Transit-oriented development & residential property values: Evidence from North-Holland

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Image: Vereniging Deltametropool (2013)

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Preface

Before you lies the thesis titled *Transit-oriented development & residential property values: Evidence from North-Holland*. A subject which is born out of particular interest in real estate and frequent transit commutes from Leiden and Groningen over the past time. As many Dutch station districts, the ones in Leiden and Groningen were and still are in the process of urban (re)development and densification. Densification in the Netherlands is, however, commonly accompanied by reluctance to live in high-rise buildings; rather live with our feet firmly on the ground than with our heads in the clouds. In light of the controversy and as inhabitant of station districts, I started to wonder about the potential impacts of these kind of developments and whether transit-oriented development is an interesting strategy for the upcoming building task. Therefore, as a completion of the Master's degree of Economic Geography at the University of Groningen at the faculty of Spatial Sciences, I attempt to clarify this public debate regarding densification by evaluating the relationship between transit-oriented development and residential property values.

I would like to express my sincere gratitude to Samira Barzin, who kindly and expertly supervised my research. Her knowledge and constructive feedback played an essential role. Furthermore, I want to thank economic research bureau Decisio for giving me the opportunity to carry out this research. I would like to thank all my colleagues at Decisio and especially my supervisors, Jaap Broer and Daan van Gent. Furthermore, I want to thank my family and Fanny for providing me with support through the process of writing this thesis. This accomplishment would not have been possible without them. Thank you.

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Abstract

As a result of ongoing urbanization, Dutch cities and regions are faced with urban dilemmas, such as housing affordability and congestion. A smart growth strategy, which considers housing and mobility simultaneously, is Transit-Oriented Development (TOD). Its an urban planning concept which aims to create lively, sustainable, and pedestrian and cycling friendly environments where residents live within walking distance of major transit stations and other amenities. Despite the gaining popularity, little is known about the impact of TOD on residential property values. In view of the upcoming Dutch building task, the implementation of TOD may intensify. For this reason, it is interesting to study the relationship between TOD and the Dutch residential property market.

In order to evaluate TOD and the residential property market, the research design consists of two building blocks: a TOD assessment and a hedonic pricing analysis. First, the extent to which the urban environment of station districts are oriented to transit and the quality of the transit node itself, is assessed across the province of North-Holland. Consequently, most station districts in North-Holland are characterized as barely TOD, followed by a bulk characterized as moderately TOD. Only a few are characterized as being highly TOD. Results of the TOD assessment, supplemented with transactional data of the Dutch residential property market, provide the means for a hedonic pricing analysis. By means of cross-sectional OLS regressions, a positive relationship is found between TOD and residential property values. Primarily accessibility accounts for the positive relationship. The impact of TOD on residential property values is, however, asymmetric across property types and location within station districts. When interacting TOD with property types, the effect of TOD on property values of house-like properties is negative or not significant, whereas the effect is positive for apartment-like properties. When interacting TOD with locations, effect of TOD on residential property values becomes heavier as distances expand.

Overall, TOD plays a role in explaining residential property values around commuter railway stations in the province of North-Holland, since it appears to be positively correlated with residential property values. Ground is therefore found for local governments to embrace and propagate TOD as one of the strategies to pursue the building task. Apart from the economic added value, positive health effects and ecological advantages, the findings signal a healthier demand for highly transit-oriented environments over recent time. As such, it is recommended to construct considerable shares of the new to build residences in station districts, especially adjacent to urban centers.

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1. Introduction

In 2007, humanity crossed a major landmark in its history with the majority of people living in cities (World Bank, 2019). Urbanization took place gradually in developed countries. In the Netherlands too, population growth had been distributed unevenly. Growth primarily concentrated in the *Randstad*[1]. In terms of population, urban regions are first expected to outgrow non-urban regions and second, non-urban regions in the Randstad outgrow urban regions outside the *Randstad* (De Beer et al., 2017). Thus, overall, the continuing population concentration in cities in the *Randstad* is the dominant trend. As a result of ongoing urbanization, Dutch cities and regions are faced with urban dilemmas, where it is expected that the urbanization trend may exacerbate these problems in the future.

The presence of high competition for space has led to housing shortages, so that housing affordability has become one of the major contemporary urban dilemmas. Demographic trends as declining average household heightened the competition, while the drop in housing supply during the recent economic crisis reinforced the housing shortage. However, housing supply gradually increased anew recently, but still it is insufficient to meet current demand hitherto, leading to a housing shortage of over 200,000 houses in 2018 (NVM, 2018). Consequently, the Dutch housing market has set sales' price records, especially the larger urban centers. As response to the situation, the central government desires to construct 700,000 additional houses by 2025 in order to alleviate pressure on the housing market (Rijksoverheid, 2018).

Little discussion about the necessity of the additional houses exists, but in which area and what way exactly remains source of discussion. On one hand, there are proponents of densification; for instance, *Planbureau voor de Leefomgeving* (PBL) (2016) argues that half of these new to build houses should be accommodated within existing urban boundaries, since it brings about agglomeration economies, promotes critical masses necessary to support costly infrastructural services, environmentally friendlier nature and because it preserves scarce green spaces. Additionally, densification may lead to welfare gains for residents (Ahlfeldt & Pietrostefani, 2019). However, on the other hand, concerns exist around the inhuman size of skyscrapers. It possibly alienates residents. Moreover, skyscrapers are disproportionally expensive to build wherefore the funding has proved to be a major obstacle (De Zeeuw, 2018). Opponents of densification also argue that inner city developments do not correspond with the desires of Dutch citizens (Hendrikse, 2018). Therefore, those who resist to the densification philosophy favor expansion locations on the edge of cities and towns. Yet, others predict a compromise in the shape of both highly densified urban areas - sometimes with skyscrapers - and expansion locations on the edge of cities (Bayer, 2018).

Apart from the housing issues, there are currently also mobility challenges. Consequently, headlines such as *'long traffic jams'* have been making it to the newspapers anew (De Groot et al., 2018; De Volkskrant, 2018). The current infrastructural capacity nearly exceeds the demand. Moreover, the annual forecast of the *Kennisinstituut voor Mobiliteitsbeleid* (2018) foresees a further increase in road users (8%) between 2017 and 2023. In order to

[1]The Randstad is a megalopolis in the central-western Netherlands consisting primarily of the four largest Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht) and their surrounding areas.

mitigate congestion and to cope with the forthcoming mobility challenges, CPB (2016) and PBL (2016) outline three ways: First, additional investments in road infrastructure in order to expand the capacity. Second, a more efficient use of the existing capacity could be a solution. Thereby *Mobility as a Service*[2] and pricing policies for road infrastructure might help. A third option relates to urban densification around transit junctions, wherefore long distance trips could be reduced or taken by transit.

In light of the housing and mobility challenges, actors increasingly look at transit station districts for densification since it has the ability to connect the challenges, thereby often referring to transit-oriented development (TOD). TOD aims to create lively, sustainable, and pedestrian and cycling friendly environments where residents live within walking distance of major transit stations and other amenities Over time, TOD has gained popularity among regional collaborations in the Netherlands. In the south wing of the *Randstad*, *StedenbaanPlus* and *RandstadRail* initiatives aim to improve the quality of the transit and the environment through adding residential space, office space and facilities, such as parking. A similar initiative is found in the functional urban region Arnhem-Nijmegen (Platform 31, 2013). In North-Holland various governmental institutions collaborate in order to develop station districts along several important railway corridors (Platform 31, 2013; Rooijers, 2018; Noord Holland, 2018). Moreover, since recently, TOD is an integral part of the long-term policy visions *NOVI*[3] and *Toekomstbeeld OV 2040*[4]. Thus, considerable interest in TOD exists within both regional and national governmental institutions.

1.1. Problem statement

The Netherlands is in the initial phase of a large-scale building task. Between today and 2030, over one million houses will have to be built in order to meet the national housing demand. In which area and in what way is not determined yet, wherefore a lively debate has arisen between proponents and opponents of both urban densification and expansion locations. Evidently, concerns about affordability play a role here, but also effects of area development on mobility and sustainability, among others, as well. Important strategic choices will have to be made, as the outcomes of the pursued building strategy will foremost influence the current mobility problematic.

A possible strategy is transit-oriented development (TOD). This is an integral strategy in which the housing and mobility issues are considered simultaneously. The urban planning concept is also gaining popularity in the Netherlands. At this moment, however, little is known about the relationship between TOD and pre-existing residential property values around commuter railway station. In view of the upcoming building task, the implementation of TOD may intensify and spread across the Netherlands. For this reason, it is interesting to conduct research into the relationship between TOD and the housing market: how is TOD valued by certain housing types in various TOD environments, which

[2]*Mobility as a Service* is the integration of various forms of transport services into a singly mobility service accessible on demand (Maas Alliance, 2019)
[3]*NOVI* is a coherent and inspiring vision for the physical built environment and quality of life in the Netherlands.
[4]*Toekomstbeeld OV 2040* is a common vision of Dutch governments, ProRail and transport companies on public transport.

locations are affected the most and which interaction is present between TOD-elements and residential property values?

1.1.1. Research objective

The objective in this thesis is to evaluate the relationship between TOD-ness around commuter railway stations and residential property values in North-Holland through a hedonic pricing analysis. The thesis clarifies the question whether TOD influences residential property values, which property types have price premiums or discounts in which TOD environment, whether the impact of TOD is widespread, and which elements form the core of TOD. Consequently, findings of this thesis can provide guidelines on how to pursue TOD in the Netherlands. Henceforth, this thesis contributes to the building task debate.

1.1.2. Main research question

What is the role of transit-oriented development in explaining residential property values around commuter railway stations in the Province of North-Holland.

Sub questions

1. Which elements determine the degree of TOD in a commuter railway station district?
2. What is the degree of TOD of commuter railway station districts in the province of North-Holland?
3. What is the relationship between TOD and residential property values in North-Holland's station districts?

1.2. Societal relevance

Considerable processes and trends are ongoing which make TOD a concept worth researching. Worldwide urbanization poses additional pressure on immobile and costly assets as real estate and infrastructure. In the Dutch context, the situation is alarming, since the housing market booms and the road network reaches its capacity with increasing congestion as a consequence. However, the existence of fierce debates around the issue how the building task should be approached demonstrates the need for additional insights. The different approaches can roughly be categorized in expansion locations along the city edges, densification within the city boundaries or a mixture.

