Getting there: travel behaviour choices and Dutch Transit Oriented Development

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Summary

Transit Oriented Development (TOD) is a form of sustainable development that links transportation and land use planning together. Calthorpe (1993), who introduced the concept, defines it as: moderate and high density housing along with complementary public uses, jobs, retail, and services in mixed-use development along the regional transit system'. TOD is increasingly popular in policy and scientific scenes and its principles have also found popularity in the Netherlands, for example in the NOVI (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). The concept provides a framework to find new places for (real estate or transport) development, as well as identifying possible improvements for existing locations. Despite the popularity of TOD in Dutch policy, the impact of TOD has not been researched widely in the Dutch context, nor has the actual compliance of station area developments with TOD principles. The promotion of sustainable transportation modes is often named as an important goal of TOD projects (Dijkstra & Emmerik, 2015), but the impact of TOD is still disputed in literature and has not often been researched in the Dutch context. This is why the research question for this study is as follows: *To what extent does Transit Oriented Development impact travel behaviour in the Netherlands?* This question will be answered by attending to three sub questions:

1. *To which extent can Dutch station area developments be considered Transit Oriented Developments?*
2. *How do Dutch TOD projects impact mode choice to and from the location?*
3. *How well does a 2000 metre catchment area fit to measure the impact of Dutch TOD projects?*

The **theoretical framework** provides an overview of relevant frameworks and theories for the research. The concept of Transit Oriented Development does not stand alone and can be linked to other planning concepts. TOD fits into these concepts by combining smart growth with a large focus on mobility of the linear city, the walkability and self-sufficiency of the garden city and the density of the compact city. Cervero & Kockelman (1997) introduce the 3 Ds (density, diversity and design) that are the core of much TOD research and are important in assessing if a station area development is TOD. Bertolini (1999) show that TODs can be classified on their node and place characteristics. The land-use transport feedback cycle of Wegener & Fürst (1999) shows the interaction of the development with transport based on an increase in accessibility. In addition, the hourglass model (Brand-van Tuijn, Fanoy & Schotanus, 2001) adds two scales (the macro and micro level) to this relation. These models inspire TOD classification and assessment. In addition, the impact on travel behaviour can best be modelled by utility theory. This explains (travel) choices with an economic reasoning by assessing costs and benefits of different choices and using these costs and benefits to explain behaviour. This literary overview provides a conceptual framework and an operationalisation of the concept of TOD into 5 dimensions and 11 indicators of these dimensions.

The **methodology** goes into the methods with which the operationalisation will be conducted. Evaluations in planning are often ex ante (before implementation). Instead, this evaluation is ex post (after implementation). It is an impact evaluation (Rossi, Lipsey & Freeman, 2004) and uses a DID research design to assess the impact of TOD realisation on travel behaviour. However, it is not a 'true' DID since the time of intervention (the TOD realisation) differs per location. This means that a correction for trends is still needed. This study uses quantitative methods since this fits best with impact evaluation, a positivistic research philosophy and this can answer the research question best. The methods used consist of two parts. First, GIS analyses to assess the Dutch station locations with TOD principles. This is done by first looking for station area developments and then assessing them with the indicators that followed from the operationalisation. Following this, SPSS logistic regression analyses is done using the dataset OViN/ODiN of CBS (2022). OViN/ODiN contains travel data of Dutch travellers from the years 2010-2019 on 4-digit postcode level. The analysis was conducted for two different buffers around station areas (700 metre and 2000 metre) and a distinction was made

between the TOD location as a destination or as an origin for travel. The effect of TOD realisation on the chances of taking the train as main mode of transportation were measured.

These analyses led to different **results**. There were 21 stations areas in the 2000 metre buffer that had developments that can be considered TOD and 10 station areas that had developments in the 700 metre buffer that can be considered TOD. These locations can be found in figure 10 and are mostly located in large cities. They were mostly realised in the last 5 years. Furthermore, the results of the logistic regression analyses show that for all the buffers TOD realisation does make a significant impact on travel behaviour. This is also true no matter if the journey is from or to a TOD location. The effect size lies between a factor 1.13 and 1.19 higher chance of using the train as main mode of transportation when travelling from or to a TOD location compared to trips that do not travel from or to a TOD location. The third model (which included the individual and trip characteristics) was most accurate. The location itself also has a significant, positive effect on using the train as main mode of transportation before TOD realisation. This effect is larger than the effect of TOD realisation. Several robustness checks were done and the results stay rather the same. Lastly, the impact of trip characteristics was further examined.

This leads to the **conclusions**. There are several locations in the Netherlands that can be considered TOD, but also a lot that are not balanced in the model of Bertolini (1999). As stated above, TOD realisation has a significant and positive effect on the chances of taking the train for a trip. However, these locations already have a positive impact before their realisation. The TOD realisation itself, although positive, is thus not the most important factor in travel behaviour. This could be explained by these locations being attractive for development because of their connectivity, in line with the land use feedback cycle of Wegener & Füst (1999). The inclusion of the 2000 metre buffer offers good insight into the Dutch context. The effect size is overall a bit lower compared to the 700 metre buffer. However, the results are almost always significant and for some trips (with a motive of commuting or visiting or spanning longer distances) the 2000 metre buffer holds a larger effect. This suggests that TOD can be more effective for some trips compared to others and different target groups or desired travel behaviour changes might need different approaches. Some important **recommendations** for further research can be to step of the project-based approach taken in this study and look into an area-based approach. In addition, the year of realisation can be better linked to infrastructure projects to look at the interaction of infrastructure projects and travel behaviour. It would also be interesting to assess the applicability of the 2000 metre buffer in other countries. Lastly, a lot of station area development projects are still in development, so a repetition of this study in 5 to 10 years might be interesting to assess new additions and the changing of impact over time.

Index

1. Introduction ... 6
   1.1 Research aim and research question ... 8
   1.2 Scientific relevance ... 8
   1.3 Social relevance ... 10
2. Literature review and theoretical framework ... 12
   2.1 the concept of TOD ... 12
   2.2 The concepts supporting TOD ... 12
   2.3 Classifying Transit Oriented Development ... 13
   2.4 Accessibility ... 14
   2.5 Travel behaviour models ... 15
   2.6 Conceptual model ... 18
   2.7 Operationalization ... 19
3. Methodology ... 22
   3.1 Research philosophy ... 22
   3.2 Research design ... 23
   3.3 Data collection ... 25
      3.3.1 Sample construction ... 25
      3.3.2 Input data ... 27
   3.4 Data analysis ... 27
   3.5 Validity and reliability ... 29
4. Results ... 31
   4.1 Dutch station area developments ... 31
   4.2 Impact on mode choice ... 33
      4.2.1 Descriptive statistics ... 33
      4.2.2 Travelling from TOD ... 38
      4.2.3 Travelling to TOD ... 43
   4.3 Comparing results ... 47
5. Conclusion ... 50
   5.1 Dutch Transit Oriented Developments ... 50
   5.2 TOD and travel behaviour ... 50
   5.3 Recommendations ... 52
   5.4 Final remarks ... 53

References ... 55

Appendix 1 ... 63

Appendix 2 ... 66

Appendix 3 ... 73

Appendix 4 ... 75

Appendix 5 77
Appendix 6 78

1. Introduction

The negative consequences of the automobile-dependent suburban communities that characterized post-war planning are widely known (Lee, An & Kim, 2017; Galelo, Ribeiro & Martinez, 2014). These kind of neighbourhoods and plans are economically inefficient as well as environmentally and socially unsustainable (van Lierop, Maat & El-Geneidy, 2017). The movement 'New realism' attempts to have a new response to the irrepressible demand for travel that is caused by these kinds of neighbourhoods, by reducing (the growth of) car travel (Maat, van Wee & Stead, 2005). Transit Oriented Development (TOD) is a complex form of integrated urban development that answers to multiple trends and problems in society and spatial planning in line with these new realism ideals. In addition, new realism and Transit Oriented Development are often both associated with sustainable development (Ibraeva, Correia, Silva & Antunes, 2020). Over the last decade the interest for the subject of TOD has grown enormously in the scientific world as well as among policy and development agencies (see Figure 1).

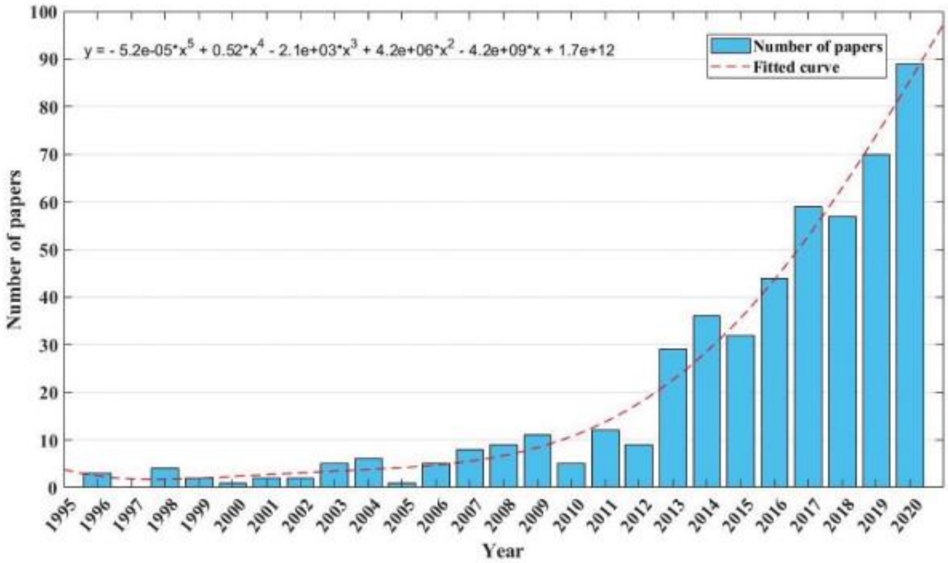


Figure 1: published articles in TOD studies, 1996–2021. Adapted from Sun, Allan, Zou & Scrafton, 2022

The concept of TOD was first introduced by Calthorpe in 1993 and it is thus a fairly young concept (Lee, Choi & Leem, 2014). Some authors however (for example see Pojani & Stead, 2014) note that the ideals underlying TOD are much older and were already prominent in European urban planning before the term came into existence. Transit Oriented Development has many definitions throughout studies. The original concept, as presented by Calthorpe (1993) entails 'moderate and high-density housing along with complementary public uses, jobs, retail, and services in mixed-use development along the regional transit system' (p41). The concept points at the crossing between mobility sciences and land use planning and focusses on the relation and exchanges between the two. It provides a framework to identify new places of (real estate or transport) development, as well as identifying improvements of existing locations.

The concept of TOD is originally an American one. In the Netherlands, TOD planning has its roots in the concept of the compact city (Alpkokin 2012). A difference with the North American policies, which directly address auto use, is that compact cities in the Netherlands are driven by policies encouraging economic development and urban containment that focus on densification both within cities and around rail stations (van Lierop, Maat & El-Geneidy, 2017). The policy of densification has been used in the Netherlands to battle urban sprawl since the 1960's in many ways and forms (Dielman, Dijst & Spit, 1999). The concept of 'concentrated decentralisation' is important in this fight against urban sprawl and has been prominent in the Netherlands as an alternative to mono-centric and sprawling urban structure (Alpkokin 2012). In this policy, instead of sprawling, new urban centres are set up that have separate amenities. The locations of decentralized concentration or 'new centres', are often connected to hypermarkets (Birkin et al., 2002, cited in Haugen, Holm, Strömgren, Vilhelmson & Westin, 2012). The exact borders of these new centres can be hard to define and can change depending on the catchment area of the function (See Cheshire, Hilber, Montebruno & Sanchis-Guarner, 2018 for an analysis for retail centre concentration). This can make it difficult to measure the exact impact and size of the geographical entity. According to Sun, Allan, Zou & Scrafton (2022) 'TODs are akin to some degree to self-contained communities that are connected' (p36) which fits with the Dutch concept of decentralized concentration and its difficulties. When looking at Transit Oriented Development projects, a distinction can be made between a developmental side and an infrastructural side.

At the development side, Dutch developments have increasingly been taking place at greyfield and brownfield locations. These are often inner-city locations where existing buildings have to be removed or transformed first before development is possible. This trend is replacing urban expansion on greenfield locations through active national planning (Claassen, Koomen & Rouwendal, 2020; Hekwolter of Hekhuis, Nijskens & Heeringa, 2017). Because of this change of location, new issues and problems with implementing developments have come up, such as higher development costs and dealing with more complex land ownerships. The instrument promoting and supporting these developments is the 'ladder of sustainable urbanisation'. It is the most important instrument that manages new urban developments (Ministerie van Infrastructuur en Milieu, 2012) and is thus essential in explaining the location possibilities and choices of new developments. The ladder prescribes that opportunities of densification should be used before considering greenfield developments. With this policy, a compact city is pursued, which is in line with the land use side of Transit Oriented Development. The prominence of the Ladder of sustainable urbanisation is thus partly responsible for the increasing popularity of the concept of Transit Oriented Development in the Netherlands (Sun, Allan, Zou & Scrafton, 2022).

Concerning the other side of Transit Oriented Development, infrastructure can play a vital role in new developments. The Dutch government invested in important infrastructural nodes in, among others, the programme of 'Nieuwe Sleutelprojecten' (see Wortelboer- van Donselaar, Jorritsma, & Visser, 2012 for a summary on the Dutch policy of node development). These projects focus mostly on the train station (Huisman, 2016) or its immediate surroundings (for example the station square). However, since the finishing of the Nieuwe Sleutelprojecten, there has been an additional focus on integral area development around these nodes. The renovation of the train station can be seen as a stimulation for station area development. When developing around nodes, actors hope to achieve synergy, in which the outcome of the development on the particular location is more than the sum of its parts (Peek, Bertolini & de Jonge, 2006). This is very much in line with TOD principles, in which node development and land use planning come together. When developing around these nodes the principles of the Ladder of sustainable urbanization are applied (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). At the same time, a more frequent public transit is supported by creating higher demand through increased accessibility (Bureau Spoorbouwmeester, 2015). Densification around stations is also mentioned in the National Strategy on Spatial Planning and the Environment (NOVI) as a useful tool to optimize the efficient use of space and mobility (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). This is described as: 'Inner city areas and areas close to and surrounding public transport hubs will be optimally used as concentrated residential and working locations with high building density combined with excellent access' (p116). Developments around transit nodes in the Netherlands are often focussed on reducing travel time and creating better connections between hubs (van Lierop, Maat & El-Geneidy, 2017) which creates public transport as a viable alternative for other modes of transport. Besides the Dutch government, other actors such as the National Railway and Prorail, have joined in this widening of the scope for urban development (Bureau Spoorbouwmeester, 2015). In the triangle of infrastructure, spatial policy and urban development, Transit Oriented Development is an instrument that is becoming increasingly interesting for and prominent in Dutch planning (Pojani & Stead, 2014).

However, it turns out that it is not always easy to implement developments around nodes of transport. In 2014, the Dutch Environmental Assessment Agency (PBL) noted that it was difficult to combine mobility developments and urban development. The report showed that the potential of these locations was only being used to a limited extent. Since the publication of this report (2014) station area and node-development has gotten more prominent and new developments have taken place (for examples see Provincie Noord-Holland & Vereniging Deltametropool, 2013). In the last decade, multiple policy reports have been published on the topic of Transit Oriented Development in the Netherlands (see Dijkstra & Emmerik, 2015 for a summary). These reports are mostly focussed on the implementation of TOD and the institutional context of urban development around hubs (Emmerik, 2018; Tan, Koster & Hoogebrugge, 2013). Additionally, there has been a considerable focus on large hubs- 'main-, brain- and greenports' (Wortelboer-van Donselaar, Jorritsma, & Visser, 2012).

Despite this interest in and attention towards the concept of Transit Oriented Development, it is currently unclear to what extent station area developments take TOD principles into account in the Netherlands. The term is used often, but correctly implementing the concept can be more difficult than that. Furthermore, the effectiveness of TOD policies in deterring congestion, improving connections and decreasing car dependency are also unclear, even though these are important motivations for implementing TOD (Knowles, Ferbrache & Nikitas, 2020). What form of transportation (mode choice) people use can shed a light on this effectiveness. Mode choice is a useful measurement to assess the impact on difference in travel choice since it considers individual travel choices. Additionally, it shows the relative shift which other measures, such as car usage or congestion, do not show.

1.1 Research aim and research question

This research will evaluate the impact of Dutch station area development projects on mode choices of travellers. The aim of this research is to assess Dutch station area developments and examine the travel behaviour changes of travellers following TOD projects completions in the Netherlands. One of the aims for station area development in the Netherlands is to improve accessibility and sustainability and to increase public transit usage (Dijkstra & Emmerik, 2015). Up until now it has been unclear to what extent these improvements have been taking place in the Dutch context. Additionally, densification on accessible locations is happening in the Netherlands (Nabielek, Boschman, Harbers, Piek & Vlonk, 2012) but this is only one part of TOD and it is yet to be studied if this leads to more sustainable travel patterns. The research therefore focused on the following research question:

To what extent does Transit Oriented Development impact travel behaviour in the Netherlands?

This research question can be broken down into multiple sub questions:

1. *To what extent can Dutch station area developments be considered Transit Oriented Developments?*
2. *How do Dutch TOD projects impact mode choice to and from the location?*
3. *How well does a 2000 metre catchment area fit to measure the impact of Dutch TOD projects?*

1.2 Scientific relevance

There is a wide range of research on the topic of Transit Oriented Development. Building on Ibraeva, Correia, Silva & Antunes (2020); Sun, Allan, Zou & Scrafton (2022); Padeiro, Louro & da Costa (2019), three stands of literature can be distinguished. First, there is literature on the conceptual and typological classification of TOD. These studies mostly consist of creating categories of 'kinds of TODs' (for example Kamruzzaman, Baker, Washington & Turrell, 2014) or rating the 'TODness of a location' (for example Singh, Fard, Zuidgeest, Brussel & van Maarseveen, 2014) and are related to the operationalisation of the concept. There has been a considerable amount of research and models into typology and the concept op TOD (Ibraeva, Correia, Silva & Antunes, 2020), also in the Dutch context (see for example Bertolini, 1999; Singh, Lukman, Flacke, Zuidgeest & van Maarseveen, 2017).

Second, there is research on the implementation and institutional context of TOD. These studies focus mostly on the process of policy transfer (for example Thomas, Pojani, Lenferink, Bertolini, Stead & van der Krabben, 2018) and the implementation process of creating a TOD (for example van Lierop, Maat & El-Geneidy, 2016). According to Galelo, Ribeiro & Martinez (2014), there has been quite some research towards identifying success factors and design guidelines for Transit Oriented Development projects. Pojani & Stead (2014) also have policy transfer as their focus of research and thus focus on the implementation of TOD in the Dutch context. Others (Tan, Bertolini & Janssen-Jansen, 2014; Thomas, Pojani, Lenferink, Bertolini, Stead, van der Krabben, 2018; Van Lierop, Maat & Geneidy, 2016) focus on this implementation and process in the context of the Netherlands as well.

Lastly, there are studies focussed on the impact of TOD projects, ranging from sustainability to economic to community building, gentrifying and travel behaviour effects. This study will fall into this third category, while building on the categorizations made in the first. It is still unclear as to what extent the goals of TOD initiatives are being met. Tan, Bertolini & Janssen-Jansen (2014) note that 'TODS promise to counter urban sprawl and car dependence whilst promoting economic development and are embraced by practitioners from many cities and regions, even though evaluation and proof of such claims are not yet definitive.' (p639). According to varying studies, travel behaviour change following a TOD realisation does not always happen and is also dependent on factors such as demographics, other nearby developments and policies in the region (Lund & Willson, 2005). The outcome of TOD projects can be diverse and unpredictable, because of its complexity and dependency on many factors (Ibraeva, Correia, Silva & Antunes, 2020). Dunphy & Porter (2006) note that 'the influence of station-area development on transit ridership is difficult to pin down […], despite the importance of transit ridership as a goal for the transit agencies' (p176).

The research on the effect of the built environment on travel behaviour is many-faceted, and focus points are the effect on public transport ridership, active travel within the TOD, the modal split, trip frequencies, trip length, vehicle miles travelled (VMT) or vehicle hours travelled (VHT) (Ibraeva, Correia, Silva & Antunes, 2020; Ewing & Cervero, 2010). Even though results from studies are mixed (see Ibraeva, Correia, Silva & Antunes, 2020; Sun, Allan, Zou & Scrafton, 2022 for an overview), mostly a positive effect of Transit Oriented Development on these variables can be seen. However, several gaps still exist in existing literature.

First, the studies that have been done are rarely longitudinal, which means they rely on comparing TOD with non-TOD locations. This brings several issues forward regarding the unique context of locations. According to Ibraeva, Correia, Silva & Antunes (2020), a longitudinal study in travel behavioural change is still missing in the literature. This research aims to contribute to filling that gap.

Second, existing studies mostly focus mainly on the residents of TOD locations, and commuter trips of these residents. Instead, this research is focussed on all travel movements towards and from the location with all trip purposes. This creates a more complete image of the impact and widens the scope for other travellers, not just residents of TOD locations.

Lastly, the existing research on travel behaviour effects of TOD is mostly based on cases in the USA (for example Ewing, Tian, Lyons, & Terzano, 2017), Asia (for example Pan, Li, Shen & Shi, 2017; Jun, Choi, Jeong, Kwon & Kim, 2015) and Australia (for example Kamruzzaman, Baker, Washington & Turrell, 2014) (see Ibraeva, Correia, Silva & Antunes, 2020 p115 and Sun, Allan, Zou & Scrafton, 2022, p39 for overviews). Hamersma, Knoope & Zijlstra (2019) question to what extent the results in these other countries can be translated to the Netherlands, since the context factors that can influence the impact of TOD on travel mode choices are different.

