrum of user needs and preferences. In contrast, Kronehoef’s lower scores in these areas result in a less favourable environment, particularly for groups that rely on walking, cycling, and public transport, although it may still offer some benefits for mixed-mode focussed groups like Group 5.

4.4. Comparison with non-user centred weights

To assess the robustness of the methodology and the influence of the assigned weights on the TOD Index results, a comparison will be made between the weights used in this study and those applied by Singh et al. (2017). By applying the same weights as Singh, this analysis aims to determine whether the results from both studies align closely or if there are significant differences in the TOD Index scores for the neighbourhoods under consideration. Differences in the results could arise due to factors such as variations in local context, methodological differences, or the distinct ways in which weights are derived. Singh et al. (2017) relied on expert input from aldermen of the Arnhem-Nijmegen city region, while this study incorporates user group preferences to tailor the analysis to the specific needs and preferences of different demographic segments. This comparison will help assess how sensitive the TOD Index is to variations in weighting and provide insight into whether user group details lead to a more nuanced and accurate representation of TOD suitability for different neighbourhoods. The difference between the user group scores and the scores of Singh et al. (2017) can be seen in Table 9.

Table 9 Comparison of TOD Index scores with weights of Singh et al. (2017)

Singh et al.

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.76	0.39	0.70	0.71	0.61	1	1.00	0.85	1.00
Kronehoef	0.34	0.36	0.20	0.30	0.31	0.49	0.78	0.84	0.15

Group 1: Car & walking oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.84	0.39	0.60	0.74	0.62	1.00	1.00	0.67	1.00
Kronehoef	0.42	0.36	0.18	0.31	0.27	0.29	0.78	0.54	0.15

Group 2: Car & bike oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.83	0.39	0.60	0.77	0.62	1.00	1.00	0.61	1.00
Kronehoef	0.39	0.36	0.18	0.33	0.27	0.29	0.78	0.56	0.15

Group 3: PT-oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.71	0.39	0.60	0.73	0.62	1.00	1.00	0.72	1.00
Kronehoef	0.38	0.36	0.18	0.29	0.27	0.29	0.78	0.55	0.15

Group 4: Bike-oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.68	0.39	0.70	0.74	0.62	1.00	1.00	0.59	1.00
Kronehoef	0.40	0.36	0.20	0.31	0.27	0.29	0.78	0.60	0.15

Group 5: Car & mix oriented

Neighbourhood	TOD Index score	Criteria							
		Passenger load	User-friendliness	Acces to and from station	Parking utilisation	Density	Diversity	Walkability and Cyclability	Economic Development
Strijp-S	0.78	0.38	0.60	0.74	0.61	1.00	1.00	0.67	1.00
Kronehoef	0.45	0.35	0.18	0.31	0.29	0.39	0.78	0.54	0.15

These variations point to the impact of the different weights assigned by Singh et al. compared to those obtained through the surveys in this research. The weightings influence how each neighbourhood's characteristics are assessed, which explains the differences observed in the TOD Index scores across the neighbourhoods and user groups. Ultimately, these results emphasise the significance of the weighting process in shaping the final assessment of neighbourhood suitability for different user groups.

5. Discussion

The findings of this study provide a nuanced understanding of how diverse user groups influence the assessment of TOD. The segmentation of users into five distinct mode choice groups highlights the varying transportation preferences and needs within urban populations. The found differences in weight distribution across criteria reinforce the importance of integrating user perspectives into TOD assessments. The TOD Index results further illustrate how well different neighbourhoods align with the needs and preferences of these groups, revealing disparities in criteria like accessibility, land use diversity, and transit capacity utilisation.

5.1. Key findings

5.1.1. Segmentation process results

The segmentation process successfully categorised five user groups based on sociodemographic characteristics, with age, employment status, and education emerging as the most relevant variables in distinguishing segments. Unlike studies that explicitly analyse the influence of these variables on a individual or household level, this research used decision tree segmentation to identify groups with distinct transportation behaviours. The results reveal how sociodemographic characteristics are distributed across the identified segments rather than determining their direct impact on mode choice.

Notably, the segmentation process grouped elderly individuals (65+) in ways that challenge prior assumptions about their public transport usage. Contrary to expectations, they did not consistently fall into segments with higher public transport reliance, suggesting that age alone is not a strong determinant of transit dependency. Additionally, higher education levels were associated with segments that favoured public transport, but this trend was primarily evident among individuals below 40 years of age. Students under 25, in particular, were grouped into segments with strong public transport reliance, likely due to the availability of free OV cards. Lastly, while previous research suggested that unemployed individuals favour public transport over car use, the segmentation results indicate that the differences between employed and unemployed individuals were not as pronounced as anticipated.

5.1.2. Weighting process results

The weighting process demonstrated that while the weights assigned to TOD criteria varied significantly between groups, at least two groups consistently assigned similar weights to each criterion. It was observed that car-oriented groups generally had comparable weighting patterns, while public transport and cycling-oriented groups showed a different but internally consistent weighting structure. This finding confirms that assigning differentiated weights based on user group preferences leads to a more tailored and relevant TOD Index, reinforcing the need for user-specific evaluations rather than a uniform approach.

One key deviation from prior research, particularly Singh et al. (2017), was the ranking of parking supply. Contrary to their findings, this study revealed that parking supply was consistently ranked as the least important criterion across most user groups. However, a notable distinction emerged between car and bicycle parking. While both scored lower compared to other criteria, car parking consistently received the lowest scores, except for Group 5, where bicycle parking ranked slightly lower. This suggests that, while access to parking remains a factor, it is not a defining characteristic for TOD assessment, particularly among groups favouring mixed or alternative mode choices.

5.1.3. TOD Index results

The TOD Index results highlighted Strijp-S as the more TOD-compliant neighbourhood compared to Kronehoef, performing particularly well in economic development, density and transit accessibility. Public transport users benefited the most from higher TOD scores, demonstrating that well-integrated transit networks enhance TOD effectiveness. Cycling-oriented users displayed mixed scores, with Kronehoef scoring slightly higher in walkability and cycling infrastructure, suggesting that some areas outside of the highest-ranking TOD zones may still hold value for non-motorised transit users. Car-dominant groups, in contrast, exhibited minimal variation in TOD Index scores between the two neighbourhoods, reinforcing the idea that TOD principles primarily influence non-car-dependent groups. The comparison with non-user centred weights validated the robustness of the TOD Index, showing only minor variations when compared to the weighting approach of Singh et al. (2017), ensuring methodological reliability. However it did show that including a user group based weighting method does influence the TOD Index.

5.2. Limitations and methodological reflections

Several limitations should be acknowledged. Starting, the decision tree segmentation method relied on available demographic and travel data, which, while comprehensive, may not fully capture all aspects influencing user preferences. Although the selected variables were identified as the most significant for segmentation, other relevant factors, such as cultural background and trip purpose, were not explicitly incorporated. While these were present in the dataset, alternative approaches, such as clustering methods or mixed-method analyses, could provide additional insights into the nuanced factors shaping travel behaviour.

Additionally, while informal consultations with users provided valuable insights for weighting the criteria, the sample size was limited, potentially affecting the generalisability of the results. The selection process for participants may have introduced biases, as responses were drawn from individuals within a personal network. A broader and more diverse sample, incorporating perspectives from a wider range of socioeconomic backgrounds and travel behaviours, could improve the robustness of the weighting process and allow for more refined subgroup analyses. Furthermore, the reliance on self-reported data introduces potential biases, such as social desirability or response inconsistency, which should be considered when interpreting the findings.

The GIS-based TOD Index assessment was constrained by the availability and quality of data, which influenced how certain indicators were measured. In particular, indicators like economic development and passenger load relied on available datasets, but some key variables, such as the exact number of business establishments and precise transit capacity utilisation, were not readily available. To overcome this, proxy variables were used, which are approximations based on related data sources. While these proxies provided useful estimates, they may not fully capture the real-world conditions or dynamics of the neighbourhoods. Furthermore, the spatial resolution of the datasets available for analysis was relatively coarse, which may have reduced the ability to capture fine-grained, localised variations in TOD suitability. These limitations could have impacted the accuracy of the TOD Index scores. Future research should focus on obtaining higher-resolution spatial and economic data to allow for more precise assessments and to better reflect the complexity of the areas being studied.