TOD is one of the densification concepts. It is interesting to delve into TOD because of its gaining popularity. Insofar, several TOD-principles are implemented in the (re)development of individual Dutch station areas and a few organizations are founded which pursue TOD. Despite the advanced stage of some projects and the urgency of the building task, it remains somewhat unclear whether residents value TOD, what elements exactly, which property types can be marketed more successfully and in which environment. Taken together, this thesis explores the wishes of residents around Dutch commuter railway stations, which is important since the Dutch are in the initial phase of housing, mobility and sustainability transitions.

A variety of stakeholders could take advantage of the findings. Urban planners, for instance, might take into account the findings as certain handlebars for future station districts' improvements or entirely new TODs. Also, researchers or consultants may use the indicators as inputs, for example, for social cost benefit analyses (SCBA) of policy alternatives or projects. This may lead to more efficient policies or projects as a result since policy makers partly base their decisions on SCBA's or similar analyses. The thesis' findings may also help policy makers with a better understanding of TOD in terms of its functionality. Insofar the discussed stakeholders are primarily limited to non-commercial actors involved in the urban built environment. Yet, insights can also be of interest for commercial stakeholders as real estate developers and investors. The effect of TOD-elements on residential property values may provide these stakeholders with a framework to assess the quality of future TOD-projects.

Findings contribute to the debate on the matter how to complete the forthcoming building task. Having accurate information allows for qualitative urban developments, which improves the urban living environment overall. As a result, municipalities' tax income may increase due to higher real estate values. Same municipalities and also real estate developers benefit from enhanced insights on which TOD-elements drive residential properties upwards. But above all, since consumers are supposed to reside in TODs, they are the ones who benefit the most in the sense that TOD may optimize the housing stock and the quality of public space. In theory, this is important information about the demand of housing which ultimately leads to a more efficient use of resources and an improved use of space.

1.3. Academic relevance

Insofar, academic literature has focused on the quality of nodes, i.e. railway stations, and in which these affect real estate prices. These studies have largely used the proximity to transit and railway accessibility as indicators. Even though the effects of these indicators on real estate prices is covered extensively, the empirical findings of these studies are ambiguous in terms of the magnitude and the direction of the impact. Yet, the meta-analyses have found an overall positive relationship between railway accessibility and real estate prices is claimed (Debrezion et al., 2007; Mohammad et al., 2013).

Few attempts are made to evaluate TOD more extensively, rather than just quality of nodes, and these studies confirmed synergistic price effects (Atkinson-Palombo, 2010; Duncan, 2011). However, the academic literature has not extensively explored the relationship between TOD(-elements) and residential property values. Therefore, this thesis fills an academic gap by evaluating TOD by all of its individual elements in order to find the directions of the effects on residential property values. It builds thereby upon a TOD-Index developed by Singh et al. (2017). As such, the thesis is a continuation of what has been done previously.

Additional recent empirical evidence from the province of North-Holland (2014-2017) adds to the currently rather thin literature on this subject. Also, the transactional data used (1996-2001 and 1995-2007) in the studies of Debrezion et al. (2011) and Koster (2012) can be thought of somewhat outdated as the dynamics on real estate market has undergone significant changes. Transactional data used in this thesis is more recent (2014-2017).

2. Conceptual framework

Central in this study is the relationship between TOD and residential property values. However, the academic literature on measuring TOD is rather thin, and empirical evidence of TOD and residential property values is even less available. Therefore, in this literature review, the main angle of approach for framing the relation between TOD and residential property values is the role of transit accessibility. The subsequent chapter, thereby, attempts to answer the following sub question:

Which elements determine the degree of TOD of a commuter railway station district?

Consequently, the next section starts with an elaboration on what TOD exactly is, how it can be evaluated and measured, and what the potential benefits are of successfully executed TODs. In the second part of the next section, the effect of commuter railway stations on residential property values is discussed in terms of theory and empirical evidence.

2.1. Transit-oriented development

Whereas measurement of transit-oriented development (TOD) is still in its infancy, a vaster body of literature has emerged providing various definitions. Yet the basic philosophy appears the same in all contexts, namely a varied program of moderate to high densities, mixed use and well-designed urban development around stations in order to support transit use and developing transit systems to connect existing and planned urban development (Bertolini et al., 2016). While the precise definition of TOD varies, in general, TOD aims to create lively, sustainable, and pedestrian and cycling friendly environments where residents live within walking distance of major transit stations and other amenities (Nasri and Zhang, 2014). Thus, in order to achieve such living environments, TOD integrates the disciplines of land use and transit systems (CTOD, 2009).

Important for the interpretation of TOD, is the distinction between nodes and places (Belzer and Autler, 2002). A station district has namely two domains. On one hand, station areas are nodes: points connecting different transit modes and providing access to transportation networks. On the other hand, it is a place: parts of cities with collections of buildings, open spaces and activities. An interrelation between the two domains exists and can affect the functionality of either domain negatively or positively (Bertolini, 1998). Therefore it is suggested that both domains, thus node and place, should be well-balanced. An important insight to understand the reasons of TOD projects yielding unsatisfactory outcomes, such as highly urbanized environments without sufficient transit or excellent transit without the critical mass to support it.

Over time various approaches are developed in order to understand the outcomes of TOD projects. Some studies approach TOD from a qualitative perspective and discuss how TOD is planned at regional urban and local scales and in which way improvements in transit services, densities or mixed-usedness can alter the degree of TOD (Cervero and Murakami, 2009; Arrington, 2009). Other studies develop an approach to evaluate the success or failure of a certain urban development (Renne, 2007; Nelson and Niles, 1999). An extensive example of such an evaluation study is carried out by Belzer and Autler (2002), who elaborate on six slightly overlapping performance criteria. Desirable TOD projects have to meet the following criteria to a large extent:

1. Location efficiency in the sense of dense neighborhoods with high-quality proximate transit, mixed land uses and pedestrian-friendly design (3Ds: density, diversity and design).
2. Value recapturing by TOD residents because of lower transportation costs than their counterparts in auto-dependent neighborhoods.
3. Livability improvements as most of the outcomes indirectly contribute to a better living environment.
4. Financial returns for public investors, private investors and actors involved, otherwise no project will get built.
5. Choice enlargement since TOD is a new type of urban development, offering internal diversity in terms of modal choice, housing types and retail provision.
6. More efficient regional land-use pattern due to less land consumption and traffic.

However, evaluations of certain urban developments in station districts is different from measuring the degree of TOD (hereafter referred to as TOD-ness). Attempts are made to measure the TOD-ness of railway stations in the Netherlands (Bertolini, 1999; Balz and Schrijnen, 2009; DeltaMetropolisAssociation, 2014). Central in these studies is the development of stations' typology and the according station grouping. Advantages of such a typology approach entail: reducing management complexity, allowing urban planners to make consistent plans across large areas and identifying strengths and weaknesses of similar railway station areas (Zemp et al., 2011). A disadvantage, however, is the inability of groupings to denote the precise TOD-ness. Also, future recommendations cannot be as accurate as possible, because stations areas are never exactly the same. In other words, there is not a general solution suitable for all situations. Lastly, not all station districts can be characterized as TOD, since mere proximity is insufficient of its own.

In order to overcome these disadvantages, Singh (2015) proposes a TOD-Index which is capable of measuring and quantifying TOD-ness. After taking into account the findings of earlier studies, Singh (2015) formulates rules with regard to the urban environment and the transit systems that possibly affects the TOD-ness of an area:

1. Transit systems should have enough free capacity. Saturated capacities cannot attract more passengers.
2. A user-friendly transit system is necessary to encourage the use of transit systems.
3. A node with better access and that provides high accessibility has increased chances of creating TOD.
4. Parking supply for bicycles and cars will help people to use transit for longer commutes.
5. Urban densities are important for TOD.
6. Land use diversity creates a vibrant and lively place out of transit node.
7. Design of urban space that makes an area walkable and cyclable is necessary for TOD.
8. Higher economic development in an area leads to higher TOD. (p. 34)

Subsequently, Singh et al. (2017) derive eight criteria from the rules listed above: density, land use diversity, urban design, economic development, access to and from nodes, optimum parking, user-friendliness and comfortable ride. Substantiation of the criteria based on a plethora of studies. Cervero and Kockelman (1997) state that the 3Ds - density, land use diversity and design - are of crucial importance for the urban environment due to the following reasons: First, with regard to densities, Singh et al. (2017) argue that population and commercial density yields larger customer bases for transit systems given that larger the populations result in larger the absolute numbers of transit passengers. Therefore, moderate to high densities sustain the use of the transit system. Second, Singh et al. (2017) claim positive influences of multifunctional station districts on TOD. Such places, with their variety of services and facilities, are able to attract people from outside to locate into the area while also retaining local residents. More diversified station districts therefore positively affect passenger flows by generating better balanced and consistent passenger flows. Regarding the third criteria - urban design - Singh et al. (2017) state that walkable and cyclable environments contribute to TOD. Reaching transit stations as quick as possible, without detours or stops, enhances the accessibility for pedestrians and cyclist and thus creates higher likelihoods of transit use. The fourth criteria for the urban environment is economic development, since higher economic development triggers more travel activity and ultimately a higher potential that these trips are made by transit given the proximity of transit (Bertolini, 1999; Renne and Wells, 2005).

Apart from urban development, it is essential for TOD that the station district is served by a high quality transit system[5]. Access and accessibility is essential for TOD (Cervero and Murakami, 2009; Evans and Pratt, 2007); or in other words, the various options to and from the transit node. Hereby the number of routes at a transit node play a role. Also, the presence of other transportation modes, such as the subway and tram, enhance access and accessibility, since these modes can either feed the greater transit system or facilitate the last kilometer travelled. Besides, access to the station for pedestrians and cyclists should not be ignored too. An user-friendly transit system is also necessary to make it attractive for people to use it. This is largely facilitated by the presence of services and facilities at the transit stop. Missing or ill-functioning services have an impact on the user-experience of the commuter, while it may also result in a less safe environment at the station. Lastly, not all transit users reside within walking distance from any form of transit or simply prefer the bicycle or car in order to reach the station. Therefore, the provision of sufficient parking facilities for cyclists and car users is of importance for TOD. This enhances the accessibility and user-friendliness for this user group. Besides, sufficient parking facilities prevent disturbance for inhabitants and pedestrians from illegal parking.