The situation in the Netherlands is a unique context because of multiple reasons. First, the Netherlands is very densely populated, especially in the Randstad, which makes public transport an attractive mode of transportation because of the average short distances to a station (Hamersma, Knoope & Zijlstra, 2019). Second, there is a large-scale public transportation network available, with one main supplier (Dutch Railways). This decreases the number of stakeholders involved in making TOD successful on the mobility side. In combination with the prominent planning culture in the Netherlands (van Lierop, Maat & El-Geneidy, 2017) this creates a strong basis for the implementation of TOD (numerous studies have been done concerning this, see above). Lastly, an important context factor that makes the Netherlands an interesting context for this research, is the prominent bike usage in the country. According to Lee, Choi & Leem (2014) the use of biking expands the catchment area of TOD, which increases the number of people effected by the development. According to van Lierop, Maat & El-Geneidy (2017), TOD catchment areas tend to be larger in the Netherlands compared to other regions due to the fact that a high number of access and egress trips to the main transit hub are made by bicycle. This is also in line with the research of Pojani & Stead (2015). However, little research is done into these Bicycle-TOD locations, and the studies that have been done are not placed in the Dutch context (see for example Lee, Choi & Leem, 2014; Tamakloe, Hong, & Tak, 2021; Fazio, Giuffrida, Le Pira, Inturri & Ignaccolo, 2020). Therefore, this Dutch context is an interesting and refreshing way to look at the impacts of Transit Oriented Development, which cannot directly be derived from existing research.

1.3 Social relevance

The social relevance of this research has two parts. First, it helps provide an overview of the current station area development initiatives in the Netherlands and the extent to which these developments are in line with TOD principles. There have been few studies concerning a systematic evaluation of the quality of designs in existing TOD project (Pojani & Stead, 2015, p132) and this research can provide an overview of to what extent the station area development projects in the Netherlands actually implement TOD principles. In order to evaluate Dutch station area projects and their impact, it is useful to assess their compliance and differences with the existing literature on TOD. According to respondents in the research of Carlton (2019), 'the ways interviewees identified TOD opportunities were often inconsistent with the TOD literature' (p508). It is therefore useful to gain insight as to what extent station area developments in the Netherlands are compliant with the design principles found in theory, to assess if the goals set by literature are realistic policy goals for these projects and through that help efficiency in policy making. There are currently a lot of developments around Dutch train stations, and the NOVI also promotes these locations for developments in the future. Therefore, it is needed to know the current presence of TOD principles in station area developments to assess the effect these policies have (see beneath). The database of Dutch TOD initiatives created in this study can also be used to further examine the topic of TOD locations in the Netherlands.

Second, this study helps to gain insight into travel behaviour changes because of TOD and can thus help in the implementation of TOD projects and critical evaluation of TOD. Not all the developments are strategic or focussed on the train station as a node that is part of a network. The developments that lack this focus can be called Transit Adjacent Developments (TAD) (Padeiro, Louro & da Costa, 2019; Singh et al., 2017). By assessing and linking TOD principles to travel behaviour change, the importance of the principles for travel behaviour can be concluded on. In the literature, increasing transit ridership and the use of active modes of transportation are cited as the primary measures of TOD success in terms of transportation. According to the analysis of van Lierop, Maat & El-Geneidy (2017) on Dutch planners 'the primary goal when developing TOD was to reduce commuters' overall travel time' (p54). In this analysis, effects of TOD and their alignment with these goals are further assessed. This also fits with the strategic vision of the Dutch Railways (NS), who's main goal it is to make the Netherlands 'sustainably accessible for everyone'. They believe that developing the areas around stations is a key aspect of making this happen (NS, 2020b). The car usually uses up 40% of inner-city spaces (NS, 2020b) and examining the potential of TOD can help use this space more efficiently.

Additionally, the proximity of the station in Dutch station area development has been used as an argument to decrease the available parking spaces per unit (for example, Cartesiusdriehoek as described by Camu, 2021). These low parking norms aim to promote public transit usage and at the same time helps the viability of the business case of the development. To examine (the extent of) this argument, research into the possible change in travel behaviour in these areas will lead to more supported decision making. This research will thus help to bridge the gap between theory and practice as noted by Carlton (2019).

Lastly, by assessing the impact of TOD on travel behaviour in the Dutch context, new links between strategies and outcomes may come forward. These links can help in optimizing strategic implementation of TOD initiatives and station area development in the Dutch context. It is important to note that plans are evolving instruments that must undergo continual revisions and updates to remain relevant to changing needs, knowledge, and experiences (Brody 2003). In this regard, evaluation should play a critical role in ensuring the applicability and relevance of both plans and programs. Evaluation provides a form of legitimacy for interventions and, ultimately, it is the mechanism by which decision makers are held accountable for their actions (Chouinard 2013). It is through evaluation that planners are able to discern whether a plan is being implemented as intended, and to identify the effects of plans (Guyadeen & Seasons, 2018). Renne & Wells (2005) state that not measuring the outcomes of TODs can lead to repeating mistakes in investment strategies. By knowing if strategies are effective in goal-fulfilment, it can help improve public fund spending (PBL, 2014). This study will in this regard build on the work of Lyu, Bertoloni & Pfeffer (2020), who examined the link between aspects of TOD and accessibility. This research will look into if the increase in accessibility in TOD projects also leads to increased sustainable transport movements. This knowledge on if and to what extent TOD development cause travel behavioural changes in the Dutch context can thus help efforts towards a more sustainable society.

2. Literature review and theoretical framework

In this chapter, an overview of relevant literature is presented. First, the concept of Transit Oriented Development is discussed, then this is related to other planning concepts that were influential in the past to understand the underlying principles better. In the next paragraph, relevant models for classifying and assessing TOD are discussed. Subsequently the concept of TOD is linked to accessibility and this links bridges the concept of TOD to travel behaviour models. This overview of literature and models leads to a conceptual framework, which is presented in paragraph 2.6 Lastly, the relevant variables following from the literary review will be operationalised in the final paragraph.

2.1 the concept of TOD

The concept of Transit Oriented Development is often centred around the 3 D's: Density, diversity and design, as introduced by Cervero & Kockelman (1997). These 3 D's can be linked to the work of Jane Jacobs (1961), who used similar demands to create a lively neighbourhood. Because of this, it is claimed that TOD projects create strong communities and places of high quality to live, work, shop and relax (Galelo, Ribeiro & Martinez, 2014). The importance of the 3 Ds for success is emphasized in many studies (see Singh et al., 2017 for an extension). Orga & Ndebele (2014) add 3 more D's (Destination, Distance and Demand management) as important components of (the success of) TOD initiatives. These additional 3 Ds broaden the scope from just managing the built environment to managing travel behaviour considerations of individuals. Xu, Guthrie, Fan, & Li (2017) take, in line with this, the definition of TOD a step further from just spatial form and towards the goals of travel behaviour changes, as their definition of TOD reads: 'the creation of mixed-use, compact, walkable neighborhoods that encourage people to live near and use public transit' (p743). The criteria for a station area project to be considered TOD can thus be deviated from the name of the concept (following Lyu, Bertolini & Pfeffer, 2016): *Transit*, the project should be centred around a node of transit. *Oriented*, the place should be focussed at and interact with the node of transit, the opposite of this is the abovementioned transit adjacent development. Lastly, a *Development* should take place at the side, in line with the abovementioned 3 Ds to encourage walking, cycling and public transit usage.

2.2 The concepts supporting TOD

In order to identify relevant theories and models for this research, it is useful to turn to related concepts that support the emergence of Transit Oriented Development (TOD) in the past decades. Sharifi (2016) emphasises the importance of this to identify the goals and underlying logic of Transit Oriented Development. According to Ibraeva, Correia, Silva & Antunes (2020), TOD is related to concepts of the garden city (see Sharifi, 2016) and the linear city (see Shadar, 2016). However, TOD is also related to the concept of smart growth and compact city. These will be discussed below. All these concepts try to attain a sustainable form of development. This is done by battling urban sprawl, which is seen as unsustainable in numerous ways (Lee, An & Kim, 2017).

To start, 'Smart Growth advocates fostering development in areas where infrastructure already exists and revitalizing downtown areas and existing neighbourhoods' (Sharifi, 2016, p8). Smart growth's focus lies beyond the neighbourhood and also incorporated the catchment area of a location and the place it takes within the network (Brenner, 2004). This is the concept that the Ladder of sustainable urbanization is based on (see chapter 1) in the Netherlands.

The concept of the compact city is also related and fundamental for the principles of TOD. Compact city strategies battle car dependency and create more accessible places. This leads to a less greenhouse gas emissions, by decreasing travel distances and increasing accessibility (Newman & Kenworthy, 1989; Lee, An & Kim, 2017). Transit Oriented Development builds on the compact city concept by adding mobility aspects to the land use patterns already incorporated. This is done by building on the relation between land use planning and transit systems to reduce congestion and promote public transport usage, which is more environmentally friendly (Tamakloe, Hong & Tak, 2021).

Lastly, TOD aims to improve accessibility of functions, within the neighbourhood in development as well as all around the region (Lyu, Bertolini & Pfeffer, 2020). TOD fits into these concepts by combining smart growth with a large focus on mobility of the linear city, the walkability and self-sufficiency of the garden city and the density of the compact city. These concepts and the important parts for TOD can be used to support the definition and operationalisation of TOD.

2.3 Classifying Transit Oriented Development

When taking a closer look at Transit Oriented Development, the analogy of the chicken or the egg emerges. Which came first: transit or development? And which of the two is a condition for the success of the other? No matter which came first, coordination between transport and land use choices and conditions is essential for TOD to be successful (Bertolini, Curtis & Renne, 2012). In the 1950s first efforts were made in the USA to study the interrelationship between transport and the spatial development of cities more systematically (Wegener, 2004). From this point onwards, the 'land-use transport feedback cycle' gained complexity and recognition (Stornebrink, 2020). This cycle from Wegener & Fürst (1999) shows the interaction between land use and transit development. It shows that an improvement in accessibility of a location will lead to a more attractive location and thus developments. This in turn will lead to a need for better accessibility, which completes the cycle. The cycle shows the dynamics of Transit Oriented Development mechanisms through time and stresses the need for a longitude impact analysis of the effects of TOD initiatives, because it is not a straight-forward relation but rather a bilateral relation.

Another highly influential model when considering the relation between transport and spatial development is Bertolini's (1999) work on the node-place model. This model is a popular way to categorize and assess locations at Transit Oriented Development (Ibraeva, Correia, Silva & Antunes, 2020). In this model, the development of the node (infrastructure) and the place (the area surrounding the node) are placed on two axes (see Figure 2). From the placement in the diagram, the position of the location becomes clear. An 'ideal' location can be either stressed (high passenger flow and intense land usage), dependent (low demand for public transit and low land use intensity) or balanced (reasonable transit supply and land-use diversity). In addition, if the passenger flow and intensity of land usage are hugely different from each other, the location is categorized as an unbalanced node or an unbalanced place. This model assesses the condition of a location and builds on the land-use transport feedback cycle in identifying development potential on the node or place side of a location to create a balance (Peek, Bertolini & de Jonge, 2006).

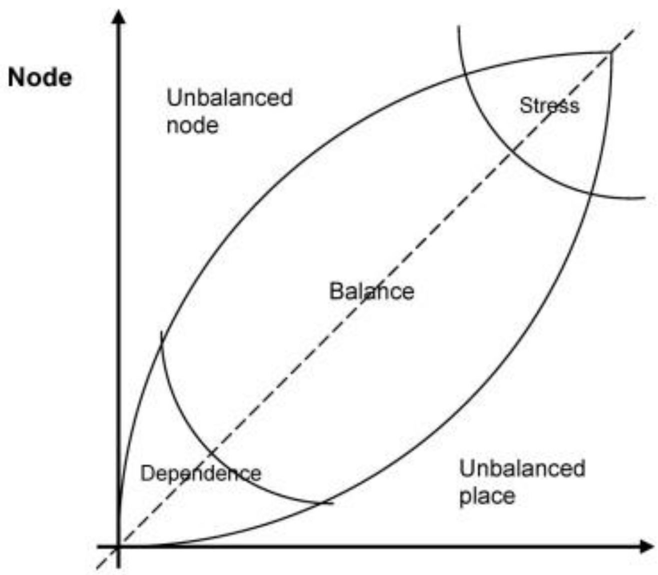


Figure 2: The node-place model (Bertolini, 1999)

The model of Bertolini (1999) has been widely applied and further adapted in the literature (see Kamruzzaman, Baker, Washington & Turrell, 2014; Peek, Bertolini & de Jonge, 2006 for an overview). The node-place concept has evolved over time from a theoretical model into a way of facilitating and structuring debate in a multi-stakeholder environment (Peek, Bertolini & de Jonge, 2006). This debate is seen as essential for achieving coordinated planning around stations. This means the model of Bertolini (1999) is also the basis for a lot of policy models to measure the relation between the place and node functions of a location. An example is the butterfly model as introduced by Vereniging Deltametropool (2013), where the model is further operationalized for assessing the balance between place and node for a location in the Dutch context.

There are many ways to measure the degree of TOD on a location, and many typologies of various kinds of (existing) TODs have been made (Singh et al., 2017). For example, there are three classifications of TOD in the study of Thomas, Pojani, Lenferink, Bertolini, Stead & van der Krabben (2018):

> '(1) new TODs, developed around new public transportation services; (2) high-density TODs, where new public transportation services are provided in existing, compact, mixed-use areas; and (3) low-density TODs, in which the density and diversity of existing, suburban-style neighbourhoods adjacent to public transportation services are increased' (p1)

However, since many studies made their own typology, the transferability of these categorizations is low (Kamruzzaman, 2014) and these categorizations often don't acknowledge the unique context of each location (Singh et al., 2017). Because of these limitations, Singh et al. (2017) propose a TOD index to assess the 'TODness' of a location based on a range of indicators. Pojani & Stead (2015) translated the design principles of TOD to the Dutch context in their research. This is useful because, as they argue, the Dutch context is different from other countries because of national cultural predilections and practices. They state that 'design templates and guidelines cannot be replicated from country to country without thought to context' (p143). Following from this research, there are eight dimensions that are important when designing a TOD in the Dutch context. These dimensions are:

- Scale and density;
- Public spaces for human use;
- Safety;
- Variety and complexity;
- Connections;
- Pedestrian and cyclist orientation;
- Transit in the urban pattern;
- car movement and parking

These dimensions are thus important in implementing TOD in the Dutch context and will be further considered in the operationalization (paragraph 2.6 Conceptual model).

Where the node-place model can be used to assess a current situation or identify the development potential of a location, it requires both a node and a place assessment of the locations. However, in this research, the relation and interaction between these two requirements is the main focus. This means that the scope of this research goes beyond that of the node-place model, since it examines the relation between developments of the place on the required functioning of the node because of assumed changes in travel choices. How a place influences travel choices links to the vast research field of travel behaviour.

2.4 Accessibility

Before turning to travel behaviour models, it is useful to consider the role of accessibility. According to Singh, et al. (2017), TOD policy must address two issues, on the one hand, it should identify places where the transit aspect should be improved and second, it should identify places where the development should be improved. This is in line with Calthorpe (1993) on the one hand, who focused on the development of new neighbourhoods around transport nodes, and Bertolini & Spit (1998) on the other, who show that TOD can also focus on redeveloping existing stations.

An increase in accessibility is, as shown by the land-use transport feedback cycle mentioned above, an important part of developments around train station areas. Accessibility can be seen in two ways, accessibility throughout the network of the urban area (in line with Lyu, Bertolini & Pfeffer, 2020) or accessibility within a neighbourhood. Accessibility is an important link between the built environment and travel behaviour choices and it is an important goal in Dutch TOD planning (van Lierop, Maat & El-Geneidy, 2017). Papa & Bertolini (2015) link this goal directly to the definition of TOD 'TOD is by definition urban development integrated with high-capacity public transport and one of its main objectives is to offer city-wide and local accessibility' (p72). A model to visualize the different kinds of accessibility is the Hourglass model (see Figure 3), this model shows 5 relations between accessibility and development. It shows that accessibility can improve throughout the network (transportation) or on the local scale (traffic).

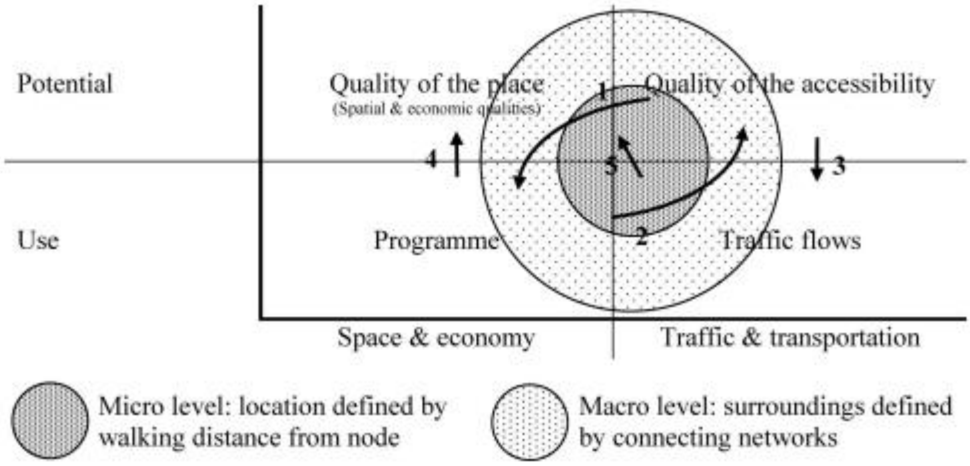


Figure 3: Hourglass model (Brand-van Tuijn et al., 2001 as cited in Peek, Bertolini & De Jonge, 2006)

Following from this, there are three ways to increase the accessibility of different amenities for a citizen. First, by creating more mixed use in the direct built environment. The meta-analysis of Ewing & Cervero (2010) shows that mode share and likelihood of walk trips are most strongly associated with the design and diversity dimensions of built environments, which influence the microlevel accessibility. Second, by improving the transit network so the individual can get to another place faster. Or third, by improving the land use of areas that are in proximity of a transit point (Lyu, Bertolini & Pfeffer, 2020). This last solution is more important than the second in improving accessibility, according to Papa & Bertolini (2015) and Lyu, Bertolini & Pfeffer (2020) and is the focus of this study. Accessibility is thus an important intermediate factor that links and explains TOD and travel behaviour.

2.5 Travel behaviour models

The travel mode choices made by travellers and the explanation for these choices are a common subject in transportation literature (Bird, Panter, Baker, Jones & Ogilvie, 2018). Prominent in this research is the Theory of Planned Behaviour, which was introduced by Ajzen (1991). This theory proposes that behaviour is a reasoned decision determined by intention, which is influenced by the attitude towards the behaviour (e.g. a positive or negative evaluation of the outcome to a situation), subjective norm (e.g. the perceived social pressure to perform the behaviour), and perceived behavioural control (PBC) (e.g. the perceived ease of control over performing that behaviour) (Bird et al., 2018). Another widely used model to examine the effects of attitudes on behaviour is Swartz's Norm Activation Model (Schwartz, 1977, mentioned in Olde Kalter, la Paix Puello & Geurs, 2020). The difficulty with assessing attitudes is that there is a difference between stated preference and revealed preference (Wegener, 2004), with a lot of studies using the Theory of Planned Behaviour using stated preference (Olde Kalter, la Paix Puello & Geurs, 2020). This means that an impact analysis is difficult to execute, since the actual travel patterns are not considered.

Attitude is thus a principal factor in behaviour and mode choices (Olde Kalter, la Paix Puello & Geurs, 2020). The effect of the built environment on behaviour choices can be different for groups with different attitudes (Joh, Nguyen & Boarnet, 2012) and socio-economic backgrounds (Sun, Allan, Zou & Scrafton, 2022). This is in line with the often-made argument against TOD impacts, that of 'self-selection'. Logic says that usually these neighbourhoods are inhabited by those who are already environmentally conscious and prefer to live in sustainable neighbourhoods (Sharifi, 2016), or like using public transport (Hamersma, Knoope & Zeilstra, 2019). However, Jon, Nguyen & Boarnet (2012) do not see this effect of self-selection in their study of walking in the South Bay area. Ewing & Cervero (2010) conclude in their meta-analysis that although this notion of self-selection does attenuate the effects of the built environment on travel, the link also exists independent of this. According to Alpkokin (2012), urban form and design variables are found to have less explanatory power than those of socio-economic variables. However, Handy, Cao & Mokhtarian (2005) show that, although attitude and socio-demographic factors have an impact, the built environment also has a causal effect on travel behaviour.

The models above use a behavioural and psychological approach to individual travel choices. Another perspective on the effect of accessibility on travel choices use a more economic reasoning (Geurs & van Wee, 2004). One of the economic models that can be used to explain travel behaviour choices is that of maximized utility. The utility-maximisation model shows the travel task being modelled as a choice process of an individual based on his personal needs and environment (McFadden, 1974). There are multiple variations of the model (McFadden, 1977), but they all calculate choice probability in different circumstances. First developed by Mcfadden (1973) and build upon by Ben-Akiva, & Lerman (1979), these models have been used often in research into the urban context and the influence of the built environment on travel behaviour. In the model, an individual's aim is not primarily to minimise travel costs, but, rather, to maximise utility (Maat, van Wee & Stead, 2005). Accessibility is seen as an important driver for travel choices (Geurs & van Wee, 2004). Accessibility can be broken down into two components in utility theory, namely locations and attractiveness of urban opportunities (benefit side); and impedances of travelling to these locations from residential areas in the network (cost side) (Nassir, Hickman, Malekzadeh & Irannezhad, 2016). This makes some choices have more utility in comparison with others. An equilibrium represents the state in which the traveller's utility has been maximized (Nakayama & Kitamura, 2000) and there is also an aspect of diminishing returns represented in the models (Geurs & van Wee, 2004). The impedances of different travel modes and destination choices in utility theory can be linked to the concept of space-time constraints (see Figure 4) and time geography, introduced by Hägerstrand (1970).