5.3. Importance of findings

The results underscore the importance of tailoring TOD assessments to different user groups, demonstrating that a one-size-fits-all approach to TOD assessment is insufficient in capturing the diverse needs and preferences of urban populations. This research highlights the necessity of differentiated weighting approaches when assessing TOD-ness of urban areas, as travel behaviour is distinctively different between user groups. Unlike previous studies that applied uniform TOD criteria across all users, this study provides empirical evidence that various user groups prioritise distinct aspects of TOD. For instance, car-dominant groups placed greater emphasis on commercial density and economic development, whereas groups with a stronger reliance on walking and cycling prioritised walkability, cycling infrastructure, and access to transit stations. These differences were identified through decision tree segmentation and a weighting process which revealed how sociodemographic factors influence transportation preferences. This reinforces the need for adaptive TOD assessments that take into account the unique needs and preferences of different user groups, rather than assuming a one-size-fits-all approach to TOD evaluation.

By integrating user needs and preferences into TOD evaluations, this research contributes to a more holistic and equitable urban planning approach. Recognising these differences can enhance urban sustainability by promoting transport infrastructure that aligns with real-world mobility patterns rather than theoretical uniformity. More equitable access to public transport can be achieved by ensuring that planning strategies account for the needs and preferences of different groups, from cyclists and pedestrians to public transport users and car-dependent individuals.

Additionally, this research sets the foundation for future studies to refine the segmentation approach further by, for example, including more variables. Expanding the analysis to include additional demographic factors, such as cultural background, household structure, and trip purpose, could provide an even more comprehensive understanding of user mobility needs and preferences.

5.4. Conclusion of discussion

This discussion has contextualised the study’s results within TOD and urban planning. By integrating user-centric weighting into the TOD Index, this research offers a more inclusive framework for evaluating assessing TOD of urban areas. The weightings, based on input from distinct user groups, reflect diverse needs and preferences, ensuring that TOD strategies are better aligned with real-world transportation behaviours. This approach moves beyond traditional top-down planning models, addressing gaps by considering populations often overlooked in standard methodologies.

While the study presents valuable insights, some methodological challenges remain, including data limitations and the subjective nature of weighting. These challenges highlight the need for continued refinement to fully capture the complexities of urban settings. Nevertheless, this research marks a significant step in making TOD practices more responsive to the diverse needs and preferences of urban populations, laying the foundation for more equitable, user-centred urban planning.

6. Conclusion

This concluding chapter provides a summary of the research, addressing the main research question along with all sub-questions. It then discusses the contributions and limitations of the study. Lastly, recommendations for future research and development are presented.

6.1. Answering of research question

The main research question of this thesis is: *"How can sociodemographic-based user segmentation improve the accuracy of TOD assessments?"* This question has been addressed through a multi-phase research design that integrates user preferences into TOD assessment methodologies.

Firstly, sub questions one was answered by conducting a literature review that established that traditional TOD assessment models largely focus on spatial and environmental criteria while neglecting the diverse needs and preferences of different user groups. The review highlighted gaps in existing methodologies and underscored the importance of integrating user segmentation into TOD frameworks.

Secondly, the research answered sub questions two and three by employing decision tree analysis to segment the Dutch population into distinct user groups based on sociodemographic characteristics and mode choice. This segmentation provided a more nuanced understanding of how different population groups interact with transit-oriented environments and what factors influence their mobility decisions.

Thirdly, research question four was answered by a MCA framework integrated with GIS to assess the impact of user-specific weightings on TOD evaluations. The application of this methodology to case study areas in Eindhoven revealed that incorporating user-derived preferences significantly altered TOD scores compared to traditional assessments.

The findings demonstrate that sociodemographic-based user segmentation enhances the accuracy of TOD assessments by ensuring that evaluations are not only based on spatial and environmental factors but also on the actual needs and preferences of diverse urban populations. By integrating user-specific preferences into the assessment process, this approach provides a more nuanced understanding of how different groups interact with transit-oriented environments, ultimately leading to more representative and context-sensitive TOD evaluations. The results show that traditional, one-size-fits-all TOD models may overlook crucial variations in user needs and preferences, whereas incorporating segmentation allows for a more inclusive framework that better reflects real-world mobility patterns and accessibility challenges. The research concludes that a user-centric approach to TOD planning leads to more equitable and effective transit-oriented urban development strategies. This methodology can help policymakers, planners, and researchers develop more targeted interventions, optimise transit accessibility for various user groups, and foster urban environments that accommodate diverse lifestyles and mobility preferences. By refining TOD assessment models with a stronger focus on user diversity, this research contributes to the development of more socially sustainable and inclusive urban planning practices.

6.2. Scientific relevance

This research has made a significant contribution to the field of TOD by integrating a user-centric approach into TOD assessments. Traditional TOD evaluations often rely on a standardised set of criteria without accounting for the varying needs and preferences of different user groups. By applying a novel segmentation method based on socioeconomic and demographic factors, this study has demonstrated that transportation preferences are not homogeneous and that planning strategies must be adapted accordingly.

The segmentation process identified that age, employment status, and education played significant roles in differentiating user groups based on their travel behaviour represented by mode choice. This analysis focused on understanding how different user groups, defined by these sociodemographic factors, score differently in terms of TOD suitability within urban areas. The findings suggest that varying priorities across user groups lead to distinct TOD scores, highlighting the need for more targeted TOD assessments that reflect the diverse needs and preferences of different populations. This differentiation is crucial for refining TOD assessments, as it provides a more accurate representation of urban mobility patterns. The weighting process further reinforced this necessity by highlighting substantial differences in how groups perceive TOD characteristics. For instance, while public transport users emphasised station accessibility, car-oriented groups placed greater importance on density and economic development, indicating that a uniform TOD framework cannot sufficiently address the mobility needs and preferences of all urban residents.

The results confirmed that uniform TOD evaluation models risk overlooking significant behavioural distinctions among user groups. By demonstrating that a differentiated approach produces a more nuanced TOD Index, this research supports a shift in urban planning methodologies toward more personalised and inclusive models. This study also builds on the work of Singh et al. (2017) by adjusting their criteria weighting framework with user segmentation and user-derived weights, thereby offering a more comprehensive TOD assessment methodology.

The study relied on available datasets, which were effective for the segmentation process. However, certain variables, such as cultural background, household structure, and trip purpose, were not included in the analysis. These variables were not deemed significant enough to justify their inclusion, as adding them could have led to the creation of too many user groups, making the segmentation process more complex and less manageable. Furthermore, the sample size for the surveys, though informative, was relatively limited, which may affect the generalisability of the findings. Integrating real-time mobility data, such as GPS tracking or data from transportation apps, and expanding the survey base in future studies would enhance the precision and applicability of this approach.

6.3. Societal relevance

This study holds significant societal relevance by advocating for a more inclusive and equitable approach to TOD planning. Traditional TOD frameworks often emphasise transit efficiency and spatial factors, sometimes overlooking the diverse mobility needs and preferences of different urban residents. By focusing on user-specific criteria weighting, this research supports urban planning strategies that not only prioritise sustainable transport but also promote social equity.

Policymakers, urban planners, municipalities and transportation agencies can use the findings to design TOD strategies that reflect the mobility requirements of various demographic groups. The research highlights the potential for TOD to provide equitable access to opportunities, particularly for those relying on non-car mobility options. Additionally, the findings suggest that current TOD methodologies may need adjustments to better align with the travel behaviours of different user groups, ensuring that planning strategies cater to a broader population.

This study demonstrates that integrating user preferences into TOD assessments can result in more inclusive and effective urban planning outcomes. Urban planners can utilise the TOD Index methodology developed here to identify neighbourhoods that better align with the needs of diverse user groups, ensuring that transit-oriented developments are not only transit-friendly but also tailored to the specific transportation behaviours of residents.