As described above, TOD consists of numerous elements, which renders implementation complicated and difficult. Vital in achieving the potential TOD benefits is an attuned combination of an urban environment and transit system. Theoretically, this allows for interactions between both sides. Without the interactions, potential TOD projects evolve into the unsatisfactory transit-adjacent developments (TAD) (Belzer and Autler 2002, Cervero et al. 2002, Dittmar and Ohland 2004). While TOD describes a compact and mixed-use station district that facilitates transit connectivity through urban design, TAD is merely near transit but fails to capitalize upon its proximity to transit. It lacks any functional connectivity to transit in terms of land-use, transit access or urban design (Cervero et al. 2002, p. 6). Consequently, it is not able to yield the attributed benefits.

[5]A high quality transit system is characterized by its ability to effectively meet the mobility needs of users by being accessible, frequent, fast, reliable, affordable and attractive (Böhler, 2010).

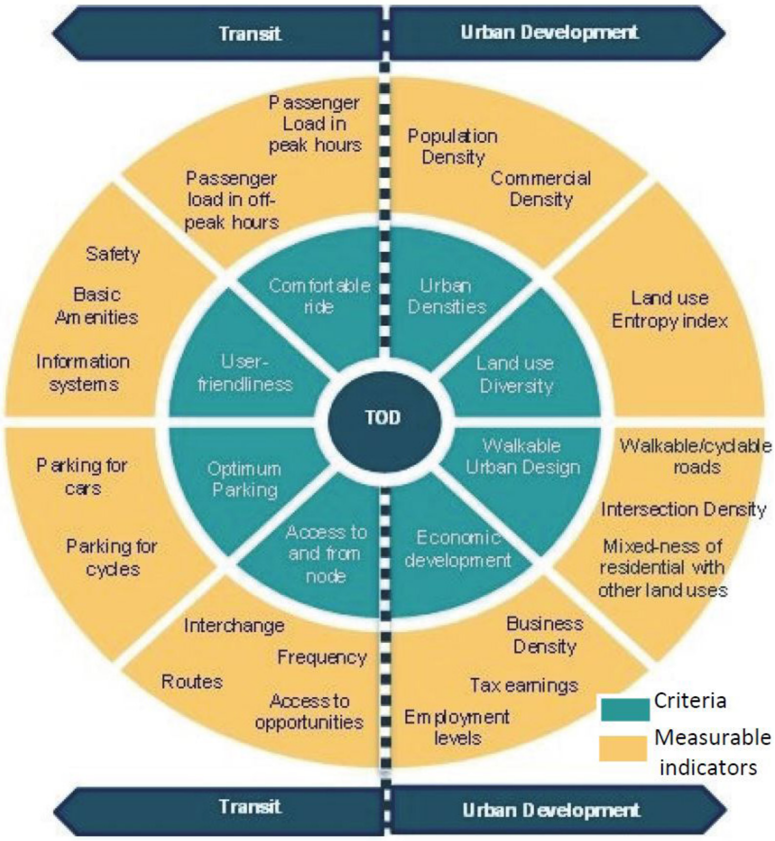

Figure 1: Rules, criteria and indicators for measuring TOD around existing railway stations (Singh et al., 2017).

2.1.1. Benefits of TOD

Nevertheless, if the transit (node) and urban environment (place) elements are of sufficient quality and in balance, the benefits of TOD are various and numerous. There are even voices saying that aspects of TOD possibly result in synergistic effects greater than the sum of its parts (Synergie tussen OV en RO, 2011). From a theoretical perspective, TOD can contribute to resolve, although only partly, challenges with regard to mobility, housing and lastly the urban environment. Furthermore, Noland et al. (2014) have used qualitative and quantitative empirical approaches to examine the beneficial impacts of TOD near eight train stations in New Jersey, United States of America. In their extensive research Noland's team finds: First, broad support among residents, planners, and developers for intense development around transit stations. Second, that residents living closer to transit stations are more frequent walkers and transit users while also being less frequent drivers, compared to those living more distantly. Nasri and Zhang (2014) also find that good transit accessibility along with other land-use characteristics encourages individuals towards a more sustainable and healthy life with more transit use and less driving. This is healthier for residents, environmentally friendlier and creates higher revenues for transit companies. Third, out-of-pocket expenses associated with using transit are less than those associated with driving costs (owning, operating, parking, taxes). Fourth, despite some differences between pedestrians, cyclists and vehicles, there are benefits of reduced vehicle casualties proximate to stations. Fifth, in terms of regional congestion costs and other external costs, there is an increase in transit usage and a decrease in vehicle usage. Derived from this, the users generally also benefit directly from reduced commuting costs. Lastly, Noland et al. (2014) find a clear relation between residential property values and proximity to transit, which is further explored in the next section.

In the first section of chapter two, the urban planning concept TOD is introduced. The general philosophy agrees on the need of a concentration of high density, mixed use and well-designed urban development near stations in order to support transit use, and developing transit systems to connect existing and planned urban development. Despite TOD's popularity and subsequent rise, measuring and quantifying TOD is still in a preliminary stage, but first attempts in developing a TOD-Index have been carried out. Singh (2015), for instance, has created an index of 21 indicators based on eight criteria which quantify the quality of the transit and the urban development. If TOD is successfully implemented, the benefits can be various and numerous and experienced by many and are possibly synergistic.

2.2. TOD and real estate values - Theory

In this literature review, exploring the relationship between TOD-ness and residential real estate prices is the particular interest. Real estate prices are determined in a product differentiated real estate market, which represents the supply-demand and allocate the scarce commodity to the highest bidder. Market mechanisms determine the price or rent charged for certain property types in different locations. It is influenced by the preferences of consumers in relation to the property characteristics and the locational aspects. Consumer preferences aside, the economic situation and governmental regulation influence the real estate prices as well (Jaffe and Sirmans, 1994).

Over the years, studies have been conducted to bring more clarity on what determines real estate prices. Most of these studies are grounded on the work of Von Thünen (1863), who has tried to explore variations in farmland values. In the *Isolated State*, Von Thünen hypothesizes four rings of agricultural activity surrounding the market place. Each of these rings represent different farmland values. Given certain assumptions, accessibility to the market place accounts for these differences in land values since higher accessibility causes lower transportation costs. In general, Von Thünen's model predicts higher land values closer to the market place.

In the 20th century, Von Thünen's model is extended by the theory of the bid–rent analysis in order to be applicable to land uses of a city (Alonso, 1964; Muth, 1969). The premise is that agents are prepared to pay a certain price, depending on the location of the land relative to the central business district (CBD), which is usually the center of economic activity. Proximity to the CBD results in higher accessibility, which in turn means lower transportation costs to and from those locations compared to more distant locations. As in Von Thünen's model, this leads to declining land rent gradients with distance from the CBD for sites that have equal utility. If translated to the contemporary real estate market, the basic theory is as follows: When locations become more attractive due to certain characteristics, demand increases and thus the bidding process pushes prices up. The willingness to pay for certain real estate properties and their locational aspects varies for different population segments and economic sectors across a modern city, which is depicted in Figure 2 and Figure 3. A spatial allocation structure of an urban economy is visible wherein young urban professionals and companies active in the service industry tend to locate either in or adjacent to the CBD.

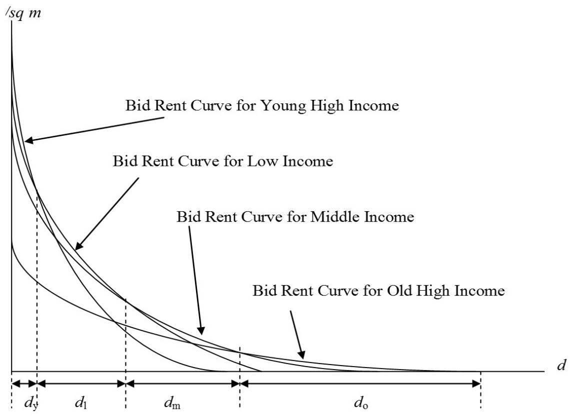

Figure 2: Urban land allocation for four different types of households (McCann, 2018).

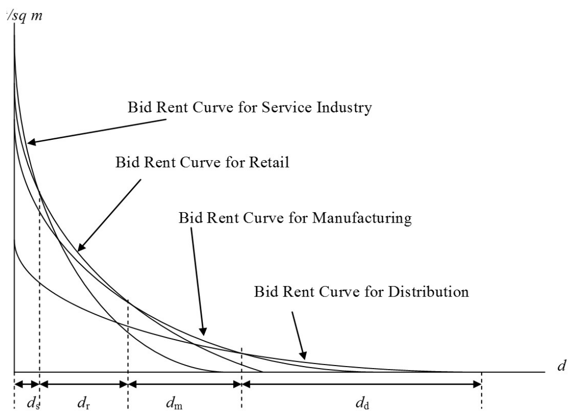

Figure 3: Urban land allocation for four different sectors (McCann, 2018).

However, neither theory fully corresponds with reality, nor do these theories take into account the effect of transit infrastructure. Investments in transit infrastructure can reduce this demand friction around the CBD to a certain degree, since transit investments increase travel options and reduce travel times to and from the CBD from certain transit nodes (Fejarang, 1994). As a result, the relative amount of accessibility, and thus attractiveness, of that particular area increases after the introduction of new transit compared to other areas at the same distance from the CBD but without transit (Baum-Snow and Kahn, 2000). Theoretically, real estate properties close to the investment area in railway stations reap benefits in terms of transport time and costs savings, which thereby drive up prices. Subsequently, it is expected that the price curve with respect to distance from the station has a negative slope where: locations farther away from the station exhibit lower property prices.

2.2.1. TOD and real estate values - Empirical evidence

In the previous decades, academics have delved into the question whether railway accessibility affects residential property values. Typically, these researches are conducted with the hedonic pricing methodology. Most commonly, studies have attempted to address accessibility through the inclusion of a proximity factor of the property to the relevant transportation modes while controlling for other variables. Empirical literature on the effects of railway stations on property values are mixed in its finding with respect to magnitude, direction and significance (Debrezion et al., 2007). A brief overview of the literature is presented here.