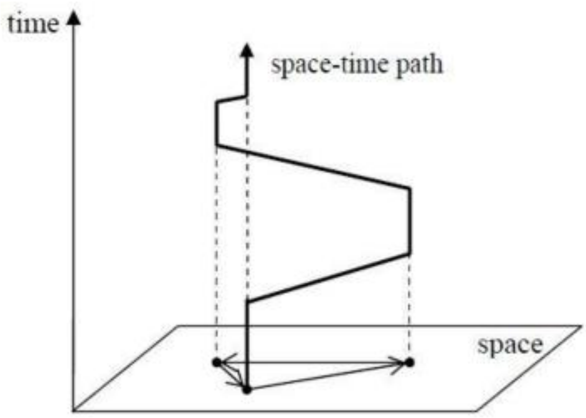
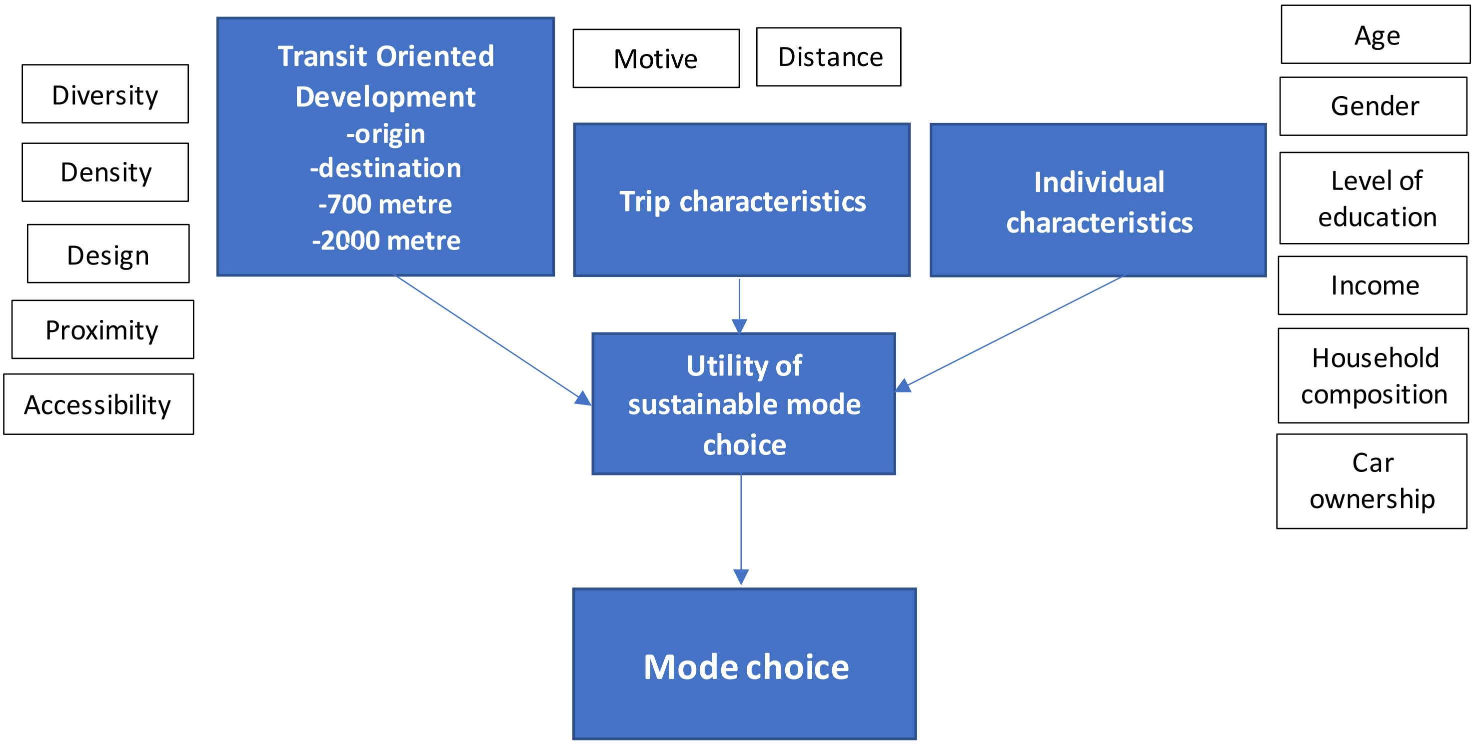


Figure 4: Space time path (Hägerstrand, 1970)

This is a different, more individual perspective on accessibility (Geurs & van Wee, 2004). These constraints are the boundary conditions in which the choices (based on utility) can be made. The accessibility of a location through different modes is vital for the travel choices made. Here a distinction can be made between research on destination choices and mode choices. As Haugen et al. (2012) notes, 'proximity is by no means not always decisive in destination choice, and people may choose to travel beyond the nearest option.' (p68). Despite increased accessibility, the commuting paradox (van Ommeren & Rietveld, 2005) prescribes that the time commuting stays the same. This is due to the constant travel time 'budgets'- people tend to expand their geographical reach instead of saving time (Haugen et al., 2012). This also regards trip chaining in multipurpose tours, although less research has been done on the effect of the build environment on these outcomes (Ewing & Cervero, 2010). This approach fits with an activity-based approach of looking at travel behaviour, which builds on the utility theory described above by looking at wider (space-time) considerations for travel choices (Maat, van Wee & Stead, 2005). This research focusses on the way people get to their location and the mode choices they make, the choices regarding destinations are represented by looking at travel motive. Although this is of course linked to the destination, and the accessibility of this destination with different modes of transport.

2.6 Conceptual model

Simkens (2020) shows that the surrounding of a station (the built environment) influences the traveller's experience. This research builds on that by assessing if this influence on the traveller's experience also leads to different travel choices. There has been a lot of research done on the effect of the built environment on travel choices (for an overview, see Ewing & Cervero, 2001; Ewing & Cervero, 2010; Sun, Allan, Zou & Scrafter, 2022). Many different characteristics of urban form have been studied, and travel patterns have been measured in a number of different ways (Maat, van Wee & Stead, 2005; Ewing & Cervero, 2010; Sun, Allan, Zou & Scrafton, 2022). As shown below and following utility theory, trip characteristics will also be taken along in this research. Individual characteristics will be considered as well, in line with time geography and different attitudes of different groups. By also considering the impact of these variables, the impact of the built environment (e.g., Transit Oriented Development) can be nuanced and put into a wider perspective. The next paragraph will go into the operationalisation of the Transit Oriented Development indicators.



2.7 Operationalization

Following from the literature review, five relevant dimensions can be distinguished as important for determining a TOD initiative. In this paragraph, these dimensions will be briefly discussed and the indicators that will be used for measuring these dimensions will be introduced. In the next chapter, the methodology for applying the operationalization presented here will be discussed.

TOD development in the catchment area

The dimensions to determine TOD developments are primarily based on the work of Cervero & Kockelman (1997) and Ewing & Cervero (2010). These aspects (Density, Diversity, Design, Destination accessibility and Distance to transit) are often found in studies as influential on mode choice and other measures of travel choices and are also prominent in TOD literature. Destination accessibility (further: location accessibility) relates to a network approach, while Distance to transit (further: proximity) represents a more local scale. These two scales (macro and micro) are also seen in the hourglass model (Brand-van Tuijn et al., 2001). These 5 D's combine the principles of urban design in Transit Oriented Development and their link with travel behaviour these will thus be used as the main components when deciding if a location is in line with TOD or not.

To assess the transit, oriented and development aspects of TOD, Lyu, Bertolini & Pfeffer (2016) introduce 94 indicators, 24 that focus on the transit aspect, 53 that focus on the development aspect and 17 that focus on the oriented aspect. It goes beyond the scope of this research to use all these indicators, and not all indicators are relevant signal indicators, as Lyu, Bertolini & Pfeffer (2016) conclude themselves. The indicators that are used can be found in Table 1. In addition, the design principles of Pojani & Stead (2015) will also be represented in the indicators. The indicators used are based on a wide review of the literature (van Lierop, Maat & El-Geneidy, 2017; Lyu, Bertolini & Pfeffer, 2016; Pojani & Stead, 2015; Cervero and Kockelman, 1997; Ewing & Cervero, 2010; Knowles, Ferbrache & Nikitas, 2020; Sun, Allan, Zou & Scrafton, 2022) and various conversations with colleagues and students.

In order to be considered TOD, a location should have a minimum of 1 positive indicator for each dimension. This method makes sure that a location is not wrongly scored as TOD because some indicators are prominently present, while others are not present at all. Beneath, the dimensions and their indicators are discussed further.

Table 1: dimensions and indicators

Dimension	Indicator
Density	Commercial density
	Residential density
Diversity	Mixedness of land use
Design	Station square
	Parking norm
Location accessibility	Hierarchical score
	Number of platforms
Proximity	bus stop density
	bike path per square km
	OV bike rental available

Density: This is the most straightforward indicator. It is in line with (among many others) van Lierop, Maat & El-Geneidy (2017), who state that medium- and high-density developments are more likely to contribute to the success of TODs as they can encourage people to walk, cycle, or use transit. This measure is also often used in research on accessibility (Lyu, Bertolini & Pfeffer, 2020). Density will be operationalised in line with the way most common in existing research (for example Singh et al., 2017).

There are two ways this indicator gets scored, population density and commercial density. '*BAG januari 2020'* is used to assess the indicator, more specifically the '*verblijfsobject'* layer. Even though there are more recent versions of the BAG, in this study the interest lies in the situation in 2019 so newer data is irrelevant and may create situations that are inaccurate. The buildings in '*verblijfsobject'* are selected on their function (either commercial or residential). The items are summarized per buffer and divided by the land area of the buffer to calculate the density of respectively commercial and residential addresses. The thresh mark is based on the classification for urbanity in the Netherlands (Centraal Bureau voor de Statistiek, 2021):

Residential density (residential addresses/sqkm)

- less than 2000 addresses per sqkm2= 0
- 2000 or more addresses per sqkm2 = 1

Commercial density (commercial enterprises addresses/sqkm)

- less than 2000 addresses per sqkm2= 0
- 2000 or more addresses per sqkm2 = 1

Diversity: Lyu, Bertolini & Pfeffer (2020) suggests that land use diversity is not good for network wide accessibility. However, in this study not only network wide accessibility is relevant, but also the accessibility within the catchment area since it might improve the utility of taking the train. Therefore, mixedness land use is taken into account. In most studies, this dimension is measured by using Entropy in geospatial data (see Singh et al., 2017). According to Ritsema van Eck & Koomen (2008), this is one of the options when classifying land use mix, which does not oversimplify the mixedness of land use. Entropy is calculated in line with Voukenas (2021) (see appendix 1 for concrete steps). This is done using the '*Bestand BodemGebruik (BBG) 2015*'. Although the data is a little bit older, it is the most useful to calculate entropy, since the other possible data source (the BAG) uses point data, which cannot be used for calculating entropy. The data in the BBG layer is very disaggregated, so a selection for urban functions is necessary. To make sure this exclusion of other categories does not produce vastly different results, a control analysis is done with all the land use types. Entropy outcomes are values between 0 and 1 (the closer towards 1, the more mixed the land use in the area) and in line with Singh et al. (2017), values above 0.5 will be seen as positive (and given a value of 1) and locations with a value below 0.5 will not be considered TOD.

Mixedness land use

- Entropy value less than 0.5 =0
- Entropy value of 0.5 or higher = 1

Design: This dimension knows the most diverse operationalisation in the existing literature. In this research, it entails the following principles of Pojani & Stead: public spaces for human use and car movement and parking. Public spaces for human use will be indicated by the availability of a station square (following Pojani & Stead (2015) without barriers such as bicycle parking as Simkens, 2020 introduces). Parking supply is another important factor for a successful TOD (Sun, Allan, Zou & Scrafton, 2022). Chatman (2013) concludes that (limited availability of) on-street parking has an influence on car usage, not just the proximity of a station. An oversupply of parking space might induce car trips (Tian, Ewing, Weinberger, Shively, Stinger & Hamidi, 2017). This is why the parking norm is a useful indicator to assess car movement and parking. The municipalities decide the parking norm in the Netherlands, often in line with the CROW guidelines (Intermaris, 2017). In these guidelines, a parking norm between 1-2 per single family home is normal, depending on the development. The parking norm for a single-family home is considered in the policy documents and everything less than this norm is considered TOD. For the presence of a public square, google maps street view is used and historical images of google earth is used to make sure the situation on google street view was the case in 2019. In addition, other important design principles are represented in the proximity dimension.

Parking norm

- 1 or more = 0

- 0 to 1= 1

Station square

- No= 0
- Yes= 1

Location Accessibility: In line with Ewing & Cervero (2010), the node-place model of Bertolini (1999), the hourglass model and also with Lyu, Bertollini & Pfeffer (2020), this dimension looks at the network side of TOD and the accessibility of the location through sustainable modes of transport. The connections principle of Pojani & Stead is tested by this indicator. Developments around transit nodes in the Netherlands are often focussed on reducing travel time and creating better connections between hubs (van Lierop, Maat & El-Geneidy, 2017), therefore it is useful to include this dimension. There are two ways this dimension gets scored, in line with the placed based concept of accessibility (see Papa & Bertolini, 2015). First, the Dutch Railways use a hierarchical score to distinguish between different stations. Often, intercity stations are larger and have more connecting trains, but to make sure that other stations that are not rated as intercity trains but still function as an important node in the network (and thus have a large accessibility). The number of platforms and connecting trains are also considered (in line with NS, 2020b). The '*station NS'* layer contains information on the hierarchical score and number of platforms, which will be used to select the cases by selecting by attribute in ARCGIS PRO. The threshold for these indicators is based on conversations with experts within the Dutch Railways.

Hierarchical score

- Sprinter station= 0
- Intercity station= 1

Number of platforms

- Less than 2 platforms= 0
- 3 or more platforms= 1

Proximity: This dimension is partly represented considering the two different catchment areas that will be used. However, a circle with a certain distance is only part of proximity. The real-world proximity might be vastly different due to road network and/or walkability. This indicator looks at the accessibility of functions within the location, which can influence chain mobility choices. It also represents the oriented aspect of the development (Lyu, Bertolini & Pfeffer, 2016), and partly overlaps with the design and diversity dimensions. In this indicator the principles of safety, pedestrian and cyclist orientation and transit in the urban pattern of Pojani & Stead are considered. Singh et al. (2017) use (among others) total length of walkable/cyclable paths. *BRT wegdeel vlak'* is used to select the roads with bikers or walking as main usage and calculating the length of these roads per square km for each buffer zone. This is compared to national average of 3630 m/sqkm (Fietsersbond, 2019). Because availability of bikes and bus connections are also relevant for chain mode choices (Tamakloe, Hong & Tak, 2021) these are added by using the layers '*9292ov_stops_januari_2016'* to calculate the density of bus stops by selecting the number of bus stops in the buffer and dividing this by the land area of the buffer. The availability of OV bike rental is determined by looking at data from the NS on the services on each station. The threshold of 10 bus stops per square km is calculated from the national average (following Tamakloe, Hong & Tak, 2021). There are three ways this indicator gets scored:

Number of bus stops

- 0 to 10 bus stops= 0
- More than 10 bus stops= 1

Length of bike paths per square km

- Less than 3,63 metre per sqkm= 0
- More than 3,63 metre per sqkm= 1

OV bike rental available

- No =0
- Yes = 1

3. Methodology

There are many ways to evaluate planning decisions, impacts and processes, and the methods to do this have changed over time (see Alexander, 2006). Guyadeen & Seasons (2018) see a difference in *plan* evaluation on one and *planning* evaluation on the other side, with the first focussing on the content of a single plan and the second on the more general planning process. Another distinction is in the timing of the evaluation (Alexander, 2006). According to Lichfield (2001), there should be a larger focus on in itinere (ongoing) and ex post (after) evaluation in spatial planning in addition to the more common ex ante (before) evaluation (which supports the plan making itself). This research focusses on the ex-post evaluation. Research or policy evaluations focussing on the effects of TOD in the Netherlands have mostly been ex ante, during the plan making or focussed on the process.

A possible solution to the shortcomings of evaluation in spatial planning studies and practice lies in the concept of programme evaluation. Programme evaluation is commonly used in social sciences and can form a solution to current segmented evaluation and the gap between theory in practice. Rossi, Lipsey & Freeman (2004) note that programme evaluation is useful in all fields where issues are raised about the effectiveness of organised social action, which fits with TOD projects and this research. Guydeen & Seasons (2018) see two types of programme evaluation, namely formative and summative evaluations. This research fits with the summative type of programme evaluations, since it focusses on the outcomes after the development has happened, instead of in itinere evaluations (which fits with formative evaluations). In addition, Rossi, Lipsey & Freeman (2004) state: 'the evaluation of a program generally involves assessing one or more of five domains: (1) the need for the program, (2) the program's design, (3) its implementation and service delivery, (4) its impact, or outcomes, and (5) its efficiency.' (p26). This research will focus on the fourth point- the impact of TOD.

When using impact evaluation, the net improvement of the situation because of the intervention is measured (Rossi, Lipsey & Freeman, 2004). This way of examining impact can compromise for the lack of ex post evaluation in planning (Guyadeen & Seasons, 2018). In this chapter, the methodology of the research will be set out. First, the underlying assumptions of the research philosophy will be discussed. Next, the research design of the impact evaluation will be looked into. The data collection and data analysis will be discussed after this and lastly the validity and reliability of the research will be considered.

3.1 Research philosophy

Before looking at the consequences of impact evaluation for the research design it is useful to look at research philosophy since this is the basis for assumptions and choices made in the next steps. According to Moses & Knutsen (2012), a methodology builds upon ontology (what is real) and epistemology (what is knowledge?) to form an answer to the question 'how can things be known?'. The choices taken regarding methodology, epistemology and ontology are guided by a paradigm the researcher stands by (Guba & Lincoln, 1994). Saunders, Thornhill & Lewis (2015) call this paradigm the research philosophy. The research philosophy is the outer shell of the research onion, as presented by Saunders, Thornhill & Lewis (2015) (see Figure 5), and sets the conditions for choices in the inner layers of this onion and thus the choices made later in the research.

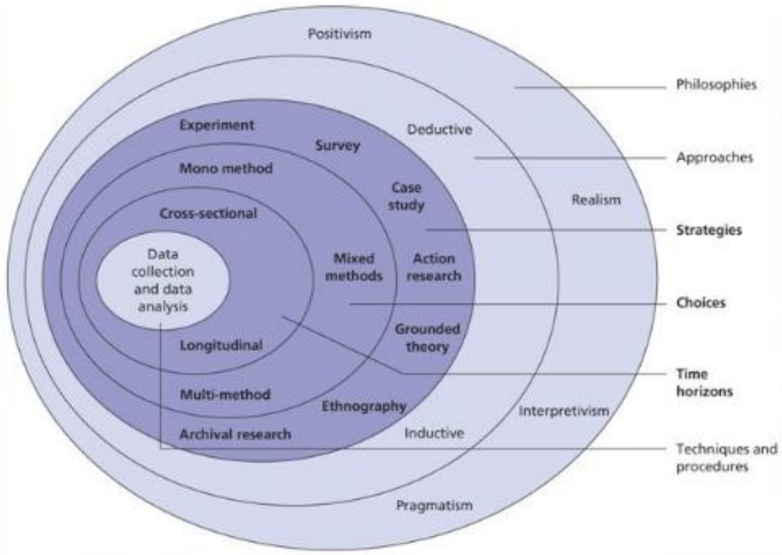


Figure 5: the research onion (Saunder, Thornhill & Lewis., 2009)

Where Moses & Knutsen (2012) only see two kinds of methodology, Guba & Lincoln (1994) see paradigms more as a spectrum, in which four main paradigms can be distinguished. Plan and impact evaluations mostly use a positivistic approach, since they focus on quantifying impact and measuring it in an objective way. This research thus fits with a positivistic philosophy of the research onion and Guba & Lincoln (1994). This philosophy's basis is that knowledge of reality can and should be acquired in an objective manner through empirical observations and systematic research (van Thiel, 2014, p32).

3.2 Research design

In impact theory, there are two possible ways to shape the research. The first is experimental and the second is quasi-experimental (Rossi, Lipsey & Freeman, 2004). Although experimental research design is the golden standard for positivistic and quantitative research (Wing, Simon & Belllo-Gomez, 2018), the research design used here is quasi-experimental. This is because it does not involve randomly assigned intervention and control groups, in which the first receives TOD status and the other does not, as experimental design requires. A perfect experimental research design is very hard to accomplish in social sciences (van Thiel, 2014) and especially when planning decisions are involved, which exist in a complex web of institutional, economical and local contextual factors (Lierop, Maat & El-Geneidy, 2016). By using programme theory and using multiple indicators and dimensions in the research design, this complexity and context of the situation is acknowledged and accounted for in this study. There are, however, still some difficulties in the ability to draw conclusions from a quasi-experimental impact research design that have to do with the biases that can occur.