6.4. Recommendations

This study provides valuable insights into how user group preferences can be integrated into the assessment of TOD. The findings highlight the importance of considering diverse user groups and their varying priorities when evaluating urban areas for TOD suitability. While the research methodology developed here offers a solid foundation, several areas can be enhanced to increase the precision, adaptability, and applicability of TOD assessments. Future research can build upon the insights gained in this study by addressing the limitations identified and exploring new ways to refine the segmentation process, incorporate dynamic data, and test the methodology in broader urban contexts. The following recommendations are proposed:

- Refining user group segmentation with broader variables: While this study identified age, employment status, and education as the most significant factors for transportation preferences, future research could expand the segmentation process by incorporating a broader set of sociodemographic variables. Factors such as cultural background, trip purpose, trip length, household structure, and income may provide additional insights into user behaviour, especially in diverse urban areas. However, it's important to explore segmentation methods that ensure a manageable number of user groups, even when incorporating these extra variables. Furthermore, additional travel behaviour variables, such as trip purpose, length, and frequency, should be considered to offer a more comprehensive understanding of user preferences. Employing more advanced clustering techniques could help identify sub-groups within the existing segments, leading to an even deeper understanding of user preferences.
- Integration of real-Time and longitudinal Data: The current study relied on cross-sectional data, which provides a snapshot of user preferences but may not capture dynamic changes over time. Future research should consider integrating real-time mobility data (e.g., GPS, smartphone apps) and longitudinal data to track changes in travel behaviour. Long-term studies could help uncover how TOD priorities evolve in response to shifts in urban infrastructure, policy changes, and broader societal trends, such as remote work or climate change. For instance, how might user preferences for transit access or walkability change in response to new transit routes or infrastructure investments? Longitudinal data would help urban planners predict future needs and design more adaptable and sustainable TOD projects.
- Testing the methodology in diverse urban contexts: While this study focused on neighbourhoods within Eindhoven, the methodology should be tested in other cities with varying levels of transit infrastructure, demographic compositions, and urban forms. Comparative studies across different urban contexts—such as cities with well-established transit systems versus those with emerging networks—could reveal how the TOD Index and user group preferences adapt to these differences. Such studies would be particularly valuable in understanding whether certain TOD criteria are universally important or if they must be adjusted based on the specific urban context.

This approach could also explore the applicability of the TOD Index in different cultural settings and transportation environments.

- Broad-scale surveys: To better capture the full range of user preferences and behaviours, future research could benefit from conducting larger-scale surveys. This would allow for a more representative sample of different user groups, improving the accuracy and relevance of the data collected.

7. References

9292. (n.d.). Plan je reis met het OV en deelvervoer. https://9292.nl/

Allen, J., & Farber, S. (2020). Planning transport for social inclusion: An accessibility-activity participation approach. Transportation Research. Part D, Transport and Environment, 78, 102212. https://doi.org/10.1016/j.trd.2019.102212

Aminu, M., Matori, A. N., Yusof, K. W., Malakahmad, A., & Zainol, R. B. (2017). Analytic network process (ANP)-based spatial decision support system (SDSS) for sustainable tourism planning in Cameron Highlands, Malaysia. Arabian Journal of Geosciences, 10(13). https://doi.org/10.1007/s12517-017-3067-0

Anwar, A., Leng, H., Ashraf, H., & Haider, A. (2024). Measuring the Transit-Oriented Development (TOD) levels of Pakistani megacities for TOD application: A case study of Lahore. Sustainability, 16(5), 2209. https://doi.org/10.3390/su16052209

Ardeshiri, A., & Vij, A. (2019). Lifestyles, residential location, and transport mode use: A hierarchical latent class choice model. Transportation Research Part a Policy and Practice, 126, 342–359. https://doi.org/10.1016/j.tra.2019.06.016

Calthorpe, P. (1993). The next American metropolis: Ecology, community, and the American Dream. Princeton Architectural Press.

Carlton, I. (2009, September 1). Histories of Transit-Oriented Development: Perspectives on the Development of the TOD Concept. https://escholarship.org/uc/item/7wm9t8r6

CBS. (2024, July 4). Onderweg in Nederland (ODIN) 2023 - onderzoeksbeschrijving. Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/longread/rapportages/2024/onderweg-in-nederland--odin---2023-onderzoeksbeschrijving?onepage=true

Cervero, R. (2002). Built environments and mode choice: toward a normative framework. Transportation Research. Part D, Transport and Environment, 7(4), 265–284. https://doi.org/10.1016/s1361-9209(01)00024-4

Chen, Z., Li, P., Jin, Y., Bharule, S., Jia, N., Li, W., Song, X., Shibasaki, R., & Zhang, H. (2022). Using mobile phone big data to identify inequity of aging groups in transit-oriented development station usage: A case of Tokyo. Transport Policy, 132, 65–75. https://doi.org/10.1016/j.tranpol.2022.12.010

Dawkins, C., & Moeckel, R. (2016). Transit-Induced gentrification: Who will stay, and who will go? Housing Policy Debate, 26(4–5), 801–818. https://doi.org/10.1080/10511482.2016.1138986

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. https://doi.org/10.1016/j.tranpol.2014.04.004

De Witte, A., Hollevoet, J., Dobruszkes, F., Hubert, M., & Macharis, C. (2013). Linking modal choice to motility: A comprehensive review. Transportation Research Part a Policy and Practice, 49, 329–341. https://doi.org/10.1016/j.tra.2013.01.009

Department for Communities and Local Government. (2009). Multi-criteria analysis: a manual. In Department for Communities and Local Government. https://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf

Díaz-Pérez, F. M., & Bethencourt-Cejas, M. (2016). CHAID algorithm as an appropriate analytical method for tourism market segmentation. Journal of Destination Marketing & Management, 5(3), 275–282. https://doi.org/10.1016/j.jdmm.2016.01.006

Eindhoven Open Data. (n.d.). Eindhoven open data. https://data.eindhoven.nl/pages/home/

Ettema, D., & Nieuwenhuis, R. (2017). Residential self-selection and travel behaviour: What are the effects of attitudes, reasons for location choice and the built environment? Journal of Transport Geography, 59, 146–155. https://doi.org/10.1016/j.jtrangeo.2017.01.009

Greene, R., Devillers, R., Luther, J. E., & Eddy, B. G. (2011). GIS-Based Multiple-Criteria Decision Analysis. Geography Compass, 5(6), 412–432. https://doi.org/10.1111/j.1749-8198.2011.00431.x

HDR. (n.d.). Peter Calthorpe. https://www.hdrinc.com/person/peter-calthorpe

Hermes. (n.d.-a). Dienstregeling. https://www.hermes.nl/nl/resultaten/dienstregeling?route=%7B%22route_id%22%3A43141%2C%22route_long_name%22%3A%22Uden+-+Gerwen+-+Eindhoven+Station%22%2C%22route_short_name%22%3A%22322%22%7D&date=02-01-2025&time=19%3A00&direction=1&directionId=0

Hermes. (n.d.-b). Dienstregeling en halte-informatie. https://www.hermes.nl/nl/onze-routes/dienstregeling-en-halte-informatie#dienstregeling

Hrelja, R., Olsson, L., Pettersson-Löfstedt, F., & Rye, T. (2022). Challenges of delivering TOD in low-density contexts: the Swedish experience of barriers and enablers. European Transport Research Review, 14(1). https://doi.org/10.1186/s12544-022-00546-1

Hsu, C. H., & Kang, S. K. (2007). CHAID-based segmentation: international visitors' trip characteristics and perceptions. Journal of Travel Research, 46(2), 207–216. https://doi.org/10.1177/0047287507299571

Huang, R., Grigolon, A., Madureira, M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. Journal of Transport and Land Use, 11(1). https://doi.org/10.5198/jtlu.2018.1110

IBM. (n.d.-a). Decision tree. https://www.ibm.com/topics/decision-trees

IBM. (n.d.-b). IBM SPSS Decision Trees 29. https://www.ibm.com/docs/en/SSLVMB_29.0.0/pdf/IBM_SPSS_Decision_Trees.pdf

Ibrahim, S. M., Ayad, H. M., Turki, E. A., & Saadallah, D. M. (2023). Measuring Transit-Oriented Development (TOD) levels: Prioritize potential areas for TOD in Alexandria, Egypt using GIS-Spatial Multi-Criteria based model. Alexandria Engineering Journal /Alexandria Engineering Journal, 67, 241–255. https://doi.org/10.1016/j.aej.2022.12.053

ITDP. (2017, June). TOD Standard - Institute for Transportation and Development Policy. Institute for Transportation and Development Policy - Promoting Sustainable and Equitable Transportation Worldwide. https://itdp.org/publication/tod-standard/

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2013). Residential dissonance and mode choice. Journal of Transport Geography, 33, 12–28. https://doi.org/10.1016/j.jtrangeo.2013.09.004

Kattiyapornpong, U., & Miller, K. E. (2006). Understanding Travel Behavior using Demographic and Socioeconomic Variables as Travel Constraints. https://opus.lib.uts.edu.au/bitstream/10453/3076/1/2006005312.pdf

Khare, R., Villuri, V. G. K., Chaurasia, D., & Kumari, S. (2021). Measurement of transit-oriented development (TOD) using GIS technique: a case study. Arabian Journal of Geosciences, 14(10). https://doi.org/10.1007/s12517-021-07142-y

Klerks, M. (2024, November 7). Aantal banen op fietsafstand van Eindhoven hoogste van heel Noord-Brabant. Eindhovens Dagblad. https://www.ed.nl/eindhoven/aantal-banen-op-fietsafstand-van-eindhoven-hoogste-van-heel-noord-brabant~aaa30cb2/?cb=1dd79a04-29b9-4546-a34e-bb333bfc030a&auth_rd=1#:~:text=Binnen%20een%20straal%20van%20tien,Centraal%20Bureau%20voor%20de%20Statistiek.