Grass (1992) has revealed a direct and positive relationship between the opening of transit stations and residential property values in Washington D.C, which is in line with earlier studies (Grether and Miezkowski, 1974; Dewees, 1976; Damm, 1980 and Wolf, 1979). Also, Voight (1991) has found that the user value of commuter rail systems partly capitalizes into the value of residences, since areas connected to train services hold a price premium compared to similar neighborhoods and houses without train services. Similarly, for Toronto, Bajic (1983) has claimed that the direct savings from improvements in transit capitalizes into residential property values. Weak and insignificant evidence is found by Gatzlaf and Smith (1993) for the effect of the metro network on residential property values in Miami after the development of the metro stations. Recently, Ahlfeldt (2010) finds little evidence that access to intercity rail connections significantly impact real estate prices. In contrast, transit investments may also negatively affect residential property values. In context of the CalTrain in San Fransisco Bay Area, no significant positive impact on house values is found. Houses within 300 meters of a CalTrain are even sold at a major discount of $51,000 on average, due to negative externalities as nuisance and vibrations (Landis et al., 1995).

Empirical evidence from the Netherlands is not straightforward too. Debrezion et al. (2011) have analyzed the effect of railway accessibility on residential property values in Amsterdam, Rotterdam and Enschede. Railway accessibility is measured by proximity to railway stations, proximity to railway lines and the quality of railway services. Besides, it makes a distinction between the nearest railway station and the most frequently chosen railway station. Interestingly, adding to the ambiguous empirical evidence, Debrezion et al. (2011) find that residential property values are more influenced by the most frequently used station than by the nearest railway station. Additionally, the differences in the residential property values are significantly larger for the more urbanized areas (Amsterdam and Rotterdam). While Debrezion et al. (2011) have analyzed existing railway stations, Koster et al. (2012) have investigated the effects of new commuter railway stations in Dutch suburbs. Although the authors emphasize the importance of the local context, no statistically significant impact on residential property values is found as a result of the new station openings. Lastly, after having applied a differences-in-differences strategy, a recent study in the Dutch context indicates that the effects of TOD on residential property values are highly heterogeneous (Van Ruijven et al., 2019).

Evidently, these mixed findings may be the reflection of the nature of the data, particular spatial characteristics, temporal effects and the used methodology. Debrezion et al. (2007) have extended the list with factors upon which the impact of transit on residential property values depends. First, the quality of railway stations differs from each other in levels of service in terms of frequency, network connectivity and service coverage. Also, the level and quality of facilities at the railway station is of importance. Second, railway stations affect the values of residential and commercial properties differently. Third, the impact of railway stations on residential property values depend on demographic factors, such as income and social divisions. Mohammad et al. (2013) have supplemented the list with property or land values, the rail system life cycle maturity and the geographical location (North American, European and Asian cities).

Resulting from the meta-analyses, Debrezion et al. (2007) and Mohammad et al. (2013) state that transit proximity still matters, but depends on a few points: First, commuter railway stations are expected to have higher impacts on the residential property values compared to light railway or subway stations due to higher service coverage. Second, the impact of railway stations on residential values is geographically widespread. Mohammad et al. (2013) even find highest impacts for residential properties between 500 to 801 meters from a railway station. Another interesting finding of this study is that the impact of transit is found to be higher in the European and East Asian context. On the other hand, however, Mohammad et al. (2013) report that the location within the city (whether in the CBD or not) and a consideration of neighborhood type does not affect values significantly. Last, to finalize in terms of methodological factors, Mohammad et al. (2013) show that panel or time-series data produced higher value changes than cross-sectional data. Debrezion et al. (2007) find that the presence of control variables, such as accessibility and physical house characteristics, have a cushioning effect on the magnitude of the impact of the station.

Moreover, a major point upon which the effect of transit proximity depends is the real estate market (Debrezion et al., 2007; Mohammad et al., 2013). In general, positive effects of transit proximity on commercial property values are primarily high within short distances (up to 400 meters) from the station, and then rapidly diminishes as distance grow. Contrarily, positive effects of transit proximity on residential property values prevail on longer distances (up to 1000 to 1200 meters) from the station. It is generally accepted that the impact of stations is more widespread for the residential property market, whereas the impact of transit proximity on the commercial property market is restricted to adjacent areas. A central station location is therefore more attractive for commercial activities than for residents, which is in line with the urban allocation of land use illustrated by Figure 3.

2.2.2. Synergistic effects

While there is a large body of work on the relationship between real estate values and proximity to a railway station, the literature with respect to TOD is sparse but gradually emerges. Duncan (2011) has researched the influence of TOD on the San Diego condominium market, by including interaction terms between station distance and various measures of pedestrian orientation. The analysis elaborates the previously described studies by illustrating in which way station districts premiums can be enlarged when combined with a complementary built environment (TOD). Whereas other transit capitalization literature merely implements a research design that assumes station proximity has a price effect, Duncan's work also specifically looks at pedestrian-oriented environment characteristics (well-connected street pattern, attractive commercial destinations mixed with housing, and flat walking paths). A good pedestrian environment may drive up the price of TOD independent of station accessibility (Bae, 2002). Conclusively, evidence supports a synergistic relationship between rail proximity and pedestrian environment, on real estate prices. As Duncan states:

> A condo in a good pedestrian environment and near a station (i.e. TOD) has a significantly higher value than a condo in a similar neighborhood not near a station. Conversely, a condo in a less walkable residential neighborhood near a park-and-ride station (i.e. TAD) can have values that actually fall below a condo in a similar neighborhood not near a station (Duncan, 2011).

Atkinson-Palombo (2010) has conducted a somewhat similar study on capitalization benefits of light-rail transit in Phoenix. Apart from the regular accessibility features, it considers condominiums but also adds single family properties to the housing types. It argues that more attention needs to be given to types of neighborhoods in order to create subsets, which in turn allows for comparisons of capitalization impacts in similar geographical settings. As a result, Atkinson-Palombo (2010) finds that impacts vary according to housing type and neighborhood setting. Amenity-dominated mixed-use neighborhoods, on one hand, experience modest price premiums (6%) for single-family houses and over 20% for condominiums, the latter is even boosted an additional 37% if situated in a TOD-area. Residential neighborhoods, on the other hand experience virtually no capitalization benefits for single-family houses and a discount for condos. Overall, the strongest capitalization benefits of light-rail transit accrue to condominiums in TOD communities that focus on walkable and are located in mixed use neighborhoods.

In the second section of chapter two, a few TOD-elements are explored by earlier research, of which proximity to transit and the associated accessibility are researched the most. Although the findings are ambiguous in terms of impact's magnitudes and directions, there is general consensus about positive relationships between railway accessibility and residential property values. Recent literature also confirms that the benefits of transit accessibility and TOD-based design (neighborhood types, type of properties and pedestrian-friendly environments) are linked synergistically. However, the relationship between TOD-ness, as described by Singh (2015), and residential property values is not established yet. Thus, over time, the literature has gradually progressed from focusing on the mere proximity to transit and property characteristics to the inclusion of TOD-elements. Nevertheless, a study on the general relationship between TOD-ness and residential property values has not been conducted.

3. Research design

First, the research problem with contextual background is presented. Second, TOD is conceptualized and its relationship with property prices is explored. In the third chapter the implemented methodology to address the research problem is presented. This chapter is divided into three sections: In the first section, the study area is presented. Then, a detailed explanation is given for the TOD assessment and how the results are subsequently interpreted. Last, the third section describes the implemented statistical methodology which links the results of the TOD assessment to the residential property values.

3.1. Study area

Subject to the TOD assessment is the province of North-Holland and its sixty already existing NS-railway stations plus the adjacent area. Due to the unique characteristics of the intermediate station districts and the excellent access it provides to and from Amsterdam, opportunities for home seekers, companies and facilities are available here (BNA, 2014). The station districts are situated along nine railway corridors (see Figure 4). In general, these corridors are quite mixed, where especially Amsterdam is characterized as an end destination (Deltametropool, 2013). Consequently, the corridors adjacent to Amsterdam are associated with the highest housing demand, which are therefore targeted by policies. North-Holland addresses the potential by pursuing the policy of *OV-knooppuntenontwikkeling programma* which is aimed at further developing the station districts coherently. Besides these corridors, North-Holland regards Hilversum, Hoorn and Haarlem as interesting locations for TOD. This renders the province of North-Holland interesting for analysis.

Figure 4: Study area in North-Holland. Own work projected on a base map from ArcGIS.

TOD aims to create lively, sustainable, and pedestrian and cycling friendly environments where residents live within walking distance of transit station (Nasri and Zhang, 2014). Whether particular distances are perceived walkable or not differs between places and individuals. The applied walking distance varies from 250 to 800 meters (Renne and Wells, 2005; Evans and Prett, 2007; CTOD, 2009) In this research, however, the guidelines of Singh (2015) are implemented which entails a walking distance of 800 meters. Thus, the study area consists of sixty districts of 800 meters (approximately 2 km^2) around NS-stations.

3.2. Transit-oriented development

The following section introduces the methodology used in order to assess the TOD of station districts in North-Holland. As explained, TOD builds on two pillars: Quality of the transit and the extent to which the urban environment is oriented to it. Therefore the methodology must assess station districts on both pillars for a comprehensive overview. Additionally, it must measure and quantify TOD, since evaluation of the relationship between TOD and residential property values is the primary objective. In addition, required data for potential indicators must be relatively readily available from secondary sources.

Singh et al. (2017) propose a TOD-Index which assesses TOD on the basis of eight rules pertaining to transit and the urban environment. Eight criteria are derived from this, which are measurable and quantifiable by sixteen indicators (see Figure 1). Data is collected from OpenStreetMap (OSM), Centraal Bureau voor de Statistiek (CBS), Basisregistratie Adressen en Gebouwen (BAG), Nationaal Wegen Bestand (NWB), Landelijk Informatiesysteem van Arbeidsplaatsen (LISA), Nederlandse Spoorwegen (NS), ProRail, OV Wiki, 9292.nl and Province of North-Holland. Microsoft Office is used for the computation of transit indicators, whereas geographical information systems (GIS) are used for the computation of urban environment indicators.