First there is the bias of selection (Rossi, Lipsey & Freeman, 2004). It considers the bias in non-randomised research designs in the selection of the control group. The control group may differ from the intervention group in aspects that influence the outcome, which makes the outcome impossible to interpret (Spreeuwenberg, 2010). Second, there is the bias in estimation of program effects. This bias regards the measurement of the situation when the intervention (TOD) would not have happened (the counterfactual) (Rossi, Lipsey & Freeman, 2004). Often, this bias is tackled by expecting the situation would not have changed if the intervention didn't happen. However, this is of course not necessarily the case. There are 3 categories that can cause other biases: secular trends (long term), interfering events (short term) and maturation. These external events might impact the outcomes, besides the programme intervention.

These biases are tackled in this study by doing longitudinal research with a difference in difference (DID) research design. Difference in difference is a form of quasi-experimental research design that 'compare[s] the outcomes of groups exposed to different policies and environmental factors at different times.' (Wing, Simon & Bello-Gomez, 2018, p454). The DID research design is visualised in Figure 6. It shows that the two groups (control group S1 and treatment group P1) start with differences that stay the same though time (the different starting places on the x axis), and variables that change through time, but that are the same between the groups (the blue lines). By doing this, the research design makes sure the extra difference though time (the green line) can be ascribed and explained by the variables that are being researched (P2-Q), and other influences can be isolated and excluded.

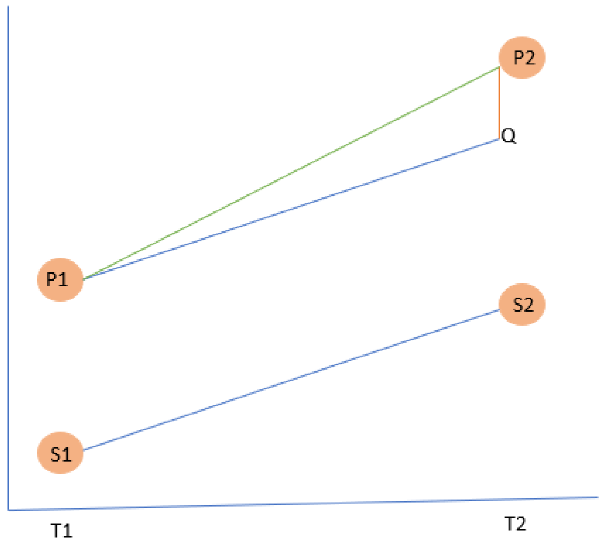


Figure 6: Difference In Difference (own image, inspired by the text of Lechner, 2011)

DID uses the idea of a control group and longitude data to correct for trends and group differences and in this way deals with the biases mentioned above. It does so by 'looking at whether the treatment group deviates from its baseline mean by a greater amount than the comparison group' (Somers, Zhu, Jacob & Bloom, 2013, p3). If there is a difference in deviation from the mean, this can be ascribed to the treatment (P2-Q in Figure 6). When designed well, the credibility of DID studies can be strong, since correction for confounders (variables that influence the results but may be unobserved) can be assured. There are, however, several challenges when constructing a DID research design. The first is with the fundamental assumption of common trends (time independent or group independent). The station areas each exist in a unique context, but the unmeasured variables that could impact outcomes can also be seen as time invariant or group invariant (for example national policy changes or general local demographic build-up).

There are different statistical framework designs in DID (Wing et al., 2019). The one relevant in this research involves multiple groups and time periods. It is important to note that this research is not a generic difference in difference design, since the intervention (the realisation of the TOD project) takes place at different times for different cases, instead of the same moment for all groups. This causes the need for correction for external trends, such as the national growth or diminish in train travellers (see paragraph 3.5). The analyses of this study will result in insight on mode choices (both with the TOD location as origin or destination and separate results for the two buffers). By comparing the changes in travel behaviour between trips to and from TOD and non-TOD locations, conclusions can be drawn on the difference TOD makes on the travel behaviour (comparing P2 and S2 in Figure 6). At the same time, the effect of before and after TOD realisation will be considered (P1 and P2 in Figure 6). A side note to be made here, is that the extent of TOD is only measured in the present, so the assumption is made that the location was not (or less) TOD before the development happened.

3.3 Data collection

Quantitative data will be used for the analysis. This is the most appropriate considering the research question which needs an impact analysis and the existing research on the topic. This means the data will have to be collected, a sample has to be constructed and the results have to be analysed. The following two paragraphs will go into this process.

3.3.1 Sample construction

To assess the impact of TOD projects, a selection of locations must first be made. According to Ibraeva, Correia, Silve & Antunes (2020), accurate selection of station areas is paramount when researching TOD: station areas need to adequately correspond to TOD characteristics in terms of urban design and walkability, otherwise, final results may be misleading. Mixing station areas with rather different characteristics can make the findings difficult to interpret (Ibraeva, Correia, Silva & Antunes, 2020). The selection of TOD locations in this research will be done for two different catchment areas (see Figure 7 for an example). The first is a catchment area of 700 metre Euclidean distance from the train station. In literature, a difference can be made between European literature, that often use 700 m and North American studies, which use a range between 1/4 mile (400 m) and 1/2 mile (800 m) (Lyu, Bertollini & Pfeffer, 2016). This distance links to 10 minutes of walking (Singh et al., 2017). For mode choice, Ibraeva, Correia, Silva & Antunes (2020) state that station proximity is likely to be the most influential factor. Other research shows that people living within 800 metres of the station, own less cars and drive less in comparison with people that live further away (Nasri & Zhang, 2014; Shatu & Kamruzzaman, 2014). Replacing the car, they use public transport more (Nasri & Zhang, 2014; Renne et al., 2016). In addition, they walk and bike more (Nasri & Zhang, 2014; Shatu en Kamruzzaman, 2014).

The second catchment area is an Euclidian distance of 2000 metre, in line with Pojani & Stead (2015). The buffer of 2000 metre represent the difference in the Dutch context and the extent biking can bring to the catchment area (Lee, Choi & Leem, 2014; van Lierop, Maat & El-Geneidy, 2017). Cervero (2007) adds to this that 'Half-mile catchments of station areas appear to be indifference zones in the sense that residents generally ride transit regardless of local urban design attributes' (p2068). According to Hamersma, Knoope & Zeilstra (2019), TOD is expected to have a small effect on the commute movements in the Netherlands, because of the already high density and accessibility of the existing train network in the Netherlands. It is interesting to examine this expectation more closely, also relating it to the increased catchment area in the Dutch context, in line with Lee, Choi & Leem (2014). The consequences of increased cycling for walking as a mode choice are unclear, due to the cultural preference for cycling over walking, which implies a larger TOD radius than elsewhere (Pojani & Stead, 2015). This makes it interesting to look beyond this catchment area to assess the difference urban design makes there. This will lead to two different databases in which the difference of the Dutch context can be examined.

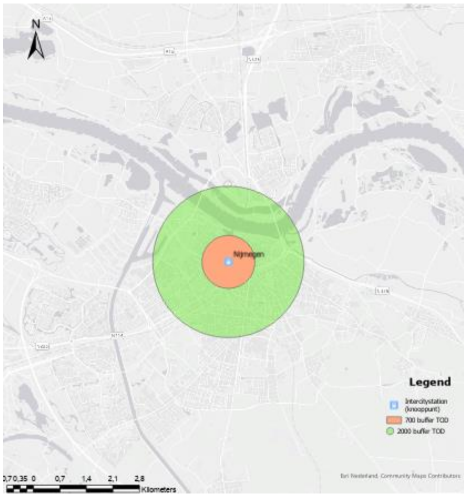


Figure 7: 2 buffers around station Nijmegen

The station area developments will be assessed based on the TOD indicators (see paragraph 2.7). This will be done in three steps, in line with Lyu, Bertilini & Pfeffer (2016). The transit aspect will be assured by only including station locations in the Netherlands. The development aspect will be assured by only including station locations where a development has been happening within the catchment area of the station, between the years 2009 and 2019. A project will be considered a development if it fits a couple of criteria. First, a real estate project must have happened. This focus on real estate (one could also look at infrastructural changes) is because changes in the built environment are the focus of this study. Transit Oriented Development has a large focus on this built environment and the principles that it prescribes to this built environment. This is why other developments go beyond the scope of this study.

Second, the development must be an area development, one new building is not enough to be considered a development. This is because the change of one building is not likely to impact travel behaviour significantly, nor is this the goal of the development. It is more interesting to look at area developments that have this travel behaviour change as a goal, to assess if changes have occurred. This is why the layer '*bestemmingsplangebied'* will be used to determine if a new zonal plan was implemented.

Lastly, the development must be started after 2009 and finished before 2019. This is because the effects have to be measured at least in the year before and after the development started and finished and the data available is between 2010 and 2019. By doing this, the impact of the development can be measured.

These three criteria will be operationalised in the following steps (more specific steps can be found in appendix 1). First, all Dutch stations (layer '*Stations NS'*) are selected and two layers with buffers are created. The following steps are taken for each buffer separately, which thus creates a separate layer, attribute table and analysis outcome for both databases. To consider the existence of a development in the buffer area, the '*Bestemmingsplangebied'* and '*BAG januari 2022'* layers are imported and selected on the years 2009 until 2020 (*documentdatum* and *bouwjaar*). The buffers are selected where both a zoning plan and new buildings are realised between 2009 and 2020. These cases are taken along to the next step. To make sure the development is finished (and in what year the development started and finished), google earth is used to look at satellite pictures of the location through the years. These images show the changes in the built environment and are used to provide the year of realisation in combination with the BAG dataset that entails building years of all the buildings. A note to be made here, is that there may have been multiple developments in one buffer zone. To determine the year of realisation, the closest development near the station and/or the largest, comprehensive development in the area is used. When an overview of all station area developments is created, an inventory of the development in line with TOD principles can be made.

In Figure 8 an overview can be seen of how the locations in the database will be selected and created in line with paragraph 2.7. An extensive description of the exact steps taken in the GIS analysis can be found in appendix 1. The assessment will be made by using multiple sources, which enhanced the validity and reliability of the research (van Thiel, 2014, p52). The end product of this second step of the research are two databases, one with all the Dutch TOD locations with a catchment area of 700 metre and one with all the TOD locations with a catchment area of 2000 metre.

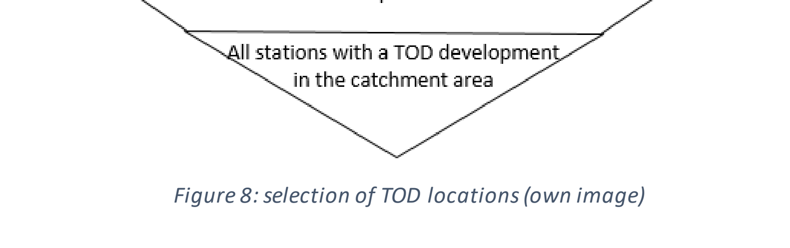


Figure 8: selection of TOD locations (own image)

These databases are intersected with the layer '*postcodes*' to make the join with OViN/ODiN data possible (see 3.4). Since only a few postcode areas are situated completely within a buffer, a selection is made that counts all postcode areas that are within the buffer (but not completely within). Consequently, the number of travellers to or from a certain postcode area can be travelling just outside the buffer. This problem in known as MAUP (Modifiable Area Unit Problem). Some postcode areas are oddly shaped or relatively large, which means some of the area can fall out of the buffer, but the trips made are still counted. However, the reverse (data not being assigned while the postcode area falls into a buffer because the centre is out) is also true which might balance the data.

3.3.2 Input data

When the database is completed the second round of data collection will commence. The second round of data collection will be done by using OViN/ODiN. This is a dataset from the Dutch central bureau of statistics on travel patterns of individuals. The data is built up from segments (parts of a journey) and it is based on yearly survey dating from 2010-2017 (OViN) and 2018-2022 (ODiN). The difference between these two is in the research design (see CBS, 2019). The dataset consists of 202 variables per respondent and contains information on the movements made by Dutch people over the age of 6 on 1 day of the year. In this study, the OViN/ODiN dataset will be used to assess the effect on the probability of choosing train over other modes of transport that a TOD realisation has. A difference will be made between travelling towards and traveling from the TOD location. The analysis will be conducted using SPSS logistic regression.

3.4 Data analysis

The data of OViN/ODiN has been used to analyse the impact TOD makes on mode choices. To determine the test that is used, the sample distribution has to be considered. Since the data from CBS is a large sample from a large yearly study a representative sample can be expected. This means parametric tests are possible since the conditions (at least 30 cases and a normal distribution, De Vocht, 2016) are met.

A regression analysis is used to find causal relations in data. In a regression analysis, the value of the dependent variable is predicted using the independent variable(s). This fits with this research since the focus is on if and how the intervention (TOD realisation) influences travel behaviour. There are various kinds of regression analysis. Here, a logistic regression analysis fits best. This analysis is appropriate when using continuous and categorical predictors to predict categorical outcomes (Field, 2018). In this research this is the case, since multiple kinds of independent variables predict if a person chooses the train. This is a categorical variable because it can be one of two categories (0=not the train as main mode of transportation, 1= the train as main mode of transportation). A logarithmical transformation is used to expresses the non-linear (continuous -> categorical) relation in a linear way. In a logistic regression, the probability of P(Y) occurring is calculated, based on predictor X, instead of the value Y based on predictor X as in a linear regression (see Figure 9). The output value will lie between 0 and 1. A value close to 0 means that Y is very unlikely to have occurred, and a value close to 1 means that Y is very likely to have occurred (Field, 2018).

$$P(\hat{Y}) = \frac{1}{1+e^{-(b_0+b_1X_{1i}+b_2X_{2i}+\cdots+b_nX_{ni})}}$$

Figure 9: Formula of logistic regression P(Y) based on multiple predictors Xs (Field, 2018, p1116)

Before conducting a logistic regression analysis, some assumptions must be tested. According to de Vocht (2017), there are three assumptions, namely those of independent observations; a dichotomous dependent variable and continuous or dichotomous independent variable(s); no multicollinearity. Allen, Bennett & Heritage (2014) add to these: no outliers; logit linearity. Two other methodological considerations are mentioned (cases to variables ratio and minimum expected frequencies), these are already tackled in the research design. Beneath, all assumptions will be shortly discussed.

Independent observations
First, logistic regression assumes independent observations. The data cannot be repeated and matched. This is the case in the OViN/ODiN database, since no respondents were questioned repeatability (CBS, 2022) and the data of each year is independent.

Dichotomous dependent variable
Second, the dependent variables has to be dichotomous. This is the case in this study (taking the train or not is dichotomous). The independent variables must be interval/ratio or dichotomous for the logistic regression analysis to work. This is also the case in the research, some dummies will be created for non-dichotomous nominal variables. This way, the variables can still be included in the analysis.

No multicollinearity
Third, there is an assumption of no multicollinearity. The independent variables cannot correlate strongly ($(r>0.9)^2$) for the analysis outcomes to be interpreted correctly. This assumption will be looked at through correlation and the variance inflation factor (VIF) statistic (see chapter 4.2).

No outliers
Logistic regression is sensitive to outliers and other influential cases. Because of the considerable number of observations in OViN/ODiN (n=1,067,818), the outcomes are less likely to be impacted by one outlier when compared to smaller datasets. In addition, there is only one continuous variable (distance) that can be of impact. To tackle this, the distance travelled will be transformed into classes with the use of dummies to make the variable nominal and dichotomous. This way, distance can be considered and the analysis is protected against influences from outliers. See chapter 4.2.1 for the classes created for distance.

Logit linearity
Lastly, this assumption tests the linearity between each continuous predictor and the dependent variables transformed logit (Allen, Bennett & Heritage, 2014). Or as Field (2018) explains it 'assumes that there is a linear relationship between any continuous predictors and the logit of the outcome variable' (p1123). In this study, there is only one continuous predictor (distance) and as explained above, this predictor will be transformed into classes. The logit linearity is thus not relevant here and does not need to be tested.

For the data to be fit for analysis, a couple of data preparation steps must be undertaken. First the different years of OViN/ODiN must be merged to create one dataset. Data aggregation is needed to do this. The aggregation consists of a merge of different rows of segments into trips, with the main mode of transport remaining. A dummy variable is added to show the usage of other modes of transport in the trip. In addition, dummies for the nature of these secondary modes used are added. For each trip, the year of the data is added as a variable before the merge. The dataset created in GIS is joined with the OViN/ODiN dataset, based on postcode data present in both. Several new dummy variables are created, based on the origin and destination postcode and if these fall into one of the TOD buffers.

Following this, another variable (TOD_after) is added for the four different buffers (origin700; origin2000; destination700; destination2000) in which the postcodes that belong to a location where TOD was implemented are noted as 1, if the data of that row was from or after the year of the realisation and a 0 if it was not a TOD location (yet), in line with Wing, Simon & Bello-Gomez (2018, p456). A before variable (TOD_before) is also added for all the buffers. By doing this, the impact of the TOD realisation can be better examined. Lastly, some categorical recodes are added for individual variables (such as age, income and car ownership).

In addition, some cases are excluded from the database. A trip within the same postcode area will not be considered and trips from or to postcode areas further than 5000 metre (calculated from the centre of the postcode area) from a station will also not be considered in the analysis. This is in line with utility theory because the utility of taking the train for these trips is very low and it therefore cannot be expected that TOD makes a difference for these trips. Lastly, it is worth noting that the station to which a trip is allocated is the one closest to the centre of the postcode area. This might not be a correct representation of reality, since people might go to another station for various reasons (space-time constraints). However, considering the distance is in line with utility theory and is the most logical way to attribute the trips to a station, compared to (for example) random allocation. The syntax that was used to run the logistic regression analyses can be found in appendix 2.

3.5 Validity and reliability

Reliability and validity are both important aspects when conducting sound research. According to Rossi, Lipsey & Freeman (2004) 'Only if outcome measures are valid, reliable, and appropriately sensitive can impact estimates be regarded as credible' (p193). According to van Thiel (2014), the reliability of a study is a function of: 1. The accuracy, and 2. The consistency with which the variables are measured. Mason (2018) adds the precision of a research tool to the condition of reliability. The reliability ensures that the research is representative and systematic. Mason (2018) states that reliability is more important in quantitative methods, since it usually cannot be measured in qualitative studies. This is the case in this research. According to Baarda (2014), describing and substantiating the choices for methods and variables increases the reliability of the research since this makes the research fit for replication. In this research this is done in the paragraphs above and in the appendix as well. Another way of increasing the reliability of the study is by ensuring the measurement instruments and variables are sound (van Thiel, 2014). This can be done by discussing the choices made with other researchers, which is called inter-researcher reliability (van Thiel, 2014). In this study, the reliability is assured through careful documentation of the research supporting the choices made throughout the research process, such as the operationalisation (see paragraph 2.7). In addition, by using multiple sources and variables to measure the TOD principles in the dataset, the reliability of the study increases. The choices made are supported by talking to both supervisors, colleagues and in addition, to peers with related subjects.

The validity of a research design can be described as the degree to which the tool measures what it claims to measure and the degree it is 'true'. If a study is valid, it represents the real conditions and relations in real life. It links thus to the concepts of epistemology and ontology (in line with Mason, 2018). Unlike reliability, results do not have to be similar to be valid. Rossi, Lipsey & Freeman (2004) note that in programme theory, overall validity turns out to depend very much on whether a measure is accepted as valid by the appropriate stakeholders that are involved in the programme. So, if multiple experts agree on the measure, this increases its validity. There are different types of validity which will now be discussed.

Internal validity entails the degree to which conclusions about causal relationships can be made. The correct operationalization of the study and the correct choice of variables contributes to the instrumental (=internal) validity of the research (Baarda, 2014). This kind of validity can further be tested by statistics, in conversations with other researchers or by using an instrument that has been standardized. In this research, the operationalisation and indicators chosen are based on an extensive literature review, which increases the internal validity. Furthermore, the usage of mixed sources also supports the validity of this research (Baarda, 2014), by providing a broader coverage of the concept (Rossi, Lipsey & Freeman, 2004). According to Maciejewski (2020), the lack of randomisation in quasi-experimental research designs threats the internal validity of research. There are two ways this study battles this threat. First, through difference in difference research design. This research design is made to tackle different biases and to correct for trends to measure the true impact. Athey & Imbens (2017) note that not all difference in difference designs are necessarily high in validity. This depends on among other factors the numbers of cases. In this study, all Dutch station areas are considered and this makes sure that covariables can be corrected for. Second, through testing for statistical robustness and sensitivity (in line with Rossi, Lipsey & Freeman, 2004). This is also in line with Wing et al. (2018), who state that 'Robustness checks and sensitivity analysis can probe the main assumptions that support the internal validity of the research design' (p458-459). In this study this is done extensively by using multiple buffers and comparing the results of multiple selections and models (see paragraph 4.3).

External validity is the extent to which the results of the study can be generalised (van Thiel, 2014). The study sample and representation of this sample play a key role in this. Related to this is the ecological validity, which prescribes the extent to which the results can be applied outside of research settings. The real-life results might be different due to context variables when doing experimental research. The right choice of method contributes to the ecological validity of the research (Baarda, 2014). This research is set in the real world within the contexts of the different locations and developments. Furthermore, all Dutch station locations are considered so generalisation is not necessary to form conclusions. The difference between the two different catchment areas can be used to support decisions in other research and to strengthen those external validities.

4. Results

In this chapter the results of the GIS and the SPSS analysis will be discussed. The database of TOD locations is the main result of the GIS analysis and can be found in appendix 3. Prominent and notable results from this will be discussed beneath. Next, the SPSS analysis is considered. This is done by first looking at some descriptive statistics and later test the results these descriptive statistics indicate by conducting logistic regression analyses. The output of the analyses are presented and compared. Lastly, the robustness of the model used is assessed by selecting on different trip characteristics and buffers and examining the output. The results presented here will be used to feed into the answers to the research questions in the next chapter.