Limtanakool, N., Dijst, M., & Schwanen, T. (2005). The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips. Journal of Transport Geography, 14(5), 327–341. https://doi.org/10.1016/j.jtrangeo.2005.06.004

Lucas, K. (2012). Transport and social exclusion: Where are we now? Transport Policy, 20, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013

Magidson, J., & Vermunt, J. K. (2005). An extension of the CHAID tree-based segmentation algorithm to multiple dependent variables. In Springer eBooks (pp. 176–183). https://doi.org/10.1007/3-540-28084-7_18

Meli, J. (2022). Influence of socioeconomic variables on mode choice in Switzerland: A comparison of three large-scale RP/SP data sets [Master thesis]. In IVT & ETH Zurich, IVT, ETH Zurich, Zurich.

https://ethz.ch/content/dam/ethz/special-interest/baug/ivt/ivt-dam/publications/students/701-800/sa752.pdf

Motlagh, M. G., Amraei, B., & Halimi, M. (2020). Evaluating the hazardous potential of the dieback of the Zagros Oak forests using the multi-criteria decision-making methods. Arabian Journal of Geosciences, 13(19). https://doi.org/10.1007/s12517-020-05992-6

NS. (n.d.-a). Reisplanner | Plan je reis | NS. https://www.ns.nl/reisplanner/#/

NS. (n.d.-b). Reizigersgedrag | NS Dashboard. https://dashboards.nsjaarverslag.nl/reizigersgedrag

Odu, G. (2019). Weighting methods for multi-criteria decision making technique. Journal of Applied Sciences and Environmental Management, 23(8), 1449. https://doi.org/10.4314/jasem.v23i8.7

OpenStreetMap contributors. (2015) Planet dump. Retrieved from https://planet.openstreetmap.org

PDOK & Rijkswaterstaat. (n.d.). Dataset: Nationaal Wegen Bestand (NWB) - Wegen. https://www.pdok.nl/introductie/-/article/nationaal-wegen-bestand-nwb-wegen

Poholka, H. (2011). Locating Optimal Affordable Housing Sites : A Determination of Potential Site Locations for New Affordable Housing Units using Multi-criteria Analysis: A Case Study of Kelowna, British Columbia. DIVA. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A430290&dswid=-4817

Pojani, D., & Stead, D. (2014). Dutch planning policy: The resurgence of TOD. Land Use Policy, 41, 357–367. https://doi.org/10.1016/j.landusepol.2014.06.011

Pollack, S., Bluestone, B., & Billingham, C. (2010). Maintaining Diversity in America’s Transit-Rich Neighborhoods: Tools for Equitable Neighborhood Change. In Dukakis Center for Urban and Regional Policy.

Rice, L. (2004). Transportation Spending by Low-Income California Households: Lessons for the San Francisco Bay Area. Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/content/pubs/report/R_704LRR.pdf

Schorcht, M., Jehling, M., & Krüger, T. (2023). Where are cities under pressure? – An indicator for measuring the impact of building changes on urban density. Ecological Indicators, 149, 110142. https://doi.org/10.1016/j.ecolind.2023.110142

Singh, Y. J., Fard, P., Zuidgeest, M., Brussel, M., & Van Maarseveen, M. (2014). Measuring transit oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen. Journal of Transport Geography, 35, 130–143. https://doi.org/10.1016/j.jtrangeo.2014.01.014

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

Song, Y., & Lu, Y. (2015). Decision tree methods: applications for classification and prediction. Shanghai Archives of Psychiatry, 27–27(2), 130–135. https://pmc.ncbi.nlm.nih.gov/articles/PMC4466856/pdf/sap-27-02-130.pdf

Sun, Y., Han, B., & Lu, F. (2024). An overview of TOD level assessment around rail transit stations. Urban Rail Transit. https://doi.org/10.1007/s40864-023-00211-3

Thomas, R., & Bertolini, L. (2020). Transit-Oriented development. In Springer eBooks. https://doi.org/10.1007/978-3-030-48470-5

Thomas, R., Pojani, D., Lenferink, S., Bertolini, L., Stead, D., & Van Der Krabben, E. (2018). Is transit-oriented development (TOD) an internationally transferable policy concept? Regional Studies, 52(9), 1201–1213. https://doi.org/10.1080/00343404.2018.1428740

University of Groningen Geodienst. (2022, April 5). Openbaar Vervoer Nederland. https://hub.arcgis.com/maps/RUG::openbaar-vervoer-nederland/about

Van Acker, V., & Witlox, F. (2009). Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. Journal of Transport Geography, 18(1), 65–74. https://doi.org/10.1016/j.jtrangeo.2009.05.006

Van Luven, M. (n.d.). Een eerlijke verdeling van mobiliteit: de rol van verdelingsprincipes. https://www.goudappel.nl/nl/actueel/een-eerlijke-verdeling-van-mobiliteit-de-rol-van-verdelingsprincipes

Vanoutrive, T. (2018). Minder inkomen, dus minder mobiel, dus minder kansen? In Jaarboek Armoede en Sociale Uitsluiting 2018 (p. 277). USAB. https://repository.uantwerpen.be/docman/irua/cf5689/155232.pdf

Vij, A., Carrel, A., & Walker, J. L. (2013). Incorporating the influence of latent modal preferences on travel mode choice behavior. Transportation Research Part a Policy and Practice, 54, 164–178. https://doi.org/10.1016/j.tra.2013.07.008

Whooz. (n.d.). Retrieved September 24, 2024, from https://www.whooz.nl/nl

Yi, Z., Zhang, Z., & Wang, H. (2024). Measuring metro station area's TODness: An exploratory study of Shenyang based on multi-source urban data. Transactions in GIS. https://doi.org/10.1111/tgis.13148

Zaręba, A., Widawski, K., Krzemińska, A., & Dzikowska, A. (2019). Multiscale Transit Oriented Development (TOD) for sustainable communities. IOP Conference Series. Earth and Environmental Science, 214, 012099. https://doi.org/10.1088/1755-1315/214/1/012099

Zhao, Y., Hu, S., & Zhang, M. (2024). Evaluating equitable Transit-Oriented development (TOD) via the Node-Place-People model. Transportation Research Part a Policy and Practice, 185, 104116. https://doi.org/10.1016/j.tra.2024.104116

A Appendix – Code for select cases tool SPSS

(Relationship_Group = 1 OR Relationship_Group= 2) AND (Age_Group = 1 OR Age_Group = 2 OR Age_Group = 3 OR Age_Group = 4) AND (Education_Group = 1 OR Education_Group = 2 OR Education_Group = 3) AND (Employment_Group = 1 OR Employment_Group = 2 OR Employment_Group = 3) AND (Income_Group = 1 OR Income_Group = 2 OR Income_Group = 3) AND (Geslacht = 1 OR Geslacht = 2) AND (HerkLand = 1 OR HerkLand = 2 OR HerkLand = 3)