3.2.1. Indicators

This subsection presents the sixteen indicators included in the TOD assessment. The spatial analysis includes indicators related to the urban environment: *Density*, *Diversity*, *Design* and *Economy*. Furthermore, it includes indicators related to transit: *User-friendliness*, *Parking* and *Accessibility*.

Not every indicator and criterium is equally important for TOD as concluded by Singh (2015), In Table 1, the weight of indicators and criteria used in this study can be found. Weights for indicators are fully derived from and criteria are largely derived from the Multiple Criteria Analysis (MCA) applied by Singh (2015). Aldermen, as representatives of City Region officials involved in local TOD projects, are asked by Singh to rank the criteria in order of their importance for TOD. Their ranks are aggregated using a 'Borda Count method' and the final rankings are subsequently converted to weights according a 'rank sum method'.

Singh's study forms the fundament, but the weights implemented here are slightly adjusted since the criteria *Comfortable ride* is not taken into account. *Comfortable ride* intends to identify potential locations (with relatively low ridership) for more TOD. The NS has not agreed to share the required information, since train occupancy rates is business sensitive information. In the study of Singh (2015), *Comfortable ride* has an attached weight of 20%, which is consequently subdivided over *Density* (4%), *Diversity* (3%), *Design* (3%), *Accessibility* (4%), *User-friendliness* (3%) and *Parking* (3%). As such, the constructed TOD-Index is slightly subjective but still provides insight in the TOD-ness of the various station districts in North-Holland.

Lastly, Table 1 lists the data sources and associated years. See Appendix A for a discussion of the indicators' relevancy, the computation and the interpretation.

Indicator	***Weights***	**Criteria**	***Weights***	**Data source**	**Year**
1. Population density (persons / sq.km)	*67%*	1. Density	*19%*	CBS	2018
2. Commercial density (commercial establishments / sq.km)	*33%*			LISA	2016
3. Land use Diversity	*100%*	2. Diversity	*6%*	BAG	2019
4. Length of walkable / cyclable paths (meters)	*40%*	3. Design	*9%*	OSM	2019
5. Intersection density (number of intersections / sq.km)	*20%*			NWB	2019
6. Mixed-ness of residential land use with other land uses	*30%*			BAG	2019
7. Impedance Pedestrian Catchment Area (IPCA)	*10%*			OSM	2019
8. Business density (business establishments / sq.km)	*100%*	4. Economy	*22%*	LISA	2016
9. Frequency of transit service (number of trains operating / hour)	*40%*	5.Accessibility	*19%*	OV Wiki	2019
10. Interchange to different routes of same transit	*30%*			NS, OV Wiki, 9292.nl	2019
11. Interchange to other transit modes	*20%*			OV Wiki, 9292.nl	2019
12. Access to opportunities (jobs)	*10%*			LISA	2016
13. Safety (number of eateries / shops)	*50%*	6. User-friendliness	*14%*	NS	2019
14. Services at station	*50%*			NS	2019
15. Bicycle parking	*50%*	7. Parking	*11%*	ProRail, NS	2015, 2017
16. Car parking (P&R)	*50%*			Noord-Holland, NS	2017

Table 1: Overview of the indicators and criteria, their associated weights, required data and the year.

3.2.2. Standardization

Due to the number of indicators in combination with the diverse numeric expression, comparisons are rendered complicated. Outcomes of the indicators are standardized with the 'maximum standardization method' in order to resolve this. Consequently, the highest value per indicator becomes '1', whereas lower values are represented by a value between 0 and 1 based on their ratio with the maximum value on the particular indicator. In this way, a comprehensive overview is given on the performance of station districts on individual TOD-indicators.

It is necessary to attribute weights to these outcomes in order to obtain the final TOD-ness. First, weights are attributed to the indicators underpinning the criteria according to their importance (see Table 1). Second, weights are attributed to the criteria according to their importance for TOD. Subsequently, calculation of the final TOD-ness of a station district is possible. The standardization process is repeated after removal of *Amsterdam Centraal* and *Schiphol-Airport* in the hedonic pricing analysis.

3.2.3. Typology

Apart from quanitfying TOD, classifying station districts in particular TOD environments is an objective. It leads to a categorization of similar station districts representing *Low TOD, Medium TOD* or *High TOD*. Through this, it is expected to find differences within and between TOD environments regarding the importance of the elements and the performance of property categories. On the basis of the TOD assessment, the following three ways are considered to obtain the suitable grouping:

1. 3-level grouping (low, medium, high) based on TOD-ness and seven criteria.
2. 3-level grouping (low, medium, high) based on sixteen indicators.
3. 2-level grouping (low, high) based on TOD-ness and sixteen indicators.

Results of the groupings are subsequently analyzed on the basis of two principles. First, the grouping ideally consists of *Low TOD, Medium TOD* or *High TOD*. Second, the observations are more or less equally distributed across the three environments. The third way functions as fallback option. The actual grouping analysis is executed in GIS and the outcomes are incorporated in Appendix B.

3.3. Hedonic pricing analysis

Hedonic pricing methodology is applied in order to explore a relationship between TOD and residential property values. In this section hedonic pricing is introduced. Followed by an explanation of the data and descriptive statistics. In the final subsection, the model specification and associated hypotheses are outlined.

A vast body of literature has used the hedonic pricing method to gain understanding of the real estate market. Hedonic pricing is based on economic theory developed by Rosen (1974). Methodologically, hedonic pricing describes the functional relationship between real estate values and associated physical as well as neighborhood characteristics. It estimates the implicit value contribution of individual characteristics, by measuring the relative importance of these characteristics. Therefore hedonic pricing treats properties as goods consisting of characteristics of which each provides (dis)utility to potential buyers. Each of these characteristics is associated with a value which is derived from the actual price paid for the good. In case of residential hedonic studies, vast datasets of transactional sales data are used as dependent variable. Associated property characteristics are prominent independent variables, and these may include square meters of living space, the number of bedrooms and bathrooms, and other features known to influence sales transactions. Furthermore, there is a general academic consensus that accessibility and environmental factors, affect property prices as well (Debrezion et al., 2007). These factors may refer to proximity to transit, transit's quality of service and land-use patterns. Above-described data is also incorporated in the OLS models.

3.3.1. Data

In this subsection the required data for the execution of the method is outlined. Overall, two building blocks are used: On one hand, residential property values and on the other hand, variables which are retrieved from the TOD assessment. From the Nederlandse Vereniging van Makelaars (NVM), a dataset is obtained on residential property transactions which originally covers the entire province of North-Holland from 2008 to 2017. However, only residential property transactions between 2014 and 2017 are subject to analysis. As visible in Figure 5, average residential property values for residential property market in North-Holland is in an upward trend. Demographic trends as shrinking average household sizes and urbanization, in combination with an expanding economy, high consumer confidence and low interest rates has enlarged the housing demand, while housing supply has been insufficient. Consequently, residential property values has risen significantly.

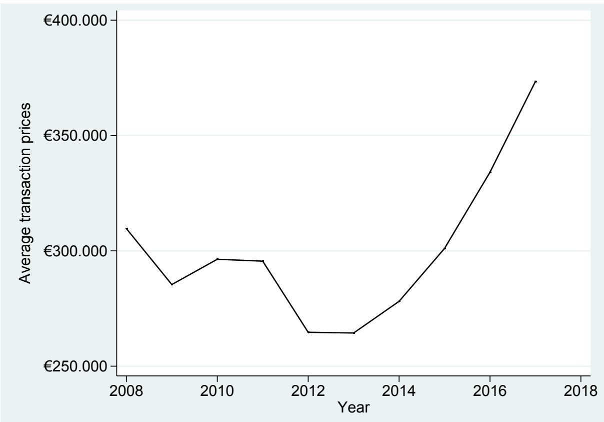

Figure 5: Development of residential property values in North-Holland between 2008 and 2018. Own work based on NVM dataset.

Processing the data consists of two more steps (see Appendix C for a detailed explanation). First, residential property transactions within a concentric ring of 800 meters around North-Holland's railway stations are selected through GIS. Second, residential properties are analyzed on outliers. In total, 39 observations are excluded since these were either characterized as observations with barely any floor area or having switched ownership for €1,-. After the exclusion of outliers, the implementation of the relevant time period (2014-2017) and concentric ring, roughly 33,000 observations remain subject to analysis.

Observations include information on physical house characteristics, such as floor and plot area, number of rooms, whether exterior space is present, parking opportunities, the geographical situation etc. In addition to enrich the dataset, each individual residential property is geocoded to enable the measurement of distance between the properties and the nearest railway station with help of GIS. Asides, each observation is nested in one of the 58 station districts. Results of the TOD assessment, are attributed to the individual residential properties. Although indicators could generate a more detailed statistical model, criteria are preferred since it can be presented more conveniently, it is directly interpretable and it is confronted with far less multicollinearity (see Appendix C). In addition, observations are categorized into *Low TOD, Medium TOD* and *High TOD.*

Descriptive statistics of the incorporated variables are given in Table 2 and Table 3. A few remarks can be made: First, Table 2 covers all subject observations, whereas Table 3 covers *Low TOD, Medium TOD* and *Medium & High TOD*. *High TOD* is replaced by *Medium & High TOD* since it violates the multicollinearity assumption of OLS. Second, it is important to note that *Floor area* and *Distance* are expressed in their original format, thus before respectively logarithmic and categorical transformations. Third, from Table 2 is visible that observations are equally distributed across houses and apartments. However, when analyzing more precisely, an unequal distribution of observations across property types is noticeable. A vast share is *Single family property*, while *Upper-floor apartment* also makes up a considerable share of the sample. Table 3 merely contains descriptive statistics on the question whether it concerns a house or an apartment. It follows from these distributions that the share of apartment-like properties increases alongside TOD. Last, a major difference are the TOD-elements in Table 3, whereas Table 2 solely contains overall TOD.