4.1 Dutch station area developments

The resulting number of cases after the GIS analysis and selections are 28 station areas for the 2000 m buffer and 17 station areas for the 700 m buffer. The locations of these station areas can be found in Figure 10 and appendix 3. The number of cases after each step of the analysis can be found in Table 2. Important to note here is that for some stations, the 700 metre buffer did meet the indicators criteria, while the 2000 metre buffer did not or vice versa. There are 10 cases where both the 700 metre buffer and the 2000 metre buffer around the same station are considered TOD. For 21 stations, there is some extent of overlap with buffers of other stations. These locations are mostly located in the Randstad (see Figure 11), but also occur in Groningen and Eindhoven. Two buffers of 700 metre have an overlap, these are located in Utrecht.

When looking at Table 2, it might seem that the later steps are less significant in deciding if the location is TOD. However, when inspecting these results closer it becomes clear that the probability of a location being TOD is larger with each selection it passes, thus making it logical that the number of dropped locations becomes less with each round. This confirms the validity of the chosen indicators, since no single indicator at the later steps makes a considerable large contribution, which confirms the coherence of the built environment indicators. In appendix 3, the final database can be found. Figure 13 shows the realisation years of the TOD locations. Note that a there is a higher number of realisations in the last years.

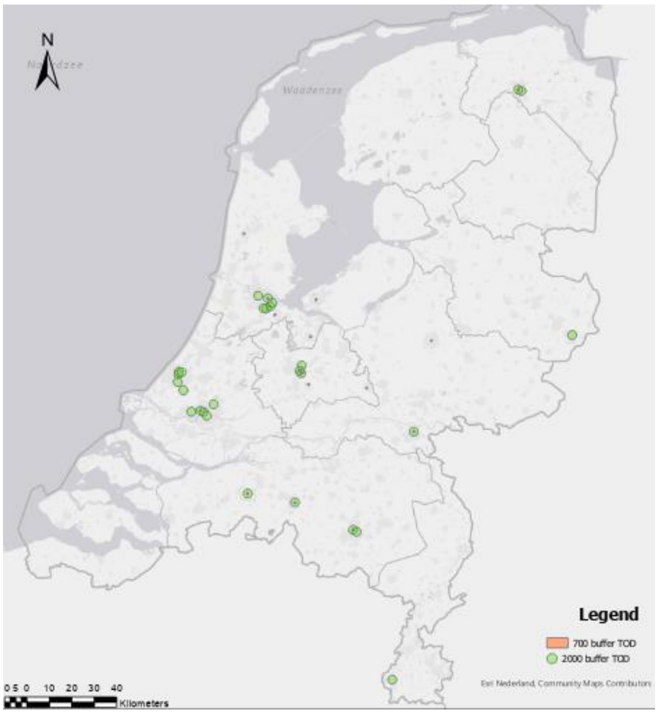


Figure 10: TOD locations in the Netherlands

Table 2: cases reduction during the GIS analysis

	2000 m buffers	*Difference*	**700 m buffers**	*Difference*
No selection	397		397	
After selection development	215	*-182*	83	*-314*
After selection density	46	*-169*	25	*-58*
After selection location accessibility	35	*-11*	19	*-6*
After selection diversity	31	*-4*	18	*-1*
After selection proximity	31	*0*	18	*0*
After selection design	28	*-3*	17	*-1*

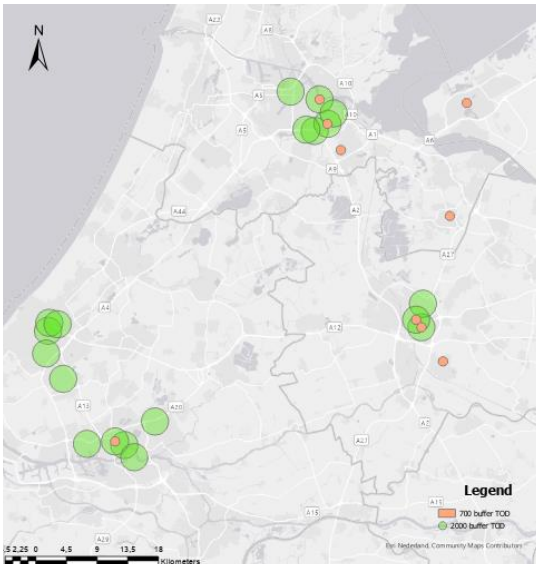


Figure 11: TOD buffers in the Randstad

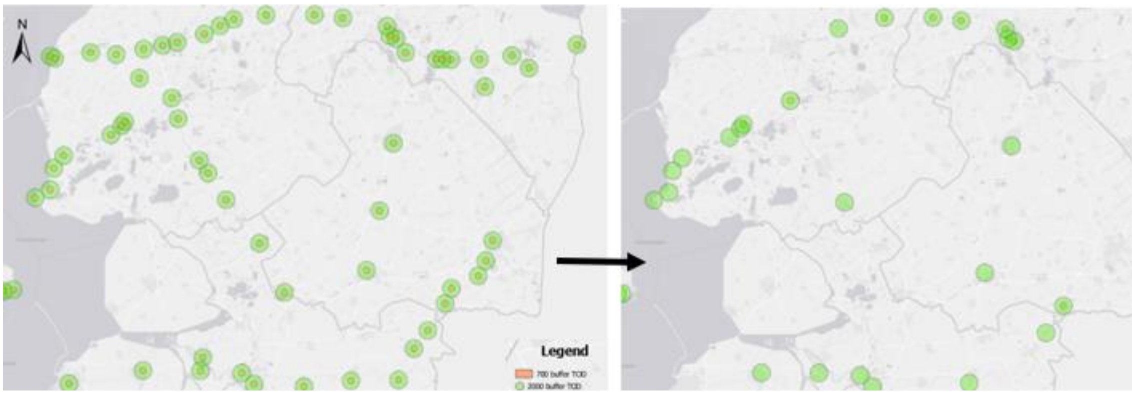


Figure 12: Example of selection density

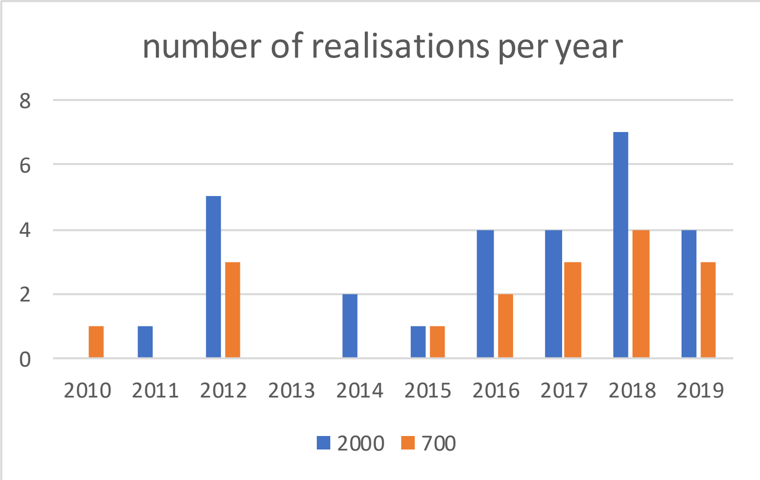


Figure 13: realisations per year for 700 m and 2000 m buffer locations

4.2 Impact on mode choice

The statistical analysis and data inspection has been conducted using SPSS (Statistical Package for Social Sciences). A significance level of 0.05 is used. This means that the H0 (there is no significant relation between the variables) is accepted or rejected with a 95% certainty (de Vocht, 2016). Before the analysis, discussed in paragraph 3.4.2. can be initiated, the last assumption has to be tested. This is the assumption of multicollinearity between the independent variables. Two tests (correlation and VIF test) are undertaken to look at this assumption. The results can be found in appendix 4. Although all the correlations are significant in the output, the Pearson correlation is not higher than 0.80 for any of the combinations. This means that there is no problem with multicollinearity (Allan, Bennett & Heritage, 2014). To consider multicollinearity further, a VIF test is conducted. No VIF value is higher than 5, which means that multicollinearity is not severe enough to require further attention. The assumption is thus met.

4.2.1 Descriptive statistics

To inspect the data, several descriptive analyses have been conducted. Namely, *frequency tables*, *crosstabs* and *descriptives* in SPSS have been used with different (combination of) variables to get the results presented below. First, to look at the common trends in the data, the number of respondents each year are compared (see Table 3). From this, it is visible that in 2018 and 2019 had the most respondents and 2016 and 2017 have the least. This can be explained by OViN stopping in 2017 and ODiN started in 2018, which continued with a new research design. This is also visible for the large rise of number of travellers by train in 2018 and 2019. This difference can thus partly be explained by this difference in number of respondents. This common trend has to be corrected for in the next paragraphs (in line with Wing, Simon & Bello-Gomez, 2018).

Table 3: number of respondents and train travellers by year

Year	Respondents	Train travellers
2010	109119 (10.2%)	1349 (5.4%)
2011	100532 (9.4%)	1840 (7.3%)
2012	105651 (9.9%)	2257 (9.0%)
2013	101008 (9.5%)	2207 (8.8%)
2014	99292 (9.3%)	2123 (8.5%)
2015	86365 (8.1%)	2009 (8.0%)
2016	83234 (7.8%)	1830 (7.3%)
2017	81610 (7.6%)	2076 (8.3%)
2018	158116 (14.8%)	4802 (19.2%)
2019	142868 (13.4%)	4578 (18.3%)

Travelling by train only makes up 2.3% of travels, as can be seen in Table 4 and Table 5, showing that bike (29.2%), walking (16.6%) and car(34.9% as driver and 12% as passenger) are much more important in the modal split. This is said with the observation that most trips are shorter than 10 kilometres (89.3%), with a median of 2.02 kilometres and 30% being shorter than 1 kilometre (see appendix 5). The train is not a logical mode choice for these distances. For the trips that have the train as main mode of transportation, the mean distance travelled is 51.6 kilometre (see Table 6), while this is 11.6 kilometres for all trips. When putting the distance into 5 groups, appendix 5 shows that the trips by train are much longer in comparison with all modes. These 5 groups will be used to transform the distance data into 5 groups that will be used in the analysis in the next paragraphs.

Of all trips, 84.7% were made from postcode areas within 5 kilometres of a station towards a postcode area within 5 kilometres of a station. When only selecting these cases, the percentage of trips by train rises from 2.3% to 2.6% (see Table 1Table 4). The origin or destination of a trip being in a TOD location (before realisation) increases the train usage to around 5% for the 2000 metre buffer and 5.8% for the 700 metre buffer. This percentage increases even more after realisation of a TOD (to respectively 6.3% and 7.6%). This seems to suggest that there is an increase in train travellers after TOD realisation. However, there is no correction for the abovementioned common trends and time variant differences in these descriptive statistics or any indication if the relation is causal yet. Therefore, in the next paragraph, this relation will be further examined.

The descriptive statistics of the independent variables can be found in Table 6. These are already selected on travelling by train, while the first two column composing all trips and all trips by train as reference. A few additional comments are relevant to make here. Shopping and commuting are the most important reasons to travel overall (respectively 20.6% and 19.1% of respondents gave this as motive for travelling). Commuting is also the most important motivation when only looking at train travellers (40.7%, see appendix 5 as well). Other important motives for train travels are education (23.7%), other social recreation (11.3%) and visiting (10.5%). The characteristics of train trips are pretty consistent between buffers. There are however some notable differences between the trips by train from or to TOD locations and the reference columns. Education level, household composition and car ownership are mainly where differences can be seen between the first two columns internally and with the TOD locations. It seems that higher educated people take the train more often and this effect is even stronger for trips to or from TOD locations overall and the effect improves after TOD realisation. In addition, one person households seem to take the train more often, at the expense of couples with kids. Again, this effect is even stronger when TOD locations are finished. Lastly, households without a car use the train more often as a main mode of transportation, while households with 2+ cars use the train less. This effect is stronger for TOD locations and even larger after TOD realisation. Households with 1 car stay relatively the same throughout the categories. In addition, the average age is lower for train travellers compared to all modes of transportation.

Table 4: main mode of transportation for origin in the buffers

		All trips	5000 station buffer	700 m TOD before	700 m TOD after	2000 m TOD before	2000 m TOD after
Percentage of total trips		100%	84.7%	3.2%	3.1%	7.7%	7.8%
Main transportation mode	*Car as driver*	34.9%	35.3%	26.2%	24.3%	26.5%	24.4%
	Car as passenger	12%	12.1%	9.1%	8.7%	9.5%	8.3%
	Train	2.3%	2.6%	5.7%	7.6%	4.7%	6.3%
	Bus/tram/metro	2.3%	2.6%	5.3%	6.2%	5.9%	6.9%
	Moped	0.9%	0.9%	1.2%	0.8%	1.2%	1%
	Bike	29.2%	28.6%	31.5%	31%	29.7%	31.7%
	Walking	16.6%	16.2%	19.9%	19.8%	21.3%	19.6%
	Other	1.7%	1.7%	1.3%	1.4%	1.3%	1.7%

Table 5: Main mode of transportation for destination in the buffer

		All trips	5000 station buffer	700 m TOD before	700 m TOD after	2000 m TOD before	2000 m TOD after
Percentage of total trips		100%	84.7%	3.3%	3.2%	7.7%	7.8%
Main transportation mode	*Car as driver*	34.9%	35.3%	26.3%	24.3%	26.7%	24.4%
	Car as passenger	12%	12.1%	9.2%	8.6%	9.6%	8.3%
	Train	2.3%	2.6%	5.9%	7.6%	4.9%	6.4%
	Bus/tram/metro	2.3%	2.6%	5.4%	6.5%	5.9%	7%
	Moped	0.9%	0.9%	1.1%	0.8%	1.2%	1%
	Bike	29.2%	28.6%	31.1%	31%	29.5%	31.7%
	Walking	16.6%	16.2%	19.7%	19.8%	21%	19.6%
	Other	1.7%	1.7%	1.2%	1.4%	1.3%	1.7%

Table 6: means and frequencies of variables with different buffers

				Origin				Destination			
		All trips with all modes of transportation	*All trips with train*	*700 m TOD before*	*700 m TOD after*	*2000 m TOD before*	*2000 m TOD after*	*700 m TOD before*	*700 m TOD after*	*2000 m TOD before*	*2000 m TOD after*
Mean distance travelled in km		11.6	51.6	51.7	51.7	52.9	53.5	50.9	50.9	52.5	52.8
Motive frequencies	*Commuting*	19.1%	40.7%	39.2%	42.2%	41.8%	43.1%	40.7%	44%	42.8%	45%
	Business	1.8%	3.1%	4.2%	4.4%	3.9%	4.2%	3.4%	3.5%	3.5%	3.7%
	Services	3.6%	1.3%	1%	1.1%	1%	1.2%	1.1%	1%	1%	1.2%
	Shopping	20.6%	5%	7.1%	8.4%	5.5%	5.9%	6.7%	8.5%	4.9%	5.4%
	Education	10.5%	23.7%	20%	13.9%	21%	16.6%	22.6%	14.1%	23.4%	17.6%
	visiting	11.5%	10.5%	9.4%	10.1%	10.4%	11%	8.6%	9.8%	9.2%	10.5%
	Other social recreation	18.2%	11.3%	13.2%	15.4%	11.6%	13.5%	12.8%	15.9%	11.5%	13.2%
	Hiking	5.7%	0.9%	1.3%	1%	1%	0.9%	0.7%	0.7%	0.5%	0.7%
	Other	9%	3.4%	4.5%	3.5%	3.6%	3.6%	3.4%	2.5%	3.3%	2.7%
Gender	*Male*	47.2%	50.2%	50.8%	50.6%	51.4%	50.2%	50.6%	50%	50%	50.2%
	Female	52.8%	49.8%	49.2%	49.4%	48.6%	49.8%	49.4%	50%	50%	49.8%
Age		41.2	34.7	35.1	36.4	35.1	35.2	34.9	35.9	34.9	34.9
Education level	*Low*	24.4%	13.3%	10.9%	9.6%	9.6%	6.8%	12%	9.3%	10.3%	6.8%
	Middle	36.3%	35.8%	33.9%	29.8%	34.3%	28.9%	33.9%	30%	35.6%	28.5%
	High	36.9%	49.2%	53.9%	59%	54.8%	62.5%	52.3%	59.1%	52.9%	62.9%
	No/other	2.4%	1.8%	1.3%	1.6%	1.3%	1.8%	1.8%	1.5%	1.3%	1.8%
Income	*Lowest*	33.3%	31.1%	31.7%	31.1%	34%	31.9%	32.1%	30.9%	34.2%	31.1%
	Middle	42.8%	41%	39.4%	38.3%	38.2%	36.7%	39.5%	37.8%	38%	37.1%
	Highest	23.9%	27.9%	28.9%	30.6%	27.8%	31.4%	28.4%	31.3%	27.8%	31.8%
Household composition	*One person household*	14.2%	21.6%	22.2%	26.7%	24.7%	28.1%	22.7%	26.6%	24.3%	28.1%
	Couple no kids	27.6%	23.3%	24.9%	27.7%	23.8%	27.2%	24.4%	27.3%	23.8%	26.7%

	Couple with kids	50.4%	44.1%	40.4%	35.8%	39.2%	34.8%	40.2%	36.1%	39.5%	35.1%
	Parent with kids	6.6%	7.8%	7.3%	6.7%	7.2%	6.8%	8%	6.8%	7.2%	7.1%
	Other composition	1.2%	3.2%	5.2%	3.1%	5.1%	3.1%	4.8%	3.1%	5.2%	3.1%
Car ownership	*No car*	10.7%	28.8%	29.3%	35.4%	32.6%	38.2%	28.4%	35.2%	31.5%	37.9%
	1 car	49.8%	46.1%	47.2%	46.1%	46.1%	43.4%	47.7%	45.9%	46.9%	43.3%
	2+ cars	39.5%	25%	23.5%	18.5%	21.2%	18.4%	23.9%	19%	21.7%	18.8%

4.2.2 Travelling from TOD

To analyse the second sub question (*'How do Dutch TOD projects impact mode choice to and from the location?'*), a logistic regression analysis is used to consider if TOD impacts the probability of using the train as mode of transport. This question is differentiated into different parts. First, if the effect of the change to TOD of the origin location analysed. The null hypothesis in this analysis is that there is no causal effect of the origin location being TOD on the probability of taking the train. After doing the logistic regression analysis, this null hypothesis can be rejected based on the analyses that have been conducted. This will be discussed in this paragraph. In Table 7, three models are presented for the 700 metre buffer, Table 8 contains the results for the 2000 metre buffer. The results are presented by reporting the odds ratio and the standard error, with an asterisk to indicate the significance of the outcome. The odds ratio is a good interpretation for categorical variables (de Vocht, 2016). An odds ratio larger than 1 suggests an increase in the chance of taking the train (P), and an odds ratio smaller than 1 suggests a decrease in the chance of taking the train. The logistic regression output in SPSS contains many more tables and values than presented here. Only the relevant results that can best be interpreted to answer the research question of this research are presented here.

The first model used is the simplest, just containing the TOD buffers and the trips from these locations after realisation with fixed effects for the year and month. By including these variables in the model, the calculated effect is corrected for the common trends. This is the basic model to compare other models and their outcomes to, to examine the impact of other variables on the difference TOD makes. Model 2 includes the individual characteristic variables and model 3 adds trip characteristics to this. Model 3 represents the conceptual model in full and by including the first two models, the impact of every group of variables (Transit Oriented Development, trip characteristics and individual characteristics) can be examined. When running these models, only the trips to and from a postcode in the 5000 metre buffer around a station were included. In every model, the year and month of the trip was included as a corrector for common trends because they are fixed effects.

Table 7: logistic regression results for 700 metre buffer

		Model 1		Model 2		Model 3	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
	TOD 700 m	2.846	0.25***	1.736	0.027***	1.844	0.031***
	TOD 700 m after realisation	1.036	0.33	1.109	0.034**	1.160	0.041***
Individual characteristics	Age			0.958	0.000***	0.973	0.001***
	Female (reference to male)			0.835	0.014***	1.288	0.016***
	Education (reference lower education)						
	Education middle			1.576	0.22***	1.252	0.025***
	Education higher			2.058	0.22***	1.492	0.025***
	No or other education			0.961	0.57	0.929	0.064
	Household (reference one person household)						
	Couple no kids			1.164	0.022***	1.365	0.025***
	Couple with kids			1.179	0.022***	1.632	0.025***
	Parent with kids			1.133	0.030***	1.310	0.035***
	Other composition			1.294	0.042***	1.559	0.051***
	Income (reference lowest incomes)						
	Middle incomes			1.439	0.018***	1.309	0.021***
	Highest incomes			1.831	0.020***	1.527	0.024***
	Car ownership (reference no car in household)						
	One car in household			0.438	0.019***	0.207	0.024***
	2+ cars in household			0.227	0.024***	0.069	0.029***
Trip characteristics	*Motive (reference commuting)*						
	Business					0.490	0.043***
	Services					0.416	0.063***
	Shopping					0.375	0.035***
	Education					3.518	0.025***
	visiting					0.449	0.028***
	Other social					0.512	0.026***
	Hiking					0.191	0.076***
	Other					0.326	0.042***

	Distance travelled (reference 0.4-20.7 kilometres)						
	Distance 20.7-31.5 kilometres					23.200	0.025***
	Distance 31.5-47 kilometres					33.514	0.026***
	Distance 47-70.1 kilometres					46.711	0.026***
	Distance 70.1-400 kilometres					53.219	0.027***
Year and month fixed effects		yes		yes		yes	
Number of cases		861266		861266		861266	
Nagelkerke R^2		0.023		0.109		0.434	
Chi-square		4420.698***		19678.308***		81359.156***	

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator ‘TOD_after’ is one when a TOD project is realised (year of realisation and all subsequent years) within 700 metres of the station closest to the zip code of origin. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively.