B Appendix – Complete Decision Tree

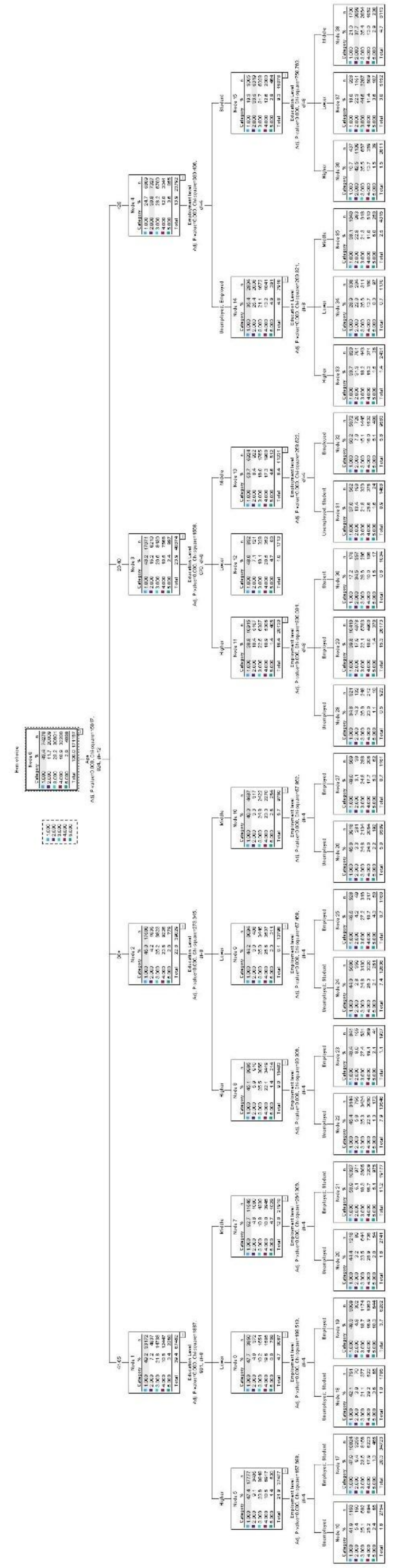

Figure 14 Output decision tree analysis full

C Appendix – Survey format

Question 1

In which of the following groups would you place yourself?

Group 1: Car > Foot > Bike > Public transport (PT)

- Node 12: (Car: 48.6%, Foot: 20.5%, Bike 19.1%, PT: 7.1%)
- Node 16: (Car: 41.9%, Foot: 25.2%, Bike: 25.1%, PT: 5.4%)
- Node 18: (Car: 42.1%, Foot: 29.2%, Bike: 21.1%, PT: 3.9%)
- Node 20: (Car: 44.4%, Foot: 26.9%, Bike: 23.5%, PT: 3.2%)
- Node 24: (Car: 44.0%, Foot: 26.3%, Bike: 24.8%, PT: 2.8%)
- Node 32: (Car: 56.2%, Foot: 16.0%, Bike: 15.1%, PT: 7.6%)

This group is characterised by car dependency as the dominant mode of transport, with walking as a strong secondary preference, followed by cycling, and limited use of public transport. It reflects users who prioritise car travel but value walking for short distances.

Group 2: Car > Bike > Foot > PT

- Node 17: (Car: 47.9%, Bike: 23.5%, Foot: 17.9%, PT: 9.4%)
- Node 19: (Car: 49.3%, Bike: 18.7%, Foot: 16.9%, PT: 4.8%)
- Node 21: (Car: 53.9%, Bike: 19.3%, Foot: 16.7%, PT: 5.1%)
- Node 22: (Car: 45.4%, Bike: 25.3%, Foot: 22.5%, PT: 5.6%)
- Node 23: (Car: 43.4%, Bike: 27.4%, Foot: 19.1%, PT: 8.0%)
- Node 25: (Car: 45.5%, Bike: 27.2%, Foot: 18.7%, PT: 4.2%)
- Node 26: (Car: 45.6%, Bike: 24.8%, Foot: 24.0%, PT: 3.3%)
- Node 27: (Car: 49.0%, Bike: 24.8%, Foot: 17.7%, PT: 3.1%)

In this group, the car remains the dominant mode, with cycling as a notable secondary preference. Walking is less common than cycling, and public transport usage is relatively low. This group indicates areas or users where biking infrastructure and convenience encourage frequent cycling alongside car use.

Group 3: PT > Others

- Node 30: (PT: 34.5%, Bike: 28.6%, Foot: 18.0%, Car: 17.2%)
- Node 36: (PT: 42.5%, Bike: 25.5%, Car: 16.7%, Foot: 13.7%)
- Node 38: (PT: 37.7%, Bike: 25.4%, Car: 21.0%, Foot: 13.0%)

PT is this group's primary mode of travel, with bicycles and walking as key alternatives. Car usage is significantly less dominant. This group likely consists of people who prefer areas with well-developed public transport networks or individuals who prioritise sustainability and accessibility over car use.

Group 4: Bike > Others

- Node 37: (Bike: 44.6%, PT: 22.3%, Car: 18.0%, Foot: 11.4%)

This group is dominated by bicycle usage, followed by public transport, cars, and walking. It represents users who prefer active or sustainable modes of transport, likely influenced by well-developed cycling infrastructure or a cultural preference for biking.

Group 5: Alternative mode choice influenced nodes (alternative modes higher, car still dominant)

- Node 28: (Car: 34.8%, Bike: 26.9%, Foot: 23.0%, PT: 14.3%)
- Node 29: (Car: 39.8%, Bike: 22.1%, Foot: 18.8%, PT: 17.9%)
- Node 31: (Car: 37.6%, Foot: 25.6%, Bike: 21.8%, PT: 13.4%)
- Node 34: (Car: 28.9%, Bike: 26.6%, PT: 22.6%, Foot: 13.7%)
- Node 35: (Car: 38.1%, PT: 22.8%, Bike: 21.3%, Foot: 11.8%)
- Node 33: (Car: 33.7%, PT: 31.3%, Bike: 18.2%, Foot: 15.3%)

The car remains dominant in this group, but alternative modes (cycling, PT, or walking) are more pronounced than in other car-dominant groups. These nodes represent transitional or mixed-mode areas where users are exploring alternatives to car dependency, potentially due to the availability or encouragement of diverse mobility options.

Based on this, fill in in which group you would place yourself:

Question 2

Below there will be eight tables in which I want to ask you to rank all the different subjects given in the leftmost column. The highest rank will be 1 and the lowest rank can be 8. However it is possible to choose to exclude a subject if you are convinced that you don't find it important for you at all, in this case, you can fill in a 0. An explanation of all subjects is first given.

1. Density

Definition: Refers to how many people and businesses are located in a certain area. High density often supports more public transport use because more people live and work near transit stations.

- Population Density: The number of people living in the area. More people means more potential transit users.
- Commercial Density: The number of businesses like shops and offices in the area. More businesses attract more people and create reasons to use public transport.

2. Land Use Diversity

Definition: Describes how many different types of buildings and spaces (like homes, shops, offices) exist in one area. A mix of uses means people can live, work, and shop within a certain area. It measures how balanced the mix of different types of buildings within said area is.

3. Walkability and Cyclability

Definition: Refers to how easy and safe it is to walk or cycle in an area. More walkable and bike-friendly areas encourage people to walk or cycle.

- Mixedness of Residential and Other Uses: How well homes are mixed with other places like shops, schools, or parks, making short trips easy on foot or by bike.
- Quality and suitability of Walkable/Cyclable Paths: The total length of paths or roads that are safe and suitable for walking or cycling.
- Intersection Density: The number of crossroads or intersections in the area. More intersections mean more route options for pedestrians and cyclists.
- Impedance Pedestrian Catchment Area (IPCA): Shows how far someone can realistically walk from a station in 10 minutes, considering obstacles like busy roads.

4. Economic Development

Definition: Looks at the economic activity in the area, which can influence how much people use transit because of jobs or shopping opportunities.

- Density of Business Establishments: How many businesses are in the area. More businesses usually mean more jobs and shopping, encouraging public transport use.

5. Capacity Utilisation of Transit

Definition: Refers to how full public transport is during busy and quiet times. Balancing this can make transit more comfortable and efficient.

- Passenger Load in Peak Hours: How many people use public transport during rush hours. Too many passengers can cause overcrowding.
- Passenger Load in Off-Peak Hours: How many people use public transport outside rush hours. Higher off-peak usage is a good sign of steady transit demand.

6. User-Friendliness of the Transit System

Definition: Refers to how comfortable and easy the transit system is to use. A user-friendly system encourages more people to use it.

- Safety of Commuters: Measured by how many shops and places to eat are at or near the station. Busy stations with shops feel safer.
- Information Display Systems: Refers to signs or screens that show transit information, like train times. Having clear, up-to-date info helps people plan their trips.