	North-Holland			
Observ.	32,926			
Dependent variable	*Mean*	*S.D.*	*Minimum*	*Maximum*
Transaction price	296601.1	215628.9	27500.0	5750000.0
Independent variables				
Physical house characteristics				
Floor area in m²	101.76	48.95	14.0	1500.00
Number of rooms	4.05	1.64	1.00	41.00
Number of bathrooms	0.90	0.50	0.00	5.00
Garden (1=yes)	0.51			
Roofterrace or balcony (1=yes)	0.50			
Parking (1=yes)	0.24			
Distance to railway station	647.76	221.74	32.47	981.61
Apartment (1=yes)	0.50			
Property type				
Simple home	0.03			
Single family property (2=yes)	0.39			
Townhouse, canalside property (3=yes)	0.04			
Bungalow, recr., houseboat (4=yes)	0.01			
Villa, country house, f. farm (5=yes)	0.03			
Groundfloor apartment (6=yes)	0.07			
Upper-floor apartment (7=yes)	0.21			
Maisonnette (8=yes)	0.03			
Flat with porch (9=yes)	0.13			
Apartment with external access (10=yes)	0.07			
Duplex apartment (11=yes)	0.00			
TOD assessment				
Overall TOD	0.36	0.13	0.17	0.62
Control variable				
Jobs per place of residence	176524	263467	522	628072

Table 2: Descriptive statistics of the observed variables in Stage 1. Own work based on the TOD assessment and the NVM dataset.

	Low TOD				Medium TOD				Medium & High TOD			
Observ.	11,244				12,305				21,682			
	Mean	*S.D.*	*Minimum*	*Maximum*	*Mean*	*S.D.*	*Minimum*	*Maximum*	*Mean*	*S.D.*	*Minimum*	*Maximum*
Dependent variable												
Transaction price	299901.3	218399.1	40000	3950000	268775.7	192731.6	33000	3153741	294874.7	214165.9	27500	5750000
Independent variables												
Physical house characteristics												
Floor area in m²	113.13	51.21	16.00	1500.00	99.64	45.91	20.00	969.00	95.86	46.66	14.00	969.00
Number of rooms	4.49	1.66	1.00	41.00	3.98	1.56	1.00	34.00	3.83	1.58	1.00	34.00
Number of bathrooms	0.91	0.51	0.00	5.00	0.89	0.49	0.00	5.00	0.89	0.49	0.00	5.00
Garden (1=yes)	0.66				0,49				0.44			
Roofterrace or balcony (1=yes)	0.43				0,50				0.54			
Parking (1=yes)	0.33				0,23				0.19			
Distance to railway station	617.64	224.90	46.55	979.21	663.98	221.38	32.47	981.33	663.36	218.46	32.46	981.60
Apartment (1=yes)	0.30				0,52				0.61			
Urban environment												
Density	0.16	0.05	0.04	0.23	0.27	0.09	0.08	0.47	0.41	0.25	0.08	1.00
Diversity	0.49	0.14	0.22	0.79	0.74	0.11	0.59	0.95	0.74	0.11	0.56	1.00
Design	0.60	0.10	0.30	0.78	0.73	0.72	0.60	0.86	0.78	0.10	0.60	0,91
Transit												
Accessibility	0.11	0.05	0.05	0.21	0.17	0.08	0.09	0.33	0.27	0.15	0.09	0,81
Parking	0.42	0.19	0.07	0.94	0.32	0.19	0.51	0.77	0.26	0.16	0.05	0,94
Control variable												
Jobs per place of residence	11241	13235	522	64414	169945	258494	1758	628072	262238	289496	1758	628072

Table 3: Descriptive statistics of the observed variables in Stage 2. Own work based on the TOD assessment and the NVM dataset.

3.3.2. Model specification

Multiple linear regression analysis is performed in order to test whether TOD correlates with residential property values. The model specification relies largely on the studies of Debrezion et al. (2007) and Singh (2015). Included physical house characteristics are largely derived from the former study, whereas characteristics related to TOD come from the latter study. The hedonic pricing analysis consists of two stages.

In Stage 1, a general relationship between TOD and residential property values is tested. Consequently, the model specification is as follows:

$$\ln(Pi) = \alpha + \beta 1 \mathit{lnFA} + \beta 2 \mathit{NR} + \beta 3 \mathit{NBR} + \beta 4 \mathit{Garden(yes)} + \beta 5 RB(\text{yes}) + \beta 6 Parking(\text{yes}) + \beta 7' PropertyType + \beta 8' Y + \beta 9' Distance + \beta 10 TOD + \beta 11('PropertyType * TOD) + \beta 12('Distance * TOD) + \beta 13 lnJobsPR + \varepsilon i$$

where *Pi* represents a logarithmic transaction price for a certain property *i*. Besides, the model specification mostly concerns variables related to the residential property. The first part of the model specification consists of variables related to the residential property, namely logarithmic floor area (*lnFA*), the number of (bath)rooms (*NR and NBR*) and whether its equipped with a garden (*Garden*), private parking (*Parking)* and balcony or roof terrace (*RB*). Property types and distance to the station are specified too. The first three variables are continuous whereas the others represent dummy variables. The reference categories are set on either residential properties not having a garden, a roof terrace / balcony or private parking. A *Simple home* is the reference for *PropertyType*. *TOD* is continuous and stands for the TOD-ness. Then, interaction variables are included for *PropertyType* and *Distance* on one hand, and *TOD* on the other. *Y* is a temporal variable and *lnJobsPR* is the logarithmic of the number of jobs in place of residence.

In Stage 1, the following hypotheses are tested:

H0: In North-Holland, there is no linear relationship between TOD and residential property values.
H1: In North-Holland, there is a linear relationship between TOD and residential property values.

H0: In North-Holland, there is no different linear relationships between TOD and residential property values for various property types.
H1: In North-Holland, there is a different linear relationships between TOD and residential property values for various property types.

H0: In North-Holland, there is no different linear relationships between TOD and residential property values for various distance bands.
H1: In North-Holland, there is a difference in linear relationships between TOD and residential property values for various distance bands.

In Stage 2, the regression analysis proceeds to test the effect of the TOD-elements for separate TOD environments. Consequently, the model specification is as follows:

$$\ln(Pi) = a + \beta1lnFA + \beta2NR + \beta3NBR + \beta4Garden(yes) + \beta5RB(\text{yes}) + \beta6Parking(\text{yes}) + \beta7'PropertyCategory + + \beta8'Y + \beta9'Distance + \beta10Density + \beta11Diversity + \beta12Design + \beta13Accessibility + \beta14Parking + \beta15lnJobs + \varepsilon i$$

where *Pi* represents a logarithmic transaction price for a certain property *i*. Besides, the model specification concerns variables related to the residential property which corresponds with Stage 1. The second and third part of the specification replaces TOD-ness and concerns the urban environment and the transit. The second part specifies composed continuous variables related to the urban environment along the lines of densities, diversity and urban design. *Density* is a combination of population and commercial establishments. *Diversity* concerns the question whether the land use is heterogenous or homogeneous. *Design* is about the degree to which the street plan is accustomed for cyclists and pedestrians. In the third part, transit is addressed by variables related to accessibility and parking. *Accessibility* is a wide-encompassing proxy on the level of quality of transit. *Parking* is the last transit related variable which pertains parking facilities for cyclists and cars.

In Stage 2, the following hypothesis are tested:

H0: In North-Holland, there are no differences in the directions of the linear relationships between the various TOD-elements and residential property values.
H1: In North-Holland, there are differences in the directions of the linear relationships between the various TOD-elements and residential property values.

4. Results

An introduction, conceptualization of TOD and the applied methodology are given in the first three chapters. The fourth chapter presents the empirical findings. First, the results of the TOD assessment are brought forward for all of the province of North-Holland's station districts. Afterwards, the results of the OLS models regarding the relationship between TOD and residential property values are presented for North-Holland entirely and for these subsamples: *Low TOD*, *Medium TOD* and *High TOD*.

4.1. Transit-oriented development in North-Holland

This section presents to what extent the station districts are oriented to the present transit, while the quality of the associated transit system is taken into account too. Thereby it aims to answer the following sub question:

What is the degree of TOD of railway station districts in the Province of North-Holland?

Sixty station districts are assessed on the basis of sixteen indicators underpinning seven elements. A detailed explanation and computation all indicators can be found in chapter 3 and Appendix A. This section first presents the TOD-ness, then performance per element and finally which station district is categorized in which TOD environment.

4.1.1. Results of the TOD assessment

Results of the TOD assessment for station districts in North-Holland are presented in Figure 6 and Table 5. Figure 6 presents the overall TOD of all station districts' geographically. Station districts on the higher end of the TOD spectrum generally tend to be situated in urbanized regions; this directly follows from the construct of TOD which is largely focused on the urban environment and whether these districts are accessible by transit. Consequently, a concentration of higher TOD districts is found on the southern edge of North-Holland and primarily in Amsterdam. The centrally located station districts of Haarlem, Hilversum and Alkmaar perform relatively well too. Asides, there is vast bulk of station districts scattered across North-Holland with moderate TOD-ness. Finally, the districts around Haarlem come out as worst in terms of TOD.