The three logistic regression analyses show that there is a significant effect of TOD realisation on the mode choice of train compared to other mode choices for trips with an origin in the 700 meter buffer, except in the first model. The significance of the Chi-square shows that all models improve the block 0 model significantly ($p<0.001$ for all X^2). It is important to note that the block 0 model already has a prediction accuracy of 97.2%. This is because, as noted in the last paragraph, the number of trips taking by train is a lot smaller in comparison to other main modes of transport. The first model suggests that there is no significant impact of TOD realisation on travel behaviour where train is chosen as the main mode. However, there is a significant and large (2.846) impact of these locations as origin overall. This effect diminishes after the TOD realisation and is no longer significant. The second model adds individual characteristics as control variables. This creates a lower effect size of TOD locations (before and after realisation) and a significant effect of TOD realisation, even though this effect is still smaller than the effect of location overall. The third model increases the effect size compared to the second model. The third model is the preferred model, as it explains 43% of the difference in main mode choices (Nagelkerke R^2) and predicts 97.3% of the observations correct. This model shows that after TOD realisation in a 700 metre buffer around the station closest to the origin postcode area, travellers have a 1.160 higher odds ratio (or 16% higher chance) to travel by train compared to other trips.

Almost all variables are significant, which is partly explained by the large number of observations. Only the 'no or other education' option for the education variable is not significant. Women score higher and a higher education level increases the chance of taking the train, as does a higher income. A couple with kids has the largest effect size out of household composition (compared to one person households, which is the reference category). The more cars a household owns, the less likely they are to take the train. For the trip characteristics it seems that education and commuting are the only motives with a positive effect size, education having a large one compared to commuting. In addition, the chances of taking the train seem to increase with the distance of the trip.

The same models were run for the 2000 metre buffers (see Table 8). The full table can be found in appendix 6. Here, all models improve the block 0 model significantly ($p<0.001$ for all X^2) too, but now all outcomes are significant too. The first model suggests that there is a significant impact of TOD realisation on travel behaviour where train is chosen as the main mode. It increases this chance with 6%. However, before (and after) the realisation this effect was also present for these postcode areas, and it was much stronger (154%). The second model adds individual characteristics as control variables. This does not create a substantial difference in effect size for after TOD realisation compared to the first model. Nevertheless, it does mitigate the effect of the locations overall with 100% (53% compared to abovementioned 154%). In the third model, this effect size increases again, especially for the TOD_after variable.

The third model is the best fit, as it explains 44% of the difference in main mode choices and predicts 97.3% of the observations correct. This model shows that after TOD realisation in 2000 metre around the station closest to the trip's origin postcode area, travellers have a 1.191 factor higher odds ratio (or 19% higher chance) to travel with train compared to travellers without an origin around a TOD location. This effect size is smaller than the effect of the location overall (1.683). For the effect of individual and trip characteristics, appendix 6 can be consulted. The results are comparable to the effects for the 700 metre buffer (see Table 7).

Table 8: logistic regression results for 2000 metre buffer

		Model 1		Model 2		Model 3	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
	TOD 2000 m	2.542	0.019***	1.531	0.021***	1.683	0.024***
	TOD 2000 m after realisation	1.062	0.025**	1.071	0.026**	1.191	0.030***
Individual characteristics		no		yes		yes	
Trip characteristics		no		no		yes	
Year and month fixed effects		yes		yes		yes	
Number of cases		861266		861266		861266	
Nagelkerke R^2		0.030		0.109		0.435	
Chi-square		5790.729***		19564.307***		81624.924***	

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator 'TOD_after' is one the first time a TOD project is realised (year of realisation and all subsequent years) within 2000 metres of the station closest to the zip code of origin. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively

4.2.3 Travelling to TOD

Another analysis was done for travelling to a TOD location as destination of the trip. The effect of the change to TOD of the destination location is analysed in this paragraph. The null hypothesis in this analysis is that there is no causal effect of the destination location being TOD on the probability of taking the train. After doing the logistic regression analysis, this null hypothesis can be rejected. The same 3 models as in the last paragraph were used in two analyses, one for the 700 metre buffer Table 9 and one for the 2000 metre buffer Table 10.

In the first model, it seems there is a negative effect of TOD realisation on mode choice in the 700 meter buffer. However, this effect is not significant. The second model does also not offer a significant effect. These two do not fit the data well, even though they do significantly improve the block 0 model ($p<0.001$ for all X^2), the difference in main mode choice are only explained for 2.4% and 11% respectively (Nagelkerke R^2). The third model offers a vast improvement on this, as it explains 43.3% of the difference in main mode choice and predicts 97.3% of observations correctly (versus 96.9% in the null model). This model shows that there is a significant ($p<0.05$) effect of TOD realisation on mode choice in the 700 metre buffer. For these trips, travellers have a 1.139 odds ratio (or 14% higher chance) to make a trip with train as main mode of transport compared to travellers without a destination in this buffer. The TOD realisation does not improve the already existing higher chance of taking the train compared to the first two models on these locations, as the variable for TOD has a factor of 1.881.

Almost all variables are significant, which is partly explained by the large number of observations. Only the 'no or other education' option for the education variable is not significant. Women score higher and a higher education level increases the chance of taking the train, as does income. A couple with kids has the largest effect size out of household composition with one person household as a reference and the more cars a household owns, the less likely they are to take the train. For the trip characteristics it seems that education and commuting are the only motives with a positive effect size, education having a large one. In addition, the chances of taking the train seem to increase with the distance the trip takes.

The same models were run for the 2000 metre buffers (see Table 10). Here all models improve the block 0 model significantly ($p<0.001$ for all X^2) too. Just as in the 700 metre buffer above, the first two models do not offer a significant result for the TOD realisation variable. However, just as above, these two explain little compared to the third model (see Nagelkerke R^2). In the third model, the result of a TOD realisation is significant. The chance of taking the train is improved by factor 1.135 (or 13.5%) compared to trips that do not have a finished TOD location as their destination. This third model explains 43.5% of this difference in main mode choices and predicts 97.3% of the observations correctly. For the effect of individual and trip characteristics, appendix 6 can be consulted. The results are comparable to the effects for the 700 metre buffer (see Table 9).

Table 9: logistic regression results for 700 metre buffer

		Model 1		Model 2		Model 3	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
	TOD 700 m	3.017	0.025***	1.848	0.026***	1.881	0.031***
	TOD 700 m after realisation	0.975	0.032	1.043	0.034	1.139	0.041**
Individual characteristics	Age			0.958	0.0***	0.973	0.001***
	Female (reference to male)			0.836	0.014***	1.287	0.016***
	Education (reference lower education)						
	Education middle			1.572	0.022***	1.251	0.025***
	Education higher			2.053	0.022***	1.489	0.025***
	No or other education			0.964	0.057	0.925	0.064
	Household (reference one person household)						
	Couple no kids			1.167	0.022***	1.367	0.025***
	Couple with kids			1.182	0.022***	1.635	0.025***
	Parent with kids			1.133	0.030***	1.308	0.035***
	Other composition			1.291	0.042***	1.565	0.051***
	Income (reference lowest incomes)						
	Middle incomes			1.445	0.018***	1.310	0.021***
	Highest incomes			1.840	0.020***	1.526	0.024***
	Car ownership (reference no car in household)						
	One car in household			0.439	0.019***	0.207	0.024***
	2+ cars in household			0.227	0.024***	0.069	0.029***
Trip characteristics	*Motive (reference commuting)*						
	Business					0.499	0.043***
	Services					0.416	0.063***
	Shopping					0.375	0.035***
	Education					3.515	0.025***
	visiting					0.452	0.028***
	Other social					0.514	0.026***
	Hiking					0.192	0.076***

	Other					0.331	0.042****
	Distance travelled (reference 0.4-20.7 kilometres)						
	Distance 20.7-31.5 kilometres					23.234	0.025***
	Distance 31.5-47 kilometres					33.528	0.026***
	Distance 47-70.1 kilometres					46.676	0.026***
	Distance 70.1-400 kilometres					53.254	0.027***
Year and month fixed effects		yes		yes		yes	
Number of cases		861266		861266		861266	
Nagelkerke R^2		0.024		0.110		0.434	
Chi-square		4626.295***		19768.464***		81399.370***	

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator 'TOD_after' is one the first time a TOD project is realised (year of realisation and all subsequent years) within 700 metres of the station closest to the zip code of destination. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively.

Table 10: logistic regression results for 2000 metre buffer

		Model 1		**Model 2**		**Model 3**	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
	TOD 2000 m	2.698	0.019***	1.632	0.021***	1.708	0.024***
	TOD 2000 m after realisation	1.010	0.024	1.014	0.026	1.135	0.030***
Individual characteristics		no		yes		yes	

Trip characteristics		no	no	yes
Year and month fixed effects		yes	yes	yes
Number of cases		861266	861266	861266
Nagelkerke R^2		0.032	0.109	0.435
Chi-square		6120.429***	19697.973***	81579.621***

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator 'TOD_after' is one the first time a TOD project is realised (year of realisation and all subsequent years) within 2000 metres of the station closest to the zip code of destination. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively.

4.3 Comparing results

When looking at the tables and results presented above, it is interesting to compare some outcomes to assess the sensitivity of the results. First, the difference TOD as origin or destination makes can be compared. The difference between whether the TOD location is a destination or an origin location for the trip is small with a maximum of a 0.056 difference (between the TOD_after of the 2000 metre buffers). For all comparisons, the impact of the location itself is larger than the impact of the TOD realisation. It does not seem to have a substantial impact on the chance of using the train as main mode of transportation whether the trip is to or from a TOD location.

Robustness tests

Until this point, the trips to and from a buffer of 5000 metre around the station and all trips were considered. To assess the robustness of the results, some other selections were made. When only including trips from AND to a TOD location after realisation, the model (model 3) fits even better (Nagelkerke R^2= 0.606). The effects are only significant for the 2000 metre buffer (2.715 and 2.416 for respectively origin and destination), not for the 700 metre buffer. Notable is that the effects of the location itself for after this selection is negative.

When selecting on trips to AND from a TOD location overall (before and after realisation), similar effects can be seen. For the destination in the 2000 buffer the effect is strongest (22%), while for the 700 metre buffer as destination, there results are not significant. For the origin, the results for the 2000 metre buffer contain a significant impact size of 23%, while the 700 metre buffer does not produce a significant effect.

Lastly, a selection was conducted on trips to OR from a TOD location (before and after realisation). For the destination effects are significant, but only in the 2000 metre buffer the effect size of TOD_after is larger, this effect is however small (1.033). Looking at the origin in the TOD 2000 metre buffer, the effect is very significant and it shows an increase of 15% after TOD realisation of taking the train as main mode of transportation. For the 700 metre the effect size of the TOD realisation is smaller than the effect size of the location overall. This leads to the suggestion that the relative effect of TOD realisation is larger when compared to similar trips instead of all trips or trips in the 5000 metre buffer.

By comparing the buffers, the third sub question (‘*How well does a 2000 metre catchment area fit to measure the impact of Dutch TOD projects?’*) is not only tackled, the robustness of the analysis is also tested. The results of the comparison between the 700 metre TOD buffer and the 2000 metre TOD buffer might cast some light on this. The different buffers do not have a major difference in impact size when considering the TOD_after (max difference of 0.052 between origin 2000- destination 700). In addition, to test the robustness of the results further, several extra analyses were conducted. First, a fourth model was introduced. The fourth model includes all observations without the filter of 5000 metre around a station. The results of model 4 can be found in Table 11. The results should be compared to model 3 results, since that is the model that was run without the filter to create model 4. The model fits a little worse than the third model. The effect size does not change much after realisation for the TOD after realisation. The realisation still has a significant impact on the chance of taking the train with an increase between 11.7% and 16.9%. The effect size overall for the location (TOD variable) is however higher compared to model 3. This means that without the filter of trips to and a proximity (5000 metre) of the station, the effect on taking the train is larger. This is logical when thinking about the utility of taking the train, which is higher when a station is close by the destination or origin. This is also visible in when comparing the 700 metre and the 2000 metre buffer. The effects are, however, still comparable to the results presented before, which suggests robustness of the outcomes.

Table 11: model 4 outcomes

	Origin 700 m		Origin 2000 m		Destination 700 m		Destination 2000 m	
	Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
TOD	2.099	0.030***	1.930	0.023***	2.152	0.030***	1.972	0.023***
TOD_after	1.153	0.040***	1.169	0.029***	1.128	0.040**	1.117	0.029***

Robustness of trip characteristics

Model 3 shows to be a large improvement on model 2, where only the individual characteristics were included. The trip characteristics thus seem to make a big difference in the accuracy of the model. To examine the impact of trip characteristics more closely, a selection for important trip characteristics was made, after which the (model 3) logistic regression analysis was run again. The results can be found in Table 12 for motive and Table 13 for distance classes. Only the most used motives for train trips were used (see 4.2.1), since these are the most impactful and thus most interesting to investigate.

The results are not significant for the motive of education for any of the buffers. Furthermore, the origin 700 metre buffer does not produce any significant results after realisation of a TOD. Besides this, the results are consistent with previous results (TOD realisation has a positive impact on the chance of taking the train) and also show internal consistency (not many large differences between buffers). This supports the robustness of the outcomes. Commuting and visiting as trip motives have thus a significant positive impact on train as main mode choice.

Table 12: outcomes after selecting on different motives

		Origin 700 metre buffer		Origin 2000 metre buffer		Destination 700 metre buffer		Destination 2000 metre buffer	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
Commuting	TOD	1.876	0.047***	1.830	0.035***	1.699	0.049***	1.679	0.036***
	TOD_after	1.077	0.061	1.130	0.045**	1.162	0.063**	1.183	0.046***
Education	TOD	1.547	0.082***	1.315	0.061***	1.360	0.087***	1.172	0.064**
	TOD_after	0.971	0.119	0.45	0.081	1.063	0.123	1.020	0.084
Visiting	TOD	1.822	0.108***	1.614	0.080***	1.923	0.105***	1.890	0.078***
	TOD_after	1.205	0.140	1.279	0.099**	1.169	0.136	1.192	0.097*

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator 'TOD_after' is one the first time a TOD project is realised (year of realisation and all subsequent years) within 700 or 2000 metres of the station closest to the zip code of destination. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively.

When looking at distances, it shows that almost all outcomes are very significant ($p<0.001$) or significant ($p<0.05$) (see Table 13). There are quite some larger differences between the buffers in impact size. Contrary to results presented above, the effect size is often smaller in the 2000 metre buffer. This suggests that closeness to the station is an important predictor for taking the train when considering distance of the trip. The impact of the location is much larger than in results presented before, and it is largest for trips longer than 20.7 kilometres. The effect size of TOD after realisation is most consistent and largest for trips between 20.7 to 47 kilometres. For the 2000 metre buffer the effect is also prominent for larger trips. The distance class of 47 to 70.1 kilometres is only significant for the origin 2000 metre buffer. Trips of 31.5-47 kilometres towards a TOD location have the largest impact with a 30.2% to 38% higher chance to use the train as main mode of transportation.

Table 13: outcomes after selecting on different distance classes

		Origin 700 metre buffer		Origin 2000 metre buffer		Destination 700 metre buffer		Destination 2000 metre buffer	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
0.4-20.7 kilometres	TOD	1.488	0.060***	1.209	0.047***	1.466	0.061***	1.147	0.047**
	TOD_after	1.171	0.078**	1.106	0.058*	1.110	0.079	1.144	0.058*
20.7-31.5 kilometres	TOD	2.121	0.074***	1.790	0.055***	2.121	0.076***	1.887	0.056***
	TOD_after	1.325	0.098**	1.188	0.074**	1.338	0.099**	1.245	0.075**
31.5-47 kilometres	TOD	2.490	0.075***	2.467	0.058***	2.110	0.079***	2.274	0.060***
	TOD_after	1.194	0.100*	1.194	0.078**	1.380	0.102**	1.302	0.079**
47-70.1 kilometres	TOD	2.192	0.081***	2.218	0.061***	2.448	0.82***	2.245	0.062***
	TOD_after	1.057	0.109	1.121	0.079	0.906	0.110	1.130	0.080
70.1-400 kilometres	TOD	2.274	0.078***	2.075	0.059***	2.243	0.078***	2.176	0.059***
	TOD_after	0.986	0.105	1.213	0.076**	1.141	0.105	1.252	0.076**

Notes: The dependent variable is the logarithm of train as main mode of transport. The indicator 'TOD_after' is one the first time a TOD project is realised (year of realisation and all subsequent years) within 700 or 2000 metres of the station closest to the zip code of destination. Standard errors have a *, **, ***, 10%, 5%, 1% significance, respectively.

5. Conclusion

The research question central in this study was: *To what extent does Transit Oriented Development impact travel behaviour in the Netherlands?* In these concluding remarks the answer to this question will be formulated. This will be done by first focussing on the 3 sub questions:

1. *To which extent can Dutch station area developments be considered Transit Oriented Developments?*
2. *How do Dutch TOD projects impact mode choice to and from the location?*
3. *How well does a 2000 metre catchment area fit to measure the impact of Dutch TOD projects?*

5.1 Dutch Transit Oriented Developments

In order to assess the impact of Transit Oriented Development on travel behaviour in the Dutch context, the fit of Dutch station area developments with the notion of TOD has first been examined. This has been done through a GIS analysis where 5 dimension and 11 indicators were used to measure if the station area location could be seen as TOD. These dimensions were built upon the literature, mainly using Cervero & Kockelman (1997)'s 3 Ds in combination with the hourglass model (Brand- van Tuijen et al, 2001) and Pojani & Steads (2015) assessment of what is important in the Dutch context. This led to 17 locations in the 700 metre buffer and 28 locations in the 2000 metre buffer. There are numerous stations where the buffers overlap. This relates to Hamersma, Knoope & Zijlstra (2019), who discuss the short average distance to a train station in the Netherlands. The TOD locations are mostly located in the west of the Netherlands and almost all are within the limits of a large city. Amsterdam has the most TOD locations. Rotterdam, Den Haag and Utrecht also have multiple locations within one city. These four are also the four largest cities in the Netherlands, so this is not surprising. In total there are 397 stations in the Netherlands. This means that when considering the 2000 metre buffer, 7% of locations can be considered TOD. For the 700 metre this is 2%. These locations would be balanced in the node-place model of Bertolini (1999), the other non-TOD station locations can be classified as unbalanced and improvements on the place or the node could lead to more balanced and 'ideal' places. Most TOD projects have been realised in the last 5 years, which fits with Sun, Allan, Zou & Scrafton (2022) who note that the interest in the topic (and thus the implementation of these projects) has been on the rise.

5.2 TOD and travel behaviour

Following the logistic regression analysis, a couple of conclusions can be drawn. First and most importantly, Transit Oriented Development does have a significant impact on the chance of using the train as main mode of transportation. This is true for trips to (destination) and from (origin) TOD locations. However, a remark to be made here is that the effect is (much) smaller when compared to the effect these locations have overall. The effect size of a TOD realisation is around a 13%-14% increase in the chance of taking the train as main mode of transportation. This is a little higher for when the origin locations are TOD (after realisation), the effect size here is 16%-19%. The effect of the TOD location overall is much higher than this, with a 68%-88% increase in chance of using the train as main mode of transport for the origin location and the destination location. This would mean that the aims of increasing public transit usage (according to Dijkstra & Emmerik, 2015) is being fulfilled, but the effect is not as large as the effect of the location overall.

The large effect of the location suggests another relation between the travel behaviour and TOD locations. The results presented here suggests that the location chosen for a Transit Oriented Development are places where the station (node in the node-place model of Bertolini, 1999) is already strong and where the train is already relatively often chosen as main mode of transport. The distribution of the locations throughout the Netherlands (mainly in larger cities and the Randstad) also points to this. In cities, development space is scarce and because of the Ladder of sustainable urbanisation, these places are extra popular in when developing projects. This is in line with the Land-use transport feedback cycle (Wegener & Füst, 1999). The high accessibility of the location creates a location that is attractive for developments.

The impact of trip characteristics and individual characteristics on travel behaviour is significant and their inclusion improve the model so that it fits the data much better. This means that it is relevant to look at these variables when considering travel behaviour. The effect size of individual characteristics remains stable throughout the different buffers. Overall, a higher education level increases the chance of taking the train, as does income. A couple with kids has the largest effect size out of household composition with to one person households as reference and the more cars a household owns, the less likely they are to take the train. This difference in individual characteristic groups makes sense when considering the different theories on explaining travel behaviour. Individual and group characteristics do make a difference in behaviour choices, in line with Joh, Nguyen & Boarnet (2012). The inclusion of trip characteristics, however, improves the model the most. This fits with utility theory and Hägerstands time-space constraints. The results of TOD realisation that the inclusion of individual and trip characteristics in the model yielded are comparable to the models without them (TOD realisation has a significant and positive effect on using the train as main mode of transportation), but the effect size is different.