7. Access to and from the Station

Definition: Refers to how easy it is to get to the station and connect to other forms of transport. Better access encourages more people to use public transport.

- Frequency of Transit Service: How often trains or buses arrive. More frequent service means less waiting time.
- Interchange to Different Routes of the Same Transit: The number of different routes you can switch to at the station, allowing for more destinations.
- Interchange to Other Transit Modes: How easy it is to switch from a train to other transport modes, like buses or trams.
- Access to Opportunities within Walking Distance: How many jobs or activities (like shops or services) are within walking distance of the station.

8. Parking at the Station

Definition: Refers to the availability and usage of parking spaces for cars and bicycles. Good parking options encourage people to use public transport for part of their trip.

- Parking Utilization for Cars: How many car parking spaces are used compared to what's available. Too few or too many spaces can be inefficient.
- Parking Utilization for Bicycles: How many bicycle parking spaces are used. Adequate bike parking encourages people to cycle to the station.

Criteria	**Rank per group**				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Various densities					

Land use diversity					
Encouragement walking and cycling					
Current level of economic development					
Capacity utilisation of transit					
User-friendliness of transit system					
Access to and from the transit station					
Parking supply at the transit station					

Criteria	**Rank per group**				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Population density					
Commercial density					

Criteria	**Rank per group**				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Level of mixed-ness of land uses w.r.t. residential land use					
Quality and suitability of streetscape for walking					
Quality and suitability of streetscape for cycling					
Density of controlled intersections/street crossings					
Impedance Pedestrian Catchment Areas (IPCA)					

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Number of business establishments					

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Passenger load at peak hours					
Passenger load at off-peak hours					

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Safety of commuters at the transit stop					
Information display systems					

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Frequency of transit service					
Interchange to different routes of same transit					
Interchange to different transit modes					
Access to opportunities within walkable distance from transit station					

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**

Parking supply demand for cars/four-wheelers					
Parking supply demand for cycles					

D Appendix – Ranking of criteria

Table 10 Ranking of criteria

Criteria	Rank per group				
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Various densities	2	4	6	8	4
Land use diversity	1	1	5	5	1
Encouragement walking and cycling	3	5	3	1	2
Current level of economic development	4	2	7	7	7
Capacity utilisation of transit	7	7	2	3	5
User-friendliness of transit system	5	3	4	4	6
Access to and from the transit station	6	6	1	2	3
Parking supply at the transit station	8	8	8	6	8

E Appendix – Ranking of indicators

Table 11 Ranking of indicators

Indicators	Rank per group				
Densities	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Population density	2	2	2	2	1
Commercial density	1	1	1	1	1
Walking and cycling	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Level of mixed-ness of land uses w.r.t. residential land use	1	3	1	5	1
Quality and suitability of streetscape for walking	1	2	2	2	1
Quality and suitability of streetscape for cycling	2	1	3	1	2
Density of controlled intersections/street crossings	3	4	3	4	3
Impedance Pedestrian Catchment Areas (IPCA)	4	4	4	3	4
Economic development	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Number of business establishments	1	1	1	1	1
Tax earnings of municipality	2	3	3	2	2
Unemployment levels	3	2	2	3	2
Passenger load	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Passenger load at peak hours	1	1	1	1	1
Passenger load at off-peak hours	2	2	2	2	1
User-friendliness	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Safety of commuters at the transit stop	1	1	1	1	1
Information display systems	2	2	2	1	2
Access transit	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Frequency of transit service	1	1	1	1	1
Interchange to different routes of same transit	2	3	1	2	2
Interchange to different transit modes	3	4	2	3	3
Access to opportunities within walkable distance from transit station	3	2	3	3	3

Parking supply	Group 1	Group 2	Group 3	Group 4	Group 5
Parking supply demand for cars/four-wheelers	2	1	2	2	2
Parking supply demand for cycles	1	1	1	1	1

F Appendix – Full tables for TOD values

Table 12 TOD values before normalisation

Station/neighbourhood	Passenger Load		User Friendliness		Accessibility				Parking Utilisation		Density	
	Peak hour	Off-Peak hour	Display Systems	Safety	Service Frequency	Connections	Interchange	Location Accessibility	Car Parking	Cycles Parking	Population Density	Commercial Density
	passengers /capacity (in %)	*passengers /capacity (in %)*	*presence of digital display**	*number of shops at station*	*number of train/busses per hour*	*number of routes (same transit system)*	*presence of alternatives*	*number of jobs*	*parking utilisation in percentage*	*parking utilisation in percentage*	*population per sq km*	*number of commercial activities per sq km*
Strijp-S	-	-	-	-	-	-	-	**6,728**	-	-	**10476**	**113.98**
Strijp-S bus station	33%	33%	2	5.25	25	4	Yes	-	50%	75.00%	-	-
Strijp-S train station	53.50%	42.70%	2	0	9	5	Yes	-	81.52%	72.33%	-	-
Glaspoort	33%	33%	2	1.1	25	4	No	-	50%	39.09%	-	-
Kronehoef	-	-	-	-	-	-	-	**2,280**	-	-	**7116**	**11.99**
Kloosterdreef	33%	33%	0	0	5	1	No	-	55.81%	-	-	-
Europalaan	50%	33%	2	0	30	6	No	-	-	22.92%	-	-
Wattstraat	33%	33%	0	0	3	2	No	-	-	-	-	-
Sint Petruskerk	33%	33%	0	3	5	1	No	-	12.82%	-	-	-

Neighbourhood	Diversity	Pedestrian/ cycle Friendly				Economic Development
	Land use Diversity	Mixed-ness of Residential Vs. other land uses	valkable p	Intersection density	IPCA	Business Density
	Entropy index	*mixed-ness*	*meters*	*number of intersections per sq km*	*IPCA per buffer of 800 m*	*Number of business activities per sq km*
Strijp-S	0.682	0.559	8950.3	53.64	1	3010.07
Kronehoef	0.532	0.271	14291.1	25.49	1	455.77

Table 13 TOD values after normalisation

Station/neighbourhood	Passenger Load		User Friendliness		Accessibility				Parking Utilization		Density	
	Peak hour	Off-Peak hour	Display Systems	Safety	Service Frequency	Connections	Interchange	Location Accessibility	Car Parking	Cycles Parking	Population Density	Commercial Density
	passengers /capacity (in %)	*passengers /capacity (in %)*	*presence of digital display**	*number of shops at station*	*number of train/busses per hour*	*number of routes (same transit system)*	*presence of alternatives*	*number of jobs*	*parking utilisation in percentage*	*parking utilisation in percentage*	*population per sq km*	*number of commercial activities per sq km*
Strijp-S								**1.00**			**1.00**	**1.00**
Strijp-S bus station	0.33	0.33	1.00	1.00	0.83	0.67	1.00		0.50	0.75		
Strijp-S train station	0.54	0.43	1.00	0.00	0.30	0.83	1.00		0.82	0.72		
Glaspoort	0.33	0.33	1.00	0.21	0.83	0.67	0.00		0.50	0.39		
Kronehoef								**0.34**			**0.68**	**0.11**
Kloosterdreef	0.33	0.33	0.00	0.00	0.17	0.17	0.00		0.56			
Europalaan	0.50	0.33	1.00	0.00	1.00	1.00	0.00			0.23		
Wattstraat	0.33	0.33	0.00	0.00	0.10	0.33	0.00					
Sint Petruskerk	0.33	0.33	0.00	0.57	0.17	0.17	0.00		0.13			

Neighbourhood	Diversity	Pedestrian/ cycle Friendly				Economic Development
	Land use Diversity	Mixed-ness of Residential Vs. other land uses	Length of walkable paths/ roads	Intersection density	IPCA	Business Density
	Entropy index	*mixed-ness*	*meters*	*number of intersections per sq km*	*IPCA per buffer of 800 m*	*Number of business activities per sq km*
Strijp-S	1.00	1.00	0.63	1.00	1.00	1.00
Kronehoef	0.78	0.48	1.00	0.48	1.00	0.15