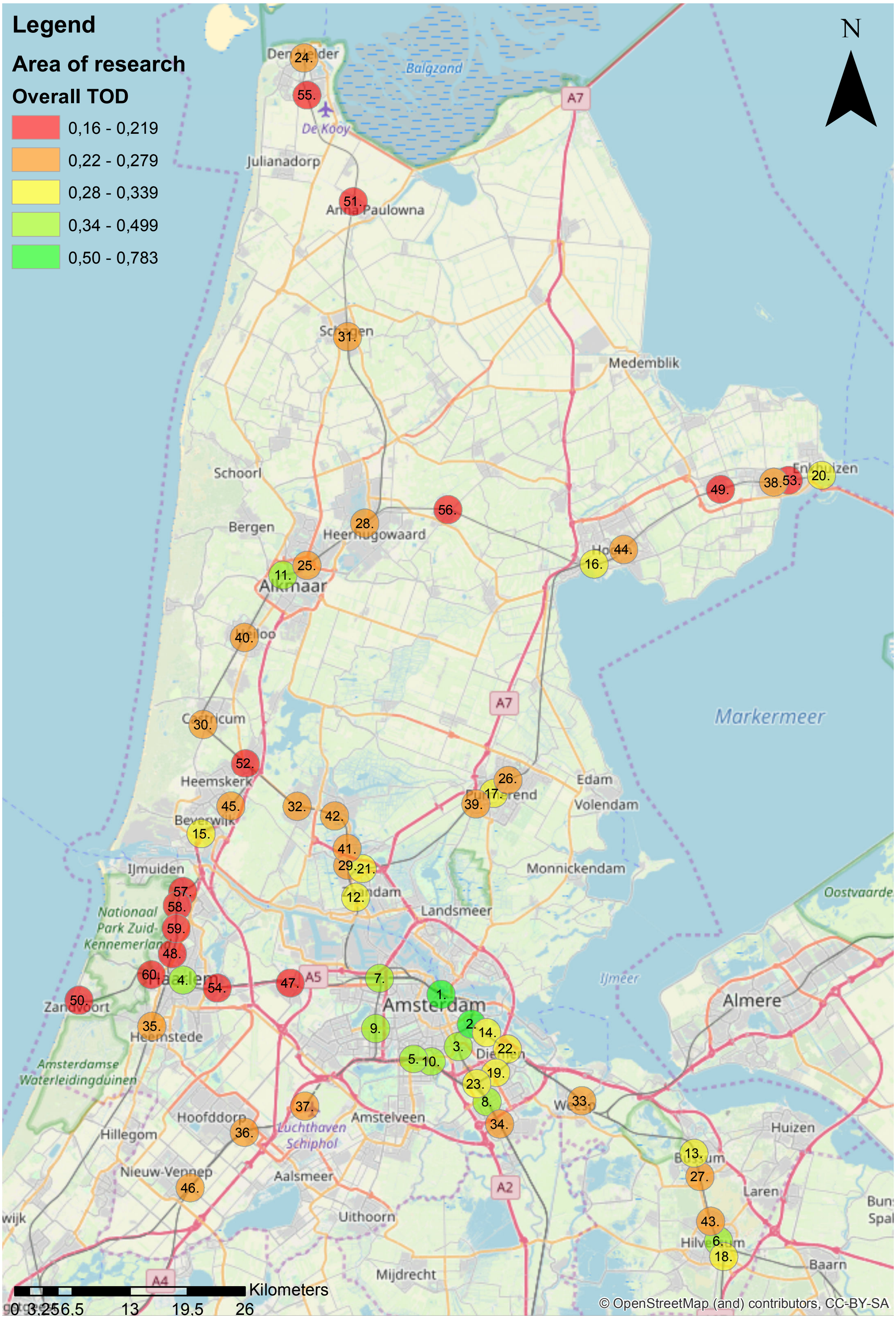

Figure 6: Geographical overview of the station districts' results of the TOD assessment. The colors display the TOD-ness, while the numbers signal the rank of the station district (see Table 4). Own work projected on ArcGIS's base map.

	Overall	Urban Development				Transit		
	TOD	Density	Diversity	Design	Economy	User-friendliness	Accessibility	Parking
1. Amsterdam-Centraal	0,7829	0,59	0,88	0,81	1,00	1,00	0,97	0,06
2. Amsterdam-Muiderpoort	0,5842	0,91	0,59	0,91	0,96	0,22	0,23	0,11
3. Amsterdam-Amstel	0,4925	0,51	0,79	0,86	0,58	0,50	0,33	0,14
4. Haarlem	0,4685	0,41	0,81	0,88	0,47	0,58	0,32	0,23
5. Amsterdam-Zuid	0,4678	0,29	0,89	0,71	0,58	0,43	0,48	0,17
6. Hilversum	0,4386	0,44	0,83	0,89	0,36	0,48	0,32	0,20
7. Amsterdam-Sloterdijk	0,4136	0,13	0,92	0,62	0,32	0,50	0,67	0,07
8. Amsterdam-Bijlmer-ArenA	0,3981	0,28	0,98	0,70	0,33	0,43	0,37	0,20
9. Amsterdam-Lelylaan	0,3753	0,39	0,81	0,86	0,40	0,23	0,21	0,20
10. Amsterdam-RAI	0,3715	0,31	0,82	0,78	0,33	0,25	0,13	0,62
11. Alkmaar	0,3647	0,24	0,84	0,84	0,19	0,53	0,24	0,34
12. Zaandam	0,3305	0,19	0,89	0,77	0,23	0,40	0,26	0,21
13. Naarden-Bussum	0,3211	0,24	0,62	0,68	0,27	0,38	0,16	0,36
14. Amsterdam-Science-Park	0,3187	0,44	0,64	0,67	0,41	0,17	0,11	0,05
15. Beverwijk	0,3177	0,16	0,98	0,60	0,12	0,34	0,11	0,77
16. Hoorn	0,3169	0,18	0,95	0,70	0,16	0,44	0,22	0,30
17. Purmerend	0,2991	0,36	0,68	0,82	0,16	0,20	0,08	0,39
18. Hilversum-Sportpark	0,2881	0,26	0,86	0,75	0,21	0,21	0,13	0,25
19. Diemen-Zuid	0,2874	0,29	0,69	0,73	0,21	0,27	0,12	0,21
20. Enkhuizen	0,2873	0,09	0,78	0,53	0,09	0,32	0,07	0,94
21. Zaandam-Kogerveld	0,2841	0,22	0,83	0,71	0,17	0,23	0,07	0,46
22. Diemen	0,2832	0,21	0,48	0,71	0,16	0,24	0,11	0,58
23. Duivendrecht	0,2811	0,22	0,88	0,63	0,13	0,33	0,27	0,08
24. Den-Helder	0,2746	0,22	0,67	0,80	0,10	0,34	0,09	0,34
25. Alkmaar-Noord	0,2731	0,17	0,63	0,65	0,08	0,29	0,12	0,59
26. Purmerend-Overwhere	0,2702	0,25	0,64	0,80	0,10	0,17	0,07	0,54
27. Bussum-Zuid	0,2672	0,18	0,66	0,64	0,16	0,32	0,10	0,38
28. Heerhugowaard	0,2667	0,10	1,00	0,66	0,09	0,33	0,13	0,42
29. Koog-aan-de-Zaan	0,2608	0,23	0,66	0,78	0,18	0,17	0,09	0,28
30. Castricum	0,2600	0,10	0,60	0,62	0,10	0,29	0,17	0,53
31. Schagen	0,2579	0,12	0,91	0,69	0,09	0,32	0,11	0,37
32. Krommenie-Assendelft	0,2562	0,15	0,54	0,71	0,15	0,27	0,10	0,40
33. Weesp	0,2545	0,14	0,77	0,63	0,13	0,20	0,20	0,33
34. Amsterdam-Holendrecht	0,2512	0,19	1,00	0,70	0,12	0,17	0,17	0,11
35. Heemstede-Aerdenhout	0,2471	0,12	0,44	0,58	0,12	0,34	0,16	0,39
36. Hoofddorp	0,2464	0,08	0,64	0,62	0,10	0,33	0,24	0,21
37. Schiphol-Airport	0,2451	0,01	0,72	0,18	0,05	0,20	0,73	0,00
38. Bovenkarspel-Grootebroek	0,2445	0,15	0,54	0,65	0,09	0,25	0,09	0,51
39. Purmerend-Weidevenne	0,2445	0,22	0,23	0,71	0,13	0,10	0,05	0,68
40. Heiloo	0,2423	0,14	0,53	0,69	0,13	0,27	0,12	0,34
41. Zaandijk-Zaanse-Schans	0,2419	0,21	0,76	0,67	0,12	0,25	0,09	0,20
42. Wormerveer	0,2404	0,10	0,77	0,47	0,10	0,25	0,10	0,58
43. Hilversum-Media-Park	0,2389	0,19	0,80	0,70	0,17	0,21	0,11	0,10
44. Hoorn-Kersenboogerd	0,2344	0,18	0,50	0,78	0,10	0,22	0,11	0,26
45. Heemskerk	0,2332	0,20	0,28	0,74	0,09	0,22	0,05	0,50
46. Nieuw-Vennep	0,2276	0,04	0,81	0,41	0,04	0,23	0,10	0,73
47. Halfweg-Zwanenburg	0,2146	0,07	0,81	0,56	0,08	0,20	0,11	0,39
48. Bloemendaal	0,2141	0,20	0,43	0,55	0,16	0,26	0,06	0,20
49. Hoogkarspel	0,2117	0,05	0,62	0,40	0,05	0,29	0,08	0,61
50. Zandvoort-aan-Zee	0,2084	0,17	0,50	0,64	0,13	0,33	0,04	0,07
51. Anna-Paulowna	0,2019	0,05	0,71	0,30	0,03	0,29	0,07	0,62
52. Uitgeest	0,1982	0,13	0,32	0,52	0,07	0,29	0,11	0,30
53. Bovenkarspel-Flora	0,1969	0,13	0,63	0,48	0,06	0,17	0,08	0,40
54. Haarlem-Spaarnwoude	0,1871	0,08	0,69	0,51	0,09	0,17	0,12	0,20
55. Den-Helder-Zuid	0,1869	0,06	0,83	0,48	0,03	0,22	0,07	0,33
56. Obdam	0,1851	0,03	0,45	0,36	0,05	0,17	0,05	0,70
57. Driehuis	0,1830	0,08	0,46	0,49	0,06	0,20	0,06	0,42
58. Santpoort-Noord	0,1783	0,10	0,49	0,55	0,07	0,13	0,05	0,37
59. Santpoort-Zuid	0,1725	0,11	0,27	0,46	0,07	0,26	0,05	0,32
60. Overveen	0,1602	0,08	0,53	0,51	0,09	0,17	0,06	0,16

Table 4: Aggregated and disaggregated overview of the results of the TOD assessment per individual station district. See Figure 6 for geographical location of the station districts. Own work.

Tabularizing TOD results make it possible to compare districts on the overall and element level, wherefore it becomes clear which station districts in North-Holland are heavily oriented towards the present transit plus high quality transit, and which districts less. Since Table 4 also provides insight into the construct of overall TOD, the relative strengths and weaknesses of the particular station districts come to light as well. However, important to note, the standardization of the assessment render comparisons merely possible within the study area. With a score of 0.78, *Amsterdam Centraal* is unrivalled in North-Holland and therefore comes the closest to the ideal TOD image. It exhibits high scores on nearly all seven elements, except on *Density*, which is due to the presence of the river *'t IJ*, and *Parking*. *Overveen* is the contrast with a score of 0.16. TOD performances of districts therefore vary considerably. Especially on the higher end of the TOD spectrum, notably between *Amsterdam Muiderpoort* and *Amsterdam Centraal*, the differences between the station districts' performance are larger. On the element level, the largest dispersions are found for *Diversity, Economy* and *Parking*.