For the motive of education when travelling to or from a TOD location there is no significant effect on the mode of transport. Commuting choices are, opposite to what Hamersma, Knoope & Zeilstra (2019) predict, significantly impacted by TOD realisation. For the motives of visiting and commuting, the 2000 metre buffer has a larger effect size than the 700 metre buffer. When considering the distance of the trip, the origin location being a TOD has a significant effect on trips between 20.7 and 47 kilometres (24%-38%). For the destination being TOD, this effect size is much smaller (18%-32%). Remarkably, the effect is not or little significant for longer trips (47+ kilometres). This could be explained by turning to the hourglass model (Brand- van Tuijen et al, 2001) and the space-time constraints of Hägerstrand (1970). The accessibility of functions is influenced by the macro level, which encompasses the network. For longer trips the connectivity of the network and the accessibility of functions through the train network might not be as well and flexible in comparison to other modes of transport. For example, longer travel times or multiple transfers might be needed to get to the destination for longer trips. This leads to a decrease in utility of using the train for longer journeys. In addition, longer trips might use multiple modes in a chain mobility. The train might not fit well into this chain, because it often requires more fragments and different mobilities by including last and first mile transport. This can be interesting to investigate in future research.

The impact of the TOD location on travel behaviour diminishes for the larger catchment area (e.g., the chance of taking the train as main mode of transportation). This is in line with Ibraeva, Correia, Silva & Antunes (2020) who conclude that station proximity is the most influential factor on mode choice. However, the difference in effect size is not big and the impact of the 2000 metre buffer is still significant. This means that the extended catchment area is valid to use in the Dutch context, as suggested by Lee, Choi & Leem (2014), Pojani & Stead (2015) and van Lierop, Maat & El-Geneidy (2017). A notable exception is the effect of trips to or from the 2000 metre TOD buffer for the motive of commuting. Here, the effect size of the 2000 metre buffer is larger after the TOD realisation, when compared to the 700 metre buffer.

When only considering trips that have a TOD location as an origin and/or a destination the results strongly enhance the argument for using a 2000 metre catchment area. For these trips, the effect of the TOD realisation is (much) larger than the location overall. These effects are only significant in the 2000 metre buffer. This means that the relative effect of TOD realisation in the 2000 metre buffer are larger when compared to similar trips instead of all trips or trips in the 5000 metre buffer. Without the filter of trips to or from a 5000 metre buffer, the effect of TOD realisation on taking the train is larger for the 700 metre buffer.

5.3 Recommendations

Before turning to the final remarks of this research, it is useful to nuance the outcomes to some extent. First off, this research was conducted in a total of 5 months, which severely limited the possible scope. There are many more interesting aspects of Transit Oriented Development that did not get to be the focus of the study. Here, the limitations of the research will be shortly discussed, including the argumentation of certain choices and ideas for further research.

There are two prominent limitations of this study that should be taken into consideration when examining the results. One of the largest problems in this research is that of determining the realisation year of TOD projects and determining if the development was a TOD project. This realisation year is based on the construction year of buildings in the buffer zone and by looking at google earth images of the buffer zone to see when projects were being developed. When in doubt, policy documents were used to investigate the year of realisation and the scale of a project further. The problem that occurred consisted of two parts. First, for some buffers multiple projects were realised between 2010-2019. Some of these were only housing, some more mixed use and they were all in different distances to the station. Which of these projects would qualify as the TOD enhancing project was not entirely clear in every case. Especially because the indicators were scored on the current situation. The difference in TOD before and after the project realisation was not measured because of this. This assumes that the project was the reason of the current TOD scores. In the cases with multiple developments, two factors were used to determine which project would be used. The proximity of the project to the station and the most recent project. These two factors determined the realisation year for that station area.

The second problem that occurred relating to the realisation year is that development projects take a long time to finish, often doing so in separate phases. In some cases, the first buildings were finished years before the last. In addition, some might be realised in November or December. The year of realisation might not correlate to the data of trips and trips from January in a year can be wrongly assigned to TOD_after for these projects. The classification used suggests that there was one TOD project realised which sprung up on January 1st, which is not the case in real life.

To tackle the realisation year problem and to link the research to policy impacts, it might be interesting to link and compare the TOD projects to the 'Nieuwe Sleutelprojecten' or other station area improvement projects. These focus on developments of the station (versus the station area which was the focus in this study) and had clearly set realisation dates. Another solution might be to select a smaller number of development cases that are TOD projects as established by professionals (for example in line with Pojani & Stead, 2015).

Another way of tackling this problem is by taking an area based (cross-sectional) approach instead of the project-based approach taken in this study. This might be an interesting way to consider TOD indicators and travel behaviour. Instead of using and scoring buffers, the postcode areas could also be scored on TOD indicators (similar to what Singh et al., 2014 did). The impact of separate indicators of TOD on travel behaviour could also be further explored. This could be done by using a TOD index. An important aspect to watch out for in doing this is a degree of overlap between the dimensions. The database created in this study can be used for this purpose. There already is some research on this topic (for example see Lyu, Bertolini & Pfeffer, 2016 about what indicators create a TOD), but a clear link with travel behaviour based on quantitative data is still missing.

A shortcoming in this area-based approach is that the trips in the OViN/ODiN database were organised on 4-digit postcode level. There are a few complications that this aggregated data might have created. First, the postcode areas were all assigned to a station, this was the station that was closest to the centre of the postcode area. Some areas, however, are oddly shaped or relatively large, which means some of the area can fall out of the buffer, but the trips made are still counted as belonging to the buffer. In addition, this assignment to the closest station might not be an accurate representation of travel choices made in the real world due to the definition of closeness (the distance was calculated as the crow flies, not considering roads). This leads to an oversimplification of the data and an overestimation of trips assigned to a buffer. Data on 6-digit postcode level (the smallest in the

Netherlands) would have led to more accurate results and a better representation of reality. This data was unfortunately not available. The method of linking trips to the postcode area is nevertheless in line with utility theory and it is the most logical way to use the available data. In addition, this area-based approach does not fit with a DID research design, since the time variance is harder to account for.

Another limitation has to do with buffers. In this research, every buffer was scored independently on the presence of the TOD indicators in the buffer zone. This led to some occasions where, around the same station, the 700 metre buffer zone did not meet the criteria but the 2000 metre buffer zone did. The question occurs that if the close surroundings of the station do not fulfil the demands of TOD, is it logical that the 2000 metre buffer does qualify as a 'real' TOD? In this study, this extent of catchment area for mode choices of interest. Because of this, the indicators were scored based on presence in the buffer at hand. Therefore, in this study, it is relevant to include 2000 metre buffers where the direct proximity of the station did not suffice. In addition, the buffer areas (700 metre and 2000 metre) in this study are based on a literature assessment.

Another way to look at these catchment areas for TOD might be to examine the exact extent of this catchment area (in line with what Cheshire, Hilber, Montebruno & Sanchis-Guarner, 2018 did for shopping areas). Furthermore, looking at the locations that qualify for TOD in the 700 metre buffers and compare these with trips to or from a buffer of 2000 metre around the same station can also be interesting. This might tackle the question of catchment area for the same station area better. In addition, the conditions for using a larger catchment area can be a focus of further research.

Another point of interest that could not be investigated for this study was the role of other public transport. In the literature, many distinct types of TODs come forward, centred around bicycle points, metro stations or bus stops. Comparing these types of TODs, their effect on travel behaviour and their applicability in the Dutch context might also be interesting to look into. The role of public transport and the built environment in chain mobility and first and last mile choices can be another way of including more than one mode in TOD research.

A multinominal logistic regression could have been compelling to look into how shifts between mode choices occur and if TOD really promotes public transport choices at the expense of car usage, as is often claimed. In this study, this was beyond the scope and focus. However, this study can be a good basis for this further research.

In addition, this research was set in the Dutch context. This is for a couple of reasons. Not only is the Dutch Railways an organisation based in the Netherlands, but the available data was also mostly focussed on the Netherlands. It could be interesting for further research to compare this data with other countries and contexts, especially when comparing the different buffer zones to see if the 2000 metre buffer around TOD stations can also be applied in other countries.

Finally, the field of spatial planning is always moving, in theory and in practice. Many station area development are currently taking place or have been recently finished. A repetition of this study in 5-10 years might give a better understanding of long-term impacts of TOD projects on travel behaviour.

5.4 Final remarks

These sub question lead to the answer to the research question: *To what extent does Transit Oriented Development impact travel behaviour in the Netherlands?* The realisation of TOD projects does impact travel behaviour in Dutch Transit Oriented Development projects. There are numerous TOD projects, and many more currently under development. The stations where these developments take place are mostly located in four big cities in the Randstad. From and to these locations the chance of taking the train (over other main modes of transport) is significantly higher. This is especially the case when comparing trips that have their origin or destination in a TOD area in combination with a destination or origin in a 2000 metre buffer around the TOD stations. For these cases, the realisation of the TOD project has a significant and large positive impact on the chance of taking the train as main mode of transportation. For many of the other results however, the impact of the location overall is more important than the realisation of the TOD project. From this, the conclusion can be drawn that the TOD realisation itself, although positive, is not the most important factor in travel behaviour. This could be explained by these locations being attractive for development because of their connectivity. This should be further explored in future research.

The inclusion of the 2000 metre buffer offers good insight into the Dutch context. The effect size is overall a bit lower compared to the 700 metre buffer. However, the results are almost always significant. This suggests that, in line with Lee, Choi & Leem (2014) and van Lierop, Maat & El-Geneidy (2017), a 2000 metre buffer is a good inclusion when considering Dutch TOD projects and their impacts. This is especially the case for the motives of visiting and commuting, for which the 2000 metre buffer has a larger effect. This suggests that developments that have to do with these motives (such as offices), do not have to be close to the station to influence mode choices.

The inclusion of individual and trip variables proved to lead to a better model and thus the built environment cannot be seen as the only factor on influencing travel behaviour, as suggested by Ewing & Cervero (2010). In fact, for some trips the effect size is different than for others (for example for commuting trips a 2000 metre buffer produces a larger effect). This suggests that TOD can be more effective for some trips compared to others and different target groups or wanted travel behaviour changes might need different approaches. In line with Handy, Coa & Mokhtarian (2005), Transit Oriented Development and geography are important factors that should be included when looking at travel behaviour. Transit Oriented Development is thus of influence of travel behaviour, and it is a great way to stimulate sustainable travel modes. However, it should not be seen as a cure-for-all and must be considered in a complicated web of institutional, individual and contextual influences. These conclusions can be used for further research but also as an argument for Transit Oriented Development projects to be realised in the discussion of where to build when space is scarce.

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Appendix index

Appendix 1: GIS steps
Appendix 2: Syntax
Appendix 3: Excel databases TOD locations
Appendix 4: Correlation and VIF outcomes
Appendix 5: Descriptive output
Appendix 6: Table full output logistic regression analysis

Appendix 1

The GIS analysis was shortly discussed in paragraph 3.3.1 and 3.4.1. In this appendix, the steps taken are presented more in depth to increase the reliability of the research.

Creating the buffers

The layers ‘Stations NS’ & ‘Prorail sporen’ are both put into the map to see if the data presented is adequate. The data corresponds so the ‘Stations NS’ data can be used to represent all stations.

Select by location-> intersect with ‘landsgrens (CBS)’ -> make layer from selected feature -> export feature under the name ‘Stations NL’

Analysis->tools->buffer->input feature ‘Stations NL’ distance 700 metre -> buffer 700

Analysis->tools->buffer->input feature ‘Stations NL’ distance 2000 metre -> buffer 2000

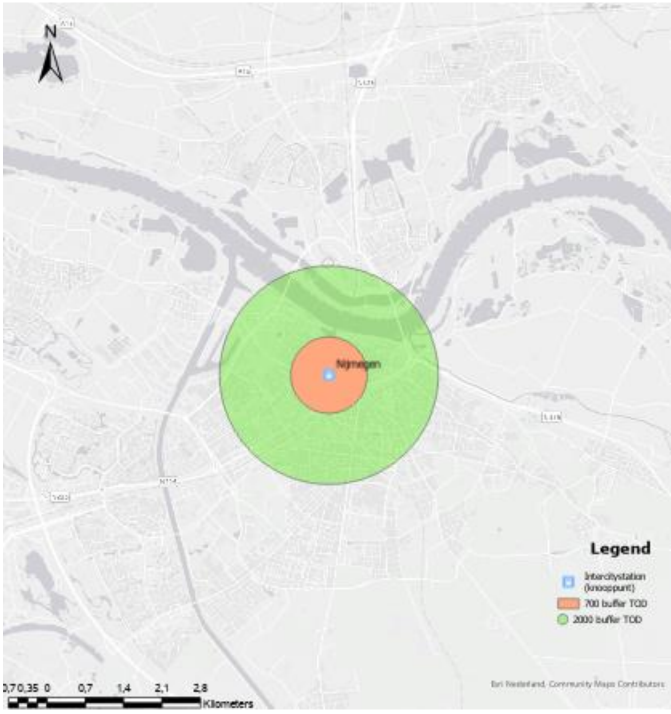

Figure 14: example- 2 buffers around station Nijmegen

Selecting on development

Import ‘ruimtelijke plannen- bestemmingsplangebied’ layer -> select by attribute -> select where STATUS is equal to onherroepelijk AND TYPEPLAN is equal to bestemmingsplan AND PLANDATUM is after 01-01-2009 AND PLANDATUM is before 01-01-2020 -> create layer from selected feature -> select by location -> input feature ‘bestemmingsplangebied_selection’, relationship completely within, selecting feature ‘buffer 700’. Repeat last step for ‘buffer 2000’. -> create layer from selected feature -> ‘bestemmingsplangebied_correct’

AND

Import layer ‘BAG januari 2022’ -> select by attribute -> select where bouwjaar is greater than 2008 and is less than 2020 AND aantal verblijfsobjecten is greater than 0 -> select by location -> input feature ‘BAG_Selection’, relationship completely within, selecting feature ‘buffer 700’. Repeat last step for ‘buffer 2000’ -> create layer from selected feature -> ‘bouwjaar_correct’

Select by location -> input feature ‘buffer 700’, relationship contains, selecting feature ‘bestemmingsplandgebied_correct’ -> add field bestemmingsplan-> calculate field, field name=1 (resulting in all selections, buffers with a bestemmingsplangebied finalised in 2009 to 2020 in them to be 1) -> switch selection -> calculate field, field name =0. Repeat for 2000 buffer.Select by location -> input feature ‘buffer 700’, relationship contains, selecting feature ‘bouwjaar_correct’ -> add field nieuwpland-> calculate field, field name=1 (resulting in all selections, buffers with a building built between 2009 and 2020 in them to be 1) -> switch selection -> calculate field, field name =0. Repeat for 2000 buffer. Select by attribute -> bestemmingsplan=1 AND nieuwpand=1 -> create layer form selected feature -> 'buffer700_dev'. Repeat for 200 buffer (buffer2000_dev). Following this, the different indicators for the 5 dimensions are measured. This is done in subgroups per dimension, since every location should have at least 1 positive indicator for each dimension. This means that with every dimension operationalised, it is expected that less station area locations are taken along for the next consideration.

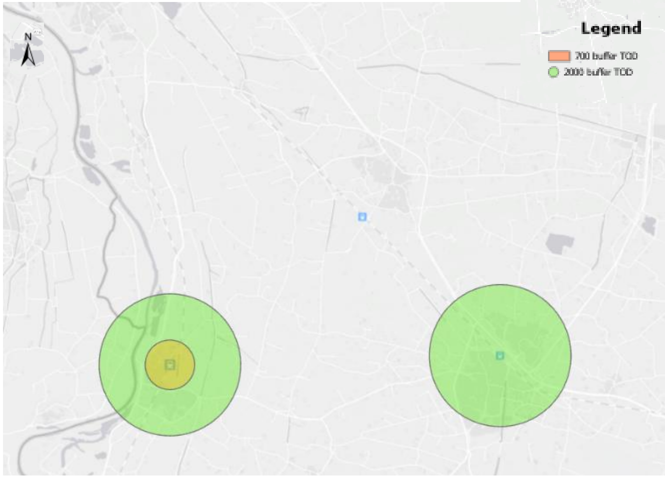

Figure 15: example- selection resulting in less buffers

Density selection
First, density is measured. This is done by using the 'verblijfsobject' layer from the BAG (januari 2020) to ensure that the analysis is done for the situation in 2019) and selecting by attribute the function of the address on either commercial (kantoor,logies, gezondheidsfuctie, bijeenkomstfunctie, onderwijsfunctie, industrie or winkel) or residential (wonen). The items in these two layers are then summerized per buffer using summarize within in. Then, a field is calculated so each buffer has a new field with in it the number of addresses divided by the surface of the buffer. This creates the density of addresses in the buffer. By applying 'select by location' when the number of addresses is higher than 2000 (1=yes, 0=no), the two indicators are created. Buffers where both indicators are 0 are not taken along to the next analysis. It is worth noting that the number of commercial enterprises per square km were in no location higher than 2000/sqkm, whith the highest density being 917/sqkm in the 700m buffer around Rotterdam central.

Accessibility selection
Location accessibility's indicators are measured by using the 'NS station' layer in arcgis. In this layers attribute table, the information on the hierarchical score and number of platforms are available. This will be used to select by attribute (TYPE is not stopstation for hierarchical score and AANTAL SPOREN is greater than 2 for number of platforms) and score the indicators. The station areas where none of the indicators are scored with 1 (=yes) will not be considered in the following analysis.

Diversity selection
For diversity, entropy is calculated using Bestand BodemGebruik (BBG) 2015. Although the data is a little bit older, it is the most useful to calculate entropy, which is widely accepted as the way to measure land use diversity. Other data on land use (for example BAG) is point based, which cannot be used for entropy calculations, since land area is an essential part in this. Since the interest is mostly in the land use types that have to do with urban functions, these (20-24 in the BBG) are selected to calculate entropy. To make sure this does not produce very different results, a control analysis is done with all the land use types. The outcome of both analysis produce the same station areas that are diverse (entropy larger than 0.5), but the one using only urban functions leaves out 3 additional station areas in the 2000 buffer. For the 700 buffer, only one station area is dismissed in the analysis using the urban land use. To calculate entropy, the next steps were conducted, based on Voukenas (2021):

- Selecting 20-24 in BBG
- Intersecting buffers and land use layer
- Dissolving based on land use and station area
- Calculate area of each land use in each buffer
- Calculating the area of each buffer and joining the layers
- Calculating the number of different land uses within each buffer (max 5) (summary statistics tool)

- Joining all the information in one layer
- Calculating entropy using this formula : (“area” / “_N_area”)*ln((“area” / “_N_area”)). Following by the analysis tool ‘cell statistics’ to determine the count and sum. Finally a new field is added with the field calculator: -“sum”/ln(“count”). This is the entropy for each buffer.

Proximity selection
The proximity dimension has 3 indicators, the first (density of ov stops) will be examined by using ARCGIS PRO. The number of ov stops will be calculated using ‘9292ov_stops_januari_2016’ for each buffer (intersect, summary statistics). Following this, the field will be calculated by using the formula ‘count bus stops/ area buffer >= 10 -> 1’. 10 is the average number of bus stops per km2 in urban areas, whereas the national average is 1.12 busstops per km2. The ‘Ov bike rental available’ will be done by using data from the NS on the services on each station. It is important to note that almost all (exept Rotterdam Zuid) have some form of OV bike rental, although the number of bikes available and kind of services vary greatly. The ‘length of bikepath or sidewalk per squere km’ is measured by using ‘BRT wegdeel vlak’ and selecting by attribute on hoofdgebuiker (fietsers, bromfietsers or voetganger), intersecting and calculating the length (m) of the roads per square km per buffer zone. The Dutch average of 3.6 km biking road per km2 is used as a threshold. All locations pass this threshold. This means that all station areas will pass this selection round.

Design selection
For the design dimension, the parking norm is measured by looking at the relevant policy documents and looking at a single housing residential norm. If the area has multiple ‘bestemmingsplannen’, the average is calculated and used. The parking norm for housing is considered. For the station square indicator, google earth will be used to establish the presence of a public square. One side of the station is enough to be considered. However, there must be public space to be enjoyed (so not only bicycle storage, or private terraces), such as green spaces or public benches. This will be done by hand for every location so this is the last dimension to be considered.

	2000 m buffers	700 m buffers
No selection	397	397
After selection development	215	83
After selection density	46	25
After selection location accessibility	35	19
After selection diversity	31	18
After selection proximity	31	18
After selection design	28	17

The year the development finished is determined by looking at google earth historical maps, and large changes are located. This is verified by looking at the layer made in the first step of this analysis, with the building years of the buildings for each buffer. A sidenote to be made by this, is that there may have been multiple developments in one bufferzone. To determine the used year of realisation, the closest development near the station and/or the largest, comprehensive development in the area is used.
Lastly, the postcodes (postcode 4 level) are imported and selected by location (intersect) with the two different buffers to determine what postcodes will be taken along as origin or destinations in the next part of the analysis using OVIM/ODIN. Here, the sidenote must be made that there are only a few postcodeareas that are completely within the buffers. For some buffers there are none (especially in the 700m buffer, there were only 2 across all the buffers), which would mean these locations could not be considered. This is undesirable so therefore the intersect is done with all the postcode areas. As a consequence, the number of travellers can be travelling just outside the buffer, since this is at postcode level.
Selection postcode areas that are within 5000 m of the station (1st step otherwise some postcode areas that are within 5000 m but their centre is not are not taken along)-> feature to point (centre is generated) -> near -> outcome: field with the distance from the centre of the postcode area to the nearest station.