G Appendix – Maps of TOD Index

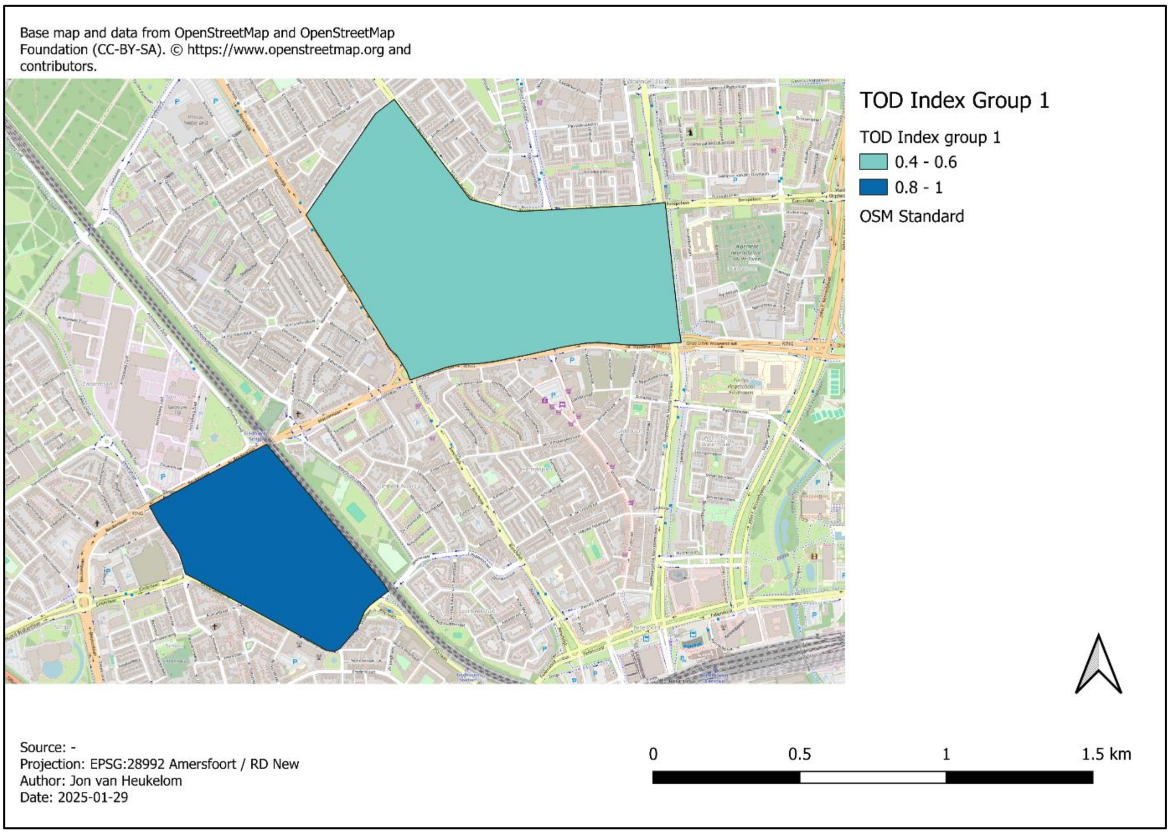

Figure 15 TOD Index group 1 (OpenStreetMap contributors, 2015)

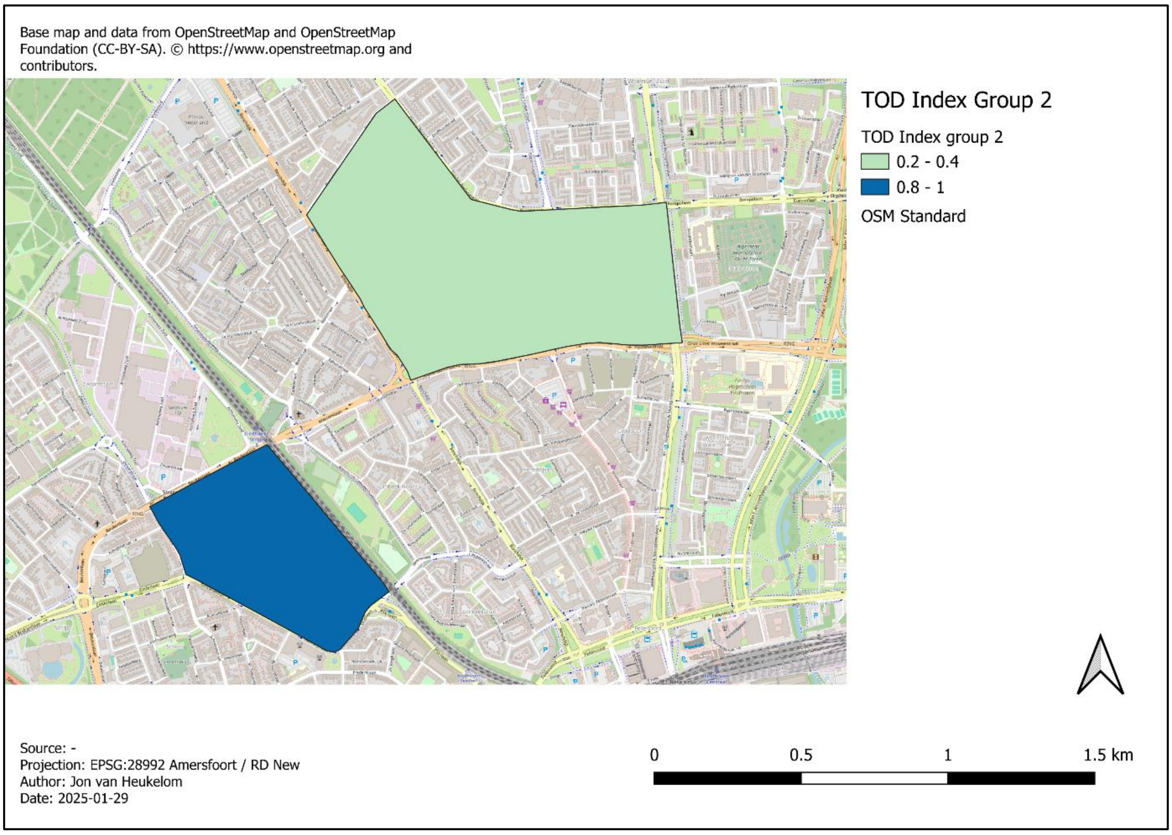

Figure 16 TOD Index group 2 (OpenStreetMap contributors, 2015)