In addition, it is worthwhile to consider correlations among the TOD-elements in order to detect collinearity and to gain understanding on how the various elements affect each other. Collinearity occurs if there are very high associations among variables, which entails that a variable almost perfectly predicts another. From Table 5, it is clear that *Density* and *Economy* are strongly associated. In addition, there is possibly also high collinearity between *Density* and *Design* on one hand and *Accessibility* and *User-friendliness* on the other. This would mean that higher urban densities result in more economic activity and a more walkable and cyclable urban environment. Likewise, although to a lesser extent, transit nodes with high levels of accessibility are user-friendlier than nodes characterized with lower accessibility. This is also the case when reversed. These kinds of multicollinearities may result in several problems in OLS regressions, which are discussed in more detail later (chapter 4.3. and Appendix C).

	Density	*Diversity*	*Design*	*Economy*	*Accessibility*	*User-friendliness*	*Parking*
Density	1.000						
Diversity	0.057	1.000					
Design	0.748	0.275	1.000				
Economy	0.953	0.139	0.139	1.000			
Accessibility	0.391	0.559	0.559	0.502	1.000		
User-friendliness	0.095	0.438	0.438	0.364	0.755	1.000	
Parking	-0.485	-0.138	-0.390	-0.523	-0.436	-0.169	1.000

Table 5: Correlation matrix of TOD-criteria.

Although there is variation in the magnitude of the correlation, the criteria mostly correlate positively with others. The presence of inhabitants and economic activity requires and attracts infrastructure for transit, pedestrians and other transportation modals. By the same token, the presence of high quality infrastructure draws in economic activity and inhabitants, resulting in higher urban densities. Exception is *Parking* (see Table 4). *Parking* is negatively correlated with all the other criteria. Possibly, this is because the provision of parking facilities is at the expense of scarce land. An explanation for the negative correlation between *Parking* and the others could be as follows: The competition for residential and commercial space constrains the supply of parking facilities. Then, taking into account the number of daily passengers, the performance on *Parking* is considerably lower. Same kind of logic applies on the other urban environment-related elements.

When considering the high ranking TOD districts, all top ten ranking districts are graded relatively high on any kind of element, but *Parking* remains the main disadvantage. Highly urbanized districts cannot fulfill the demanded parking space. *Amsterdam RAI* is the exception because of the vast P&R resulting from the presence of RAI Convention Centre. Districts with an abundance of parking space, are generally located in rural regions or sometimes on outskirts of one of the major cities, e.g., *Diemen* and *Alkmaar-Noord*. Therefore, parking opportunities appear to be insufficient in high TOD districts.

4.1.2. Typology of TOD

Station districts subject to the analysis are finally categorized in order to answer the initial research objective. Clearly, the performance of *Amsterdam Centraal* is incompatible with any other station district. Also, *Schiphol-Airport* is excluded, since it contains no residential properties. Consequently, 58 station districts participate in the categorization and hedonic pricing analysis. In total, three typologies are considered of which the detailed outcomes can be found in Appendix B.

Ultimately, a typology on the basis of TOD-ness and the seven criteria is chosen as most suitable. In Figure 6, the generated distribution of station districts across *Low TOD, Medium TOD* and *High TOD* is given. There are 28 *Low TOD* districts in primarily 'rural' areas, 22 *Medium TOD* districts in (semi-) urban areas and just eight (excluding *Amsterdam Centraal*) *High TOD* districts in the more urbanized areas. Evidently, it is not an equal distribution, but in reality, there are just not as many high TOD districts as there are those of lesser quality. Hence, the categorization of the station districts depicted below reflects reality the best.

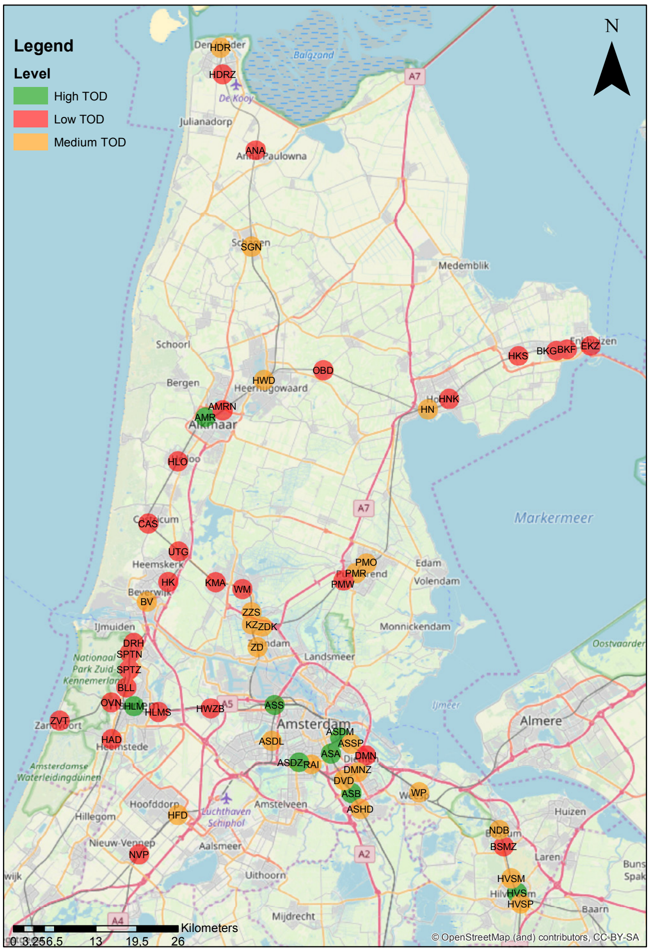

Figure 7: Geographical overview of the categorization of the station districts' results. The colors display the type of TOD environment. The abbreviation stands for the station's name. Own work projected on ArcGIS's base map.

Observed residential property transactions are approximately equally distributed across *Low TOD, Medium TOD* and *High TOD* (see Table 6). Finally, the properties sold each year are nearly equally distributed when it comes to the division house and apartment.

	2014		*2015*		*2016*		*2017*		*Total*
	House	Apartment	House	Apartment	House	Apartment	House	Apartment	
Low	1,671	718	2,069	844	2,178	1,001	1,923	840	*11,244*
Medium	1,281	1,442	1,479	1,744	1,594	1,798	1,517	1,450	*12,305*
High	583	1,720	632	1,791	741	1,819	643	1,448	*9,377*
Total	*3,535*	*3,88*	*4,180*	*4,379*	*4,513*	*4,618*	*4,083*	*3,738*	*32,926*

Table 6: Overview of the observations per year and property category.

4.2. Transit-oriented development & residential property values

This section reports OLS regression results of pertaining the relationship between TOD and residential property values. A variety of questions are relevant here. Foremost, it is interesting to find whether TOD in general affects residential property values, and whether this is a positive or a negative relationship. Asides, willingness to pay for property types in certain TOD environments and the proximity to the station is worthwhile to research. Also, it is interesting to understand which TOD-elements form the heart of the concept, relative to residential property values. Answers to these questions help to answer the following sub question:

What is the relationship between TOD and residential property values in North-Holland's station districts?

Subsequent section consists of Stage 1 and Stage 2. Stage 1, most importantly, tests whether there is a linear relationship between *TOD* and logarithmic *Transaction price*. And if so, which property types and which distance bands are affected the most. Stage 2 delves into the TOD-elements and submarkets. It clarifies which elements form the core of TOD and for which property category the willingness to pay is higher in which TOD environment. Accordingly, the OLS results are presented in two subsections.

4.2.1. Stage 1

Stage 1 explores the effect of *TOD* on the logarithmic *Transaction price*. All 32,926 observations across North-Holland are included, which allow for statements on the general relationship. Thereby Stage 1 consists of four OLS models (see Table 7): The first OLS model displays the regression coefficients of physical house characteristics, while controlling for time effects. From here, OLS models are gradually expanded by including additional control variables in order to display alterations of the effects. The four OLS models are better than no model, since the F-tests are significant. The adjusted R^2 is relevant as it considers the model-fit. In Model 1, 65.3% of the variation in logarithmic *Transaction price* is explained. Adding *TOD* and *Distance* in Model 2, improves the adjusted R^2 to 69.9%. When controlling for the logarithmic *Jobs per place of residence* in Model 3, the adjusted

R^2 slightly improves, but more importantly, *TOD* loses explanatory power since number of jobs is related to residential property values as well (Rappaport, 2008). Finally, in order to find variation in the effect of *TOD* on property types and distance bands, Model 4 includes interaction variables between *Property type* and *Distance* on one hand, and *TOD* on the other. Model 4 is able to explain 71.1% of the variation in logarithmic *Transaction price*.

Unlike the F-test and adjusted R^2, T-tests are indicators for the correlation between logarithmic *Transaction price* and the independent variables. The null hypothesis here is that the slope is zero and is rejected by P-values lower than 0.05 (**) or 0.01 (***). P-values of 0.1 (*) or more are not considered significant. Furthermore, for the interpretation, it is important to note that a log-linear model is used for all models, meaning that *Transaction price* is transformed to logarithm, which is the inverse function to exponentiation. However, there are two exceptions, namely log-log models for the effect of *Floor area* and *Jobs per place of residence* on *Transaction price*. These two variables appear to be not normally distributed wherefore a transformation is required (see Figure 17 and 18 in Appendix C).

Stage 1

	Model 1		*Model 2*		*Model 3*		*Model 4*	
Variables	*Coefficient*		*Coefficient*		*Coefficient*		*Coefficient*	
(Constant)	7.846 ***	(0.0328)	7.383 ***	(0.0319)	7.284 ***	(0.0329)	7.469 ***	(0.0493)
Physical house characteristics								
lnFloor area	0.871 ***	(0.0078)	0.891 ***	(0.0073)	0.887 ***	(0.0073)	0.891 ***	(0.0072)
Number of rooms	0.021 ***	(0.0020)	0.020 ***	(0.0018)	0.019 ***	(0.0018)	0.016 ***	(0.0018)
Number of bathrooms	0.063 ***	(0.0038)	0.058 ***	(0.0035)	0.058 ***	(0.0035)	0.061 ***	