Appendix 2

selection 5000 buffers

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection TOD trips

```
USE ALL.
COMPUTE filter_$=((vert_b0700_tod = 1 OR vert_b2000_tod = 1) OR (aank_b0700_tod
  = 1 OR aank_b2000_tod = 1)).
VARIABLE LABELS filter_$ '(vert_b0700_tod_after = 1 OR vert_b2000_tod_after = 1 ) AND '+
  '(aank_b0700_tod_after = 1 OR aank_b2000_tod_after = 1) (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

700 orig model 1

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER ver_b0700_tod_before vert_b0700_tod_after jaar maand
 /CONTRAST (jaar)=Indicator
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 orig model 2

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER ver_b0700_tod_before vert_b0700_tod_after jaar maand geslacht leeftijd opleiding_cat
  hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=indicator
 /CONTRAST (geslacht)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator(1)
 /CONTRAST (hhsamenstelling_cat)=Indicator(1)
 /CONTRAST (inkomen_cat)=Indicator(1)
 /CONTRAST (autobezit_cat)=Indicator(1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 orig model 3

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER ver_b0700_tod_before vert_b0700_tod_after jaar maand afstkls kmotiefv leeftijd geslacht
  opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (kmotiefv)=Indicator (1)
 /CONTRAST (afstkls)=Indicator (1)
 /CONTRAST (geslacht)=indicator(1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
```

```
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 orig model 4

```
FILTER OFF.
USE ALL.
EXECUTE.
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER ver_b0700_tod_before vert_b0700_tod_after jaar maand afstkls kmotiefv leeftijd geslacht
    opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
  /CONTRAST (jaar)=Indicator
  /CONTRAST (kmotiefv)=Indicator (1)
  /CONTRAST (afstkls)=Indicator (1)
  /CONTRAST (geslacht)=indicator(1)
  /CONTRAST (hhsamenstelling_cat)=Indicator (1)
  /CONTRAST (opleiding_cat)=Indicator (1)
  /CONTRAST (autobezit_cat)=Indicator (1)
  /CONTRAST (inkomen_cat)=Indicator (1)
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 orig model 1

```
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER ver_b2000_tod_before vert_b2000_tod_after jaar maand
  /CONTRAST (jaar)=Indicator
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 orig model 2

```
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER ver_b2000_tod_before vert_b2000_tod_after jaar maand leeftijd geslacht opleiding_cat
    hhsamenstelling_cat inkomen_cat autobezit_cat
  /CONTRAST (jaar)=Indicator
  /CONTRAST (leeftijd_cat)=Indicator (1)
  /CONTRAST (hhsamenstelling_cat)=Indicator (1)
  /CONTRAST (opleiding_cat)=Indicator (1)
  /CONTRAST (autobezit_cat)=Indicator (1)
  /CONTRAST (inkomen_cat)=Indicator (1)
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 orig model 3

```
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER ver_b2000_tod_before vert_b2000_tod_after jaar maand afstkls kmotiefv leeftijd geslacht
    opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
  /CONTRAST (jaar)=Indicator
  /CONTRAST (kmotiefv)=Indicator (1)
  /CONTRAST (afstkls)=Indicator (1)
  /CONTRAST (leeftijd_cat)=Indicator (1)
```

```
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 orig model 4

```
FILTER OFF.
USE ALL.
EXECUTE.
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER ver_b2000_tod_before vert_b2000_tod_after jaar maand afstkls kmotiefv leeftijd geslacht
  opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (kmotiefv)=Indicator (1)
 /CONTRAST (afstkls)=Indicator (1)
 /CONTRAST (leeftijd_cat)=Indicator (1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 dest model 1

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b0700_tod_before aank_b0700_tod_after jaar maand
 /CONTRAST (jaar)=Indicator
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 dest model 2

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b0700_tod_before aank_b0700_tod_after jaar maand leeftijd geslacht opleiding_cat
  hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (leeftijd_cat)=Indicator (1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 dest model 3

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b0700_tod_before aank_b0700_tod_after jaar maand afstkls kmotiefv leeftijd
geslacht
```

```
  opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (kmotiefv)=Indicator (1)
 /CONTRAST (afstkls)=Indicator (1)
 /CONTRAST (leeftijd_cat)=Indicator (1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

700 dest model 4

```
USE ALL.
EXECUTE.
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b0700_tod_before aank_b0700_tod_after jaar maand afstkls kmotiefv leeftijd
geslacht
  opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (kmotiefv)=Indicator (1)
 /CONTRAST (afstkls)=Indicator (1)
 /CONTRAST (leeftijd_cat)=Indicator (1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 dest model 1

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b2000_tod_before aank_b2000_tod_after jaar maand
 /CONTRAST (jaar)=Indicator
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 dest model 2

```
LOGISTIC REGRESSION VARIABLES hvm_trein
 /METHOD=ENTER aank_b2000_tod_before aank_b2000_tod_after jaar maand leeftijd geslacht opleiding_cat
  hhsamenstelling_cat inkomen_cat autobezit_cat
 /CONTRAST (jaar)=Indicator
 /CONTRAST (leeftijd_cat)=Indicator (1)
 /CONTRAST (hhsamenstelling_cat)=Indicator (1)
 /CONTRAST (opleiding_cat)=Indicator (1)
 /CONTRAST (autobezit_cat)=Indicator (1)
 /CONTRAST (inkomen_cat)=Indicator (1)
 /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
 /CLASSPLOT
 /PRINT=GOODFIT CI(95)
 /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 dest model 3

```
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER aank_b2000_tod_before aank_b2000_tod_after jaar maand afstkls kmotiefv leeftijd
geslacht
    opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
  /CONTRAST (jaar)=Indicator
  /CONTRAST (kmotiefv)=Indicator (1)
  /CONTRAST (afstkls)=Indicator (1)
  /CONTRAST (leeftijd_cat)=Indicator (1)
  /CONTRAST (hhsamenstelling_cat)=Indicator (1)
  /CONTRAST (opleiding_cat)=Indicator (1)
  /CONTRAST (autobezit_cat)=Indicator (1)
  /CONTRAST (inkomen_cat)=Indicator (1)
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

2000 dest model 4

```
USE ALL.
EXECUTE.
LOGISTIC REGRESSION VARIABLES hvm_trein
  /METHOD=ENTER aank_b2000_tod_before aank_b2000_tod_after jaar maand afstkls kmotiefv leeftijd
geslacht
    opleiding_cat hhsamenstelling_cat inkomen_cat autobezit_cat
  /CONTRAST (jaar)=Indicator
  /CONTRAST (kmotiefv)=Indicator (1)
  /CONTRAST (afstkls)=Indicator (1)
  /CONTRAST (leeftijd_cat)=Indicator (1)
  /CONTRAST (hhsamenstelling_cat)=Indicator (1)
  /CONTRAST (opleiding_cat)=Indicator (1)
  /CONTRAST (autobezit_cat)=Indicator (1)
  /CONTRAST (inkomen_cat)=Indicator (1)
  /SAVE=PRED PGROUP COOK LEVER DFBETA ZRESID
  /CLASSPLOT
  /PRINT=GOODFIT CI(95)
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
```

selection motive commuting

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=1).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=1 '+
    '(FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection motive education

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=5).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=5 '+
    '(FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
```

```
EXECUTE.
```

selection motive visiting

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=6).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND kmotiefv=6 '+
  '(FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection distanceclass 0-20

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=0).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=0 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection distanceclass 20-40

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=1).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection distanceclass 40-60

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=2).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=2 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection distanceclass 60-80

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=3).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=3 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

selection distanceclass 80-100

```
USE ALL.
COMPUTE filter_$=(vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=4).
VARIABLE LABELS filter_$ 'vert_b5000_station = 1 AND aank_b5000_station = 1 AND afstkls=4 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
```

700 metre buffer

OBJECTID_	Code	Name	new zonal plan	new real estate buildings	commercial density	residential density	entophy	parkeernorm is lower than 1	station square	number of tracks	Type	bus stop density	bike and footpath density	ov bike rental available	realisation year
1	AMR	Alkmaar	1	1	174	2125	1	1	1	5	Knooppuntintercitystation	15	11437	1	2015
2	ASA	Amsterdam Amstel	1	1	164	4016	1	1	1	2	Intercitystation	17	21717	1	2019
3	ASD	Amsterdam Centraal	1	1	948	2832	1	1	1	31	Megastation	41	15559	1	2012
4	APD	Apeldoorn	1	1	194	2272	1	1	1	3	Knooppuntintercitystation	13	9847	1	2019
5	ASB	Amsterdam Bijlmer Aren	1	1	516	2116	1	1	1	6	Knooppuntstoptreinstation	18	20950	1	2018
6	ALM	Almere Centrum	1	1	362	2196	1	1	1	4	Knooppuntintercitystation	17	23068	1	2010
7	BD	Breda	1	1	265	2196	1	1	1	7	Knooppuntintercitystation	19	14571	1	2012
8	EHS	eindhoven strijp S	1	1	310	2408	1	1	0	4	stoptreinstation	5	9295	1	2019
9	HTN	Houten	1	1	142	2150	1	1	0	2	Knooppuntstoptreinstation	4	12104	1	2018
10	GN	Groningen	1	1	374	3803	1	1	1	13	Knooppuntintercitystation	31	10926	1	2016
11	HVS	Hilversum	1	1	491	3374	1	1	1	5	Knooppuntintercitystation	12	10187	1	2012
12	NM	Nijmegen	1	1	374	3412	1	1	1	8	Knooppuntintercitystation	20	15106	1	2017
13	RTD	Rotterdam Centraal	1	1	917	4420	1	1	1	13	Megastation	30	12840	1	2017
14	TB	Tilburg	1	1	552	3724	1	1	1	3	Knooppuntintercitystation	19	13435	1	2018
15	UTVR	Utrecht Vaartsche Rijn	1	1	364	4296	1	1	1	4	Knooppuntstoptreinstation	12	15132	1	2016
16	UT	Utrecht Centraal	1	1	793	2114	1	1	1	16	Megastation	46	17644	1	2017
17	VNDC	Veenendaal Centrum	1	1	154	2374	1	1	1	2	Knooppuntstoptreinstation	12	11668	1	2018

2000 metre buffer

OBJECTID_	Code	Name	new zonal plan	new real estate buildings	commercial density	residential density	entophy >0.	parkeernorm is lower than 1	station square	number of tracks	Type	bus stop density	bike and footpath density	ov bike rental available	realisation year
1	RAI	Amsterdam RAI	1	1	281	3955	1	1	0	4	Stoptreinstation	14	12268	1	2018
2	ASA	Amsterdam Amstel	1	1	335	5425	1	1	1	2	Intercitystation	16	14147	1	2019
3	ASD	Amsterdam Centraal	1	1	795	5505	1	1	1	31	Megastation	20	10270	1	2012
4	ASS	Amsterdam Sloterdijk	1	1	176	2126	1	1	0	10	Knooppuntintercitystation	12	11396	1	2017
5	ASDM	Amsterdam Muiderpoort	1	1	345	5210	1	1	0	4	Stoptreinstation	17	15784	1	2018
6	ASDZ	Amsterdam Zuid	1	1	311	3767	1	1	1	4	Intercitystation	17	13691	1	2018
7	BD	Breda	1	1	245	2191	1	1	1	7	Knooppuntintercitystation	10	11393	1	2012
8	DT	Delft	1	1	179	3263	1	1	0	2	Knooppuntintercitystation	14	11670	1	2018
9	EHS	Eindhoven Strijp-S	1	1	196	2356	1	1	0	4	Stoptreinstation	8	11666	1	2016
10	EHV	Eindhoven Centraal	1	1	298	2761	1	1	1	6	Megastation	11	11873	1	2016
11	ES	Enschede	1	1	234	2478	1	1	1	5	Knooppuntintercitystation	10	5955	1	2011
12	GERP	Groningen Europapark	1	1	213	2121	1	1	1	4	Stoptreinstation	15	8071	1	2018
13	GN	Groningen	1	1	294	3486	1	1	1	13	Knooppuntintercitystation	16	11746	1	2018
14	GV	Den Haag HS	1	1	523	5263	1	1	1	5	Knooppuntintercitystation	21	10412	1	2018
15	GVC	Den Haag Centraal	1	1	513	4471	1	1	0	10	Megastation	20	12638	1	2017
16	LAA	Den Haag Laan v NOI	1	1	284	3607	1	1	0	4	Knooppuntstoptreinstation	18	13872	1	2012
17	MT	Maastricht	1	1	247	2207	1	1	1	8	Knooppuntintercitystation	13	9410	1	2019
18	NM	Nijmegen	1	1	260	2386	1	1	1	8	Knooppuntintercitystation	10	7907	1	2017
19	RSW	Rijswijk	1	1	133	2508	1	1	1	4	Stoptreinstation	10	16915	1	2012
20	RTA	Rotterdam Alexander	1	1	196	2689	1	1	1	2	Intercitystation	9	12944	1	2012
21	RTB	Rotterdam Blaak	1	1	853	5224	1	1	1	4	Stoptreinstation	19	12161	1	2014
22	RTD	Rotterdam Centraal	1	1	720	5226	1	1	1	13	Megastation	19	13903	1	2014
23	RTZ	Rotterdam Zuid	1	1	402	3183	1	1	0	4	Stoptreinstation	11	8624	0	2019
24	SDM	Schiedam Centrum	1	1	320	2413	1	1	0	4	Stoptreinstation	10	10568	1	2019
25	TB	Tilburg	1	1	268	3417	1	1	1	3	Knooppuntintercitystation	11	7927	1	2016
26	UTVR	Utrecht Vaartsche Rijn	1	1	456	3536	1	1	0	4	Knooppuntstoptreinstation	17	12831	1	2016
27	UTO	Utrecht Overvecht	1	1	274	3288	1	1	1	3	Knooppuntstoptreinstation	11	10427	1	2015
28	UT	Utrecht Centraal	1	1	546	4380	1	1	1	16	Megastation	17	11111	1	2017

Appendix 4

Correlations												
		Distance	Motive	Age	Education level	Household composition	Income	Number of cars in household	vert_b0700 tod_after	vert_b2000 tod_after	aank_b0700 tod_after	aank_b2000 tod_after
Distance	Pearson Correlation	1	-,124**	,038**	,087**	-,033**	,087**	,063**	,024**	,019**	,023**	,019**
	Sig. (2-tailed)		,000	,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1067602	1067602	1067602	911148	1067602	1061007	1067042	1067602	1067602	1067602	1067602
Motive	Pearson Correlation	-,124**	1	-,050**	-,020**	,051**	-,051**	-,009**	-,012**	-,021**	-,015**	-,025**
	Sig. (2-tailed)	,000		,000	,000	,000	,000	,000	,000	,000	,000	,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067795	1067795	1067795	1067795
Age	Pearson Correlation	,038**	-,050**	1	-,047**	-,448**	,066**	-,128**	-,014**	-,022**	-,014**	-,022**
	Sig. (2-tailed)	,000	,000		,000	,000	,000	,000	,000	,000	,000	,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067795	1067795	1067795	1067795
Education level	Pearson Correlation	,087**	-,020**	-,047**	1	,002	,252**	,059**	,054**	,103**	,054**	,103**
	Sig. (2-tailed)	,000	,000	,000		,116	,000	,000	,000	,000	,000	,000
	N	911148	911339	911339	911339	911339	905906	910942	911339	911339	911339	911339
Household composition	Pearson Correlation	-,033**	,051**	-,448**	,002	1	-,001	,285**	-,030**	-,056**	-,030**	-,056**
	Sig. (2-tailed)	,000	,000	,000	,116		,535	,000	,000	,000	,000	,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067795	1067795	1067795	1067795
Income	Pearson Correlation	,087**	-,051**	,066**	,252**	-,001	1	,335**	,010**	,016**	,010**	,016**
	Sig. (2-tailed)	,000	,000	,000	,000	,535		,000	,000	,000	,000	,000
	N	1061007	1061199	1061199	905906	1061199	1061199	1060670	1061199	1061199	1061199	1061199
Cars in household	Pearson Correlation	,063**	-,009**	-,128**	,059**	,285**	,335**	1	-,078**	-,139**	-,078**	-,139**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000		,000	,000	,000	,000
	N	1067042	1067235	1067235	910942	1067235	1060670	1067235	1067235	1067235	1067235	1067235

vert_b0700 tod_after	Pearson Correlation	,024**	-,012**	-,014**	,054**	-,030**	,010**	-,078**	1	,326**	,421**	,197**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000		,000	,000	,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067818	1067818	1067818	1067818
vert_b2000 tod_after	Pearson Correlation	,019**	-,021**	-,022**	,103**	-,056**	,016**	-,139**	,326**	1	,198**	,595**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000		,000	,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067818	1067818	1067818	1067818
aank_b0700 tod_after	Pearson Correlation	,023**	-,015**	-,014**	,054**	-,030**	,010**	-,078**	,421**	,198**	1	,326**
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000		,000
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067818	1067818	1067818	1067818
aank_b2000 tod_after	Pearson Correlation	,019**	-,025**	-,022**	,103**	-,056**	,016**	-,139**	,197**	,595**	,326**	1
	Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	,000	,000	,000	,000	
	N	1067602	1067795	1067795	911339	1067795	1061199	1067235	1067818	1067818	1067818	1067818

**. Correlation is significant at the 0.01 level (2-tailed).

Table 14: VIF scores for the variables

Variable	VIF score
Motive	1.024
Distance	1.040
Age	1.180
Gender	1.020
Education level	1,090
Household composition	1.282
Income	1.229
Cars in household	1.314
700 metre TOD origin	1.321
2000 metre TOD origin	1.663
700 metre TOD destination	1.321
2000 metre TOD destination	1.663

Appendix 5

Table 15: motives for train travellers

Motive	***Train as main mode***	***Total trips***
Commuting	9904	160857
Business	753	14874
Services	315	31275
Shopping	1217	182782
Education	5500	90976
visiting	2421	96114
Other social	2690	156776
Hiking	206	49064
Other	792	78527

Table 16: distances travelled by train and overall

Percentage of trips groups	***Distance travelled in kilometres by train***	***Distance travelled in kilometres overall***
0-20	0.4-20.7	0.1-1
20-40	20.7-31.5	1-2.1
40-60	31.5-47	2.1-5
60-80	47-70.1	5-12.4
0-100	70.1-400	12.4-425

Appendix 6

Origin 2000

		Model 1		Model 2		Model 3	
		Exp(B)	S.E.	Exp(B)	S.E.	Exp(B)	S.E.
	TOD 2000 m before realisation	2.542	0.019***	1.531	0.021***	1.683	0.024***
	TOD 2000 m after realisation	2.700	0.018**	1.071	0.026**	2.005	0.022***
Individual characteristics	Age			0.959	0.000***	,974	0.001***
	Female (reference to male)			0.839	0.014***	1,293	0.016***
	Education middle			1.564	0.22***	1,226	0.025***
	Education higher			1.995	0.22***	1,409	0.025***
	No or other education			0.950	0.57	,900	0.064*
	Couple no kids			1.171	0.022***	1,370	0.025***
	Couple with kids			1.194	0.022***	1,660	0.025***
	Parent with kids			1.147	0.030***	1,336	0.035***
	Other composition			1.273	0.042***	1,537	0.051***
	Middle incomes			1.461	0.018***	1,322	0.021***
	Highest incomes			1.832	0.020***	1,522	0.024***
	One car in household			0.456	0.020***	,219	,024***
	2+ cars in household			0.242	0.025***	,075	,030***
Trip characteristics							
	Business					,487	,043***
	Services					,414	,063***
	Shopping					,381	,035***
	Education					3,427	,025***
	visiting					,452	,028***
	Other social					,517	,026***
	Hiking					,193	,077***

	Other					,329	,042***
	Distance 20.7-31.5 kilometres					24,186	,025***
	Distance 31.5-47 kilometres					35,249	,026***
	Distance 47-70.1 kilometres					47,942	,027***
	Distance 70.1-400 kilometres					54,825	,027***
Year and month fixed effects		yes		yes		yes	
Number of cases		861266		861266		1067818	
Nagelkerke R^2		0.030		0.109		0.435	
Chi-square		5790.729***		19564.307***		81624.924***	

Destination 2000

		Model 1		**Model 2**		**Model 3**	
		Exp(B)	**S.E.**	**Exp(B)**	**S.E.**	**Exp(B)**	**S.E.**
	TOD 2000 m before realisation	2.698	0.019***	1.632	0.021***	1.708	0.024***
	TOD 2000 m after realisation	2.724	0.018***	1.655	0.019***	1.939	0.022***
Individual characteristics	Age			0.959	0.000***	0.973	0.001***
	Female (reference to male)			0.840	0.014***	1.291	0.016***
	Education middle			1.561	0.022***	1.228	0.025***
	Education higher			1.982	0.022***	1.413	0.025***
	No or other education			0.948	0.057	0.903	0.064
	Couple no kids			1.174	0.022***	1.374	0.025***
	Couple with kids			1.198	0.022***	1.663	0.025***
	Parent with kids			1.151	0.030***	1.335	0.035***
	Other composition			1.263	0.042***	1.536	0.051***
	Middle incomes			1.462	0.018***	1.324	0.021***
	Highest incomes			1.828	0.020***	1.521	0.024***
	One car in household			0.460	0.020***	0.219	0.024***
	2+ cars in household			0.244	0.025***	0.074	0.030***

Trip characteristics							
	Business					0.495	0.043***
	Services					0.409	0.063***
	Shopping					0.384	0.035***
	Education					3.410	0.026***
	visiting					0.458	0.028***
	Other social					0.522	0.026***
	Hiking					0.196	0.076***
	Other					0.335	0.042***
	Distance 20.7-31.5 kilometres					24.103	0.025***
	Distance 31.5-47 kilometres					35.023	0.026***
	Distance 47-70.1 kilometres					47.589	0.027***
	Distance 70.1-400 kilometres					54.613	0.027***
Year and month fixed effects		yes		yes		yes	
Number of cases		861266		861266		861266	
Nagelkerke R^2		0.032		0.109		0.435	
Chi-square		6120.429***		19697.973***		81579.621***	