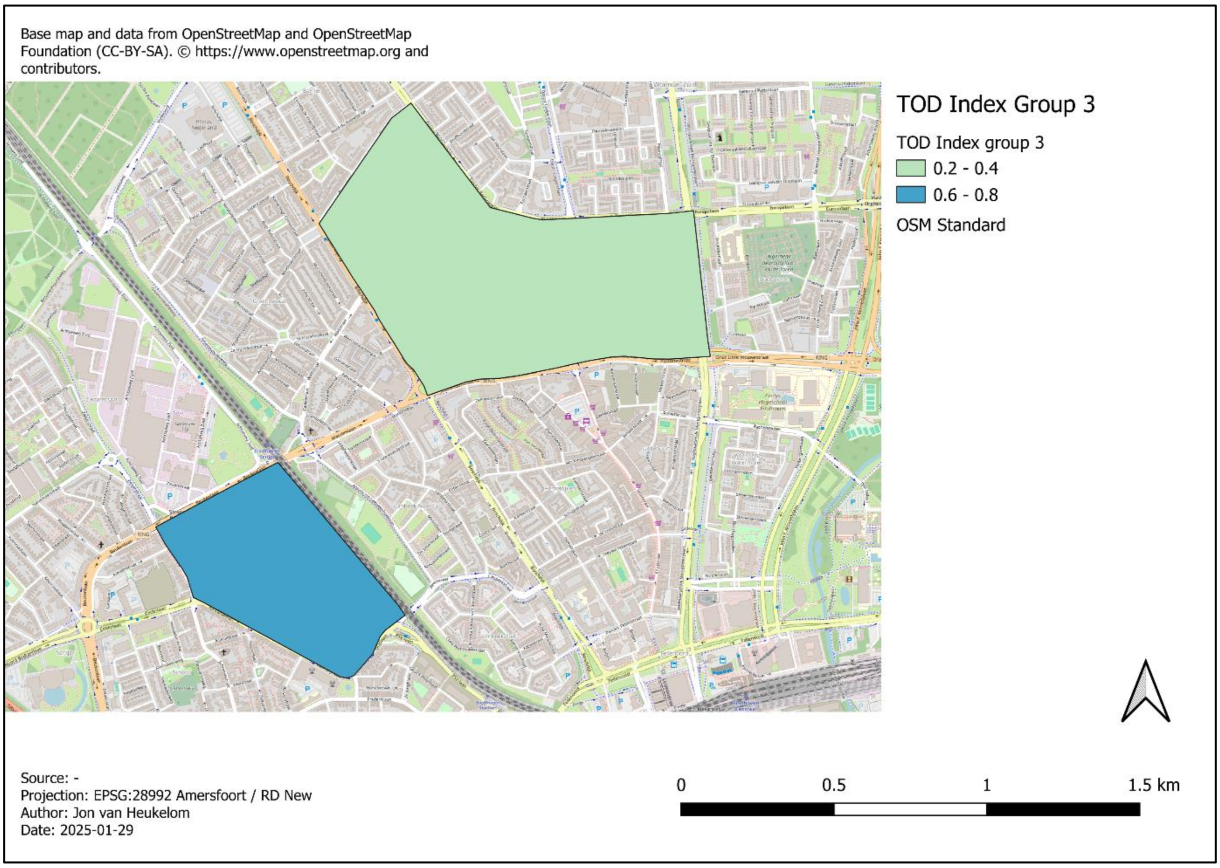

Figure 17 TOD Index group 3 (OpenStreetMap contributors, 2015)

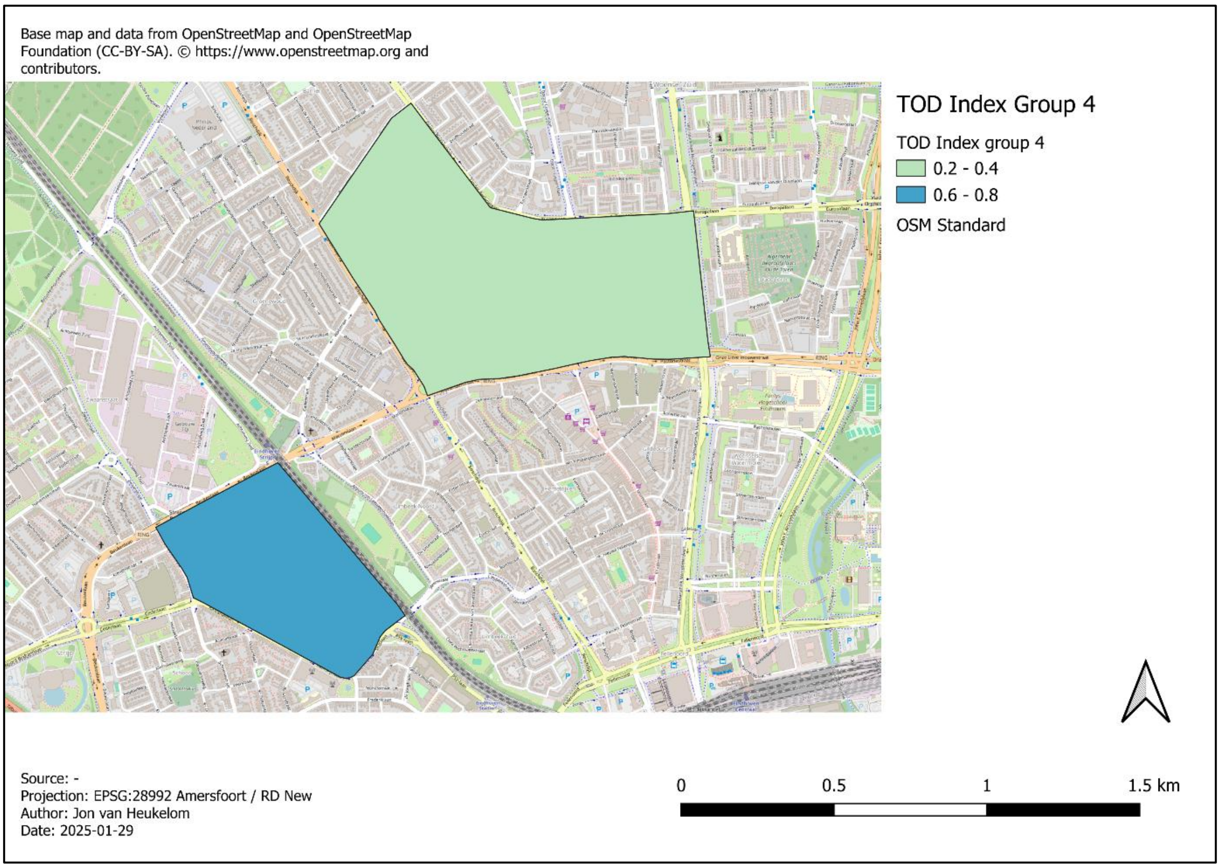

Figure 18 TOD Index group 4 (OpenStreetMap contributors, 2015)

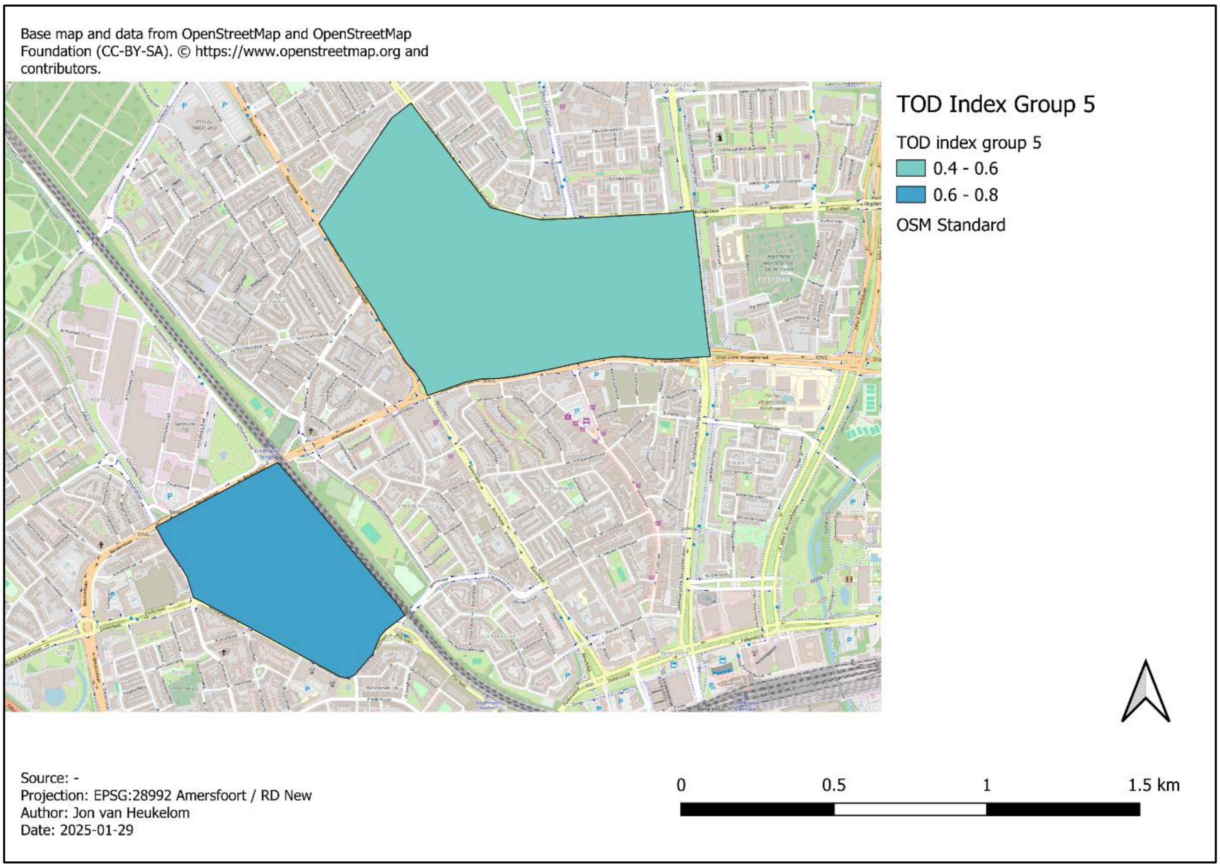

Figure 19 TOD Index group 5 (OpenStreetMap contributors, 2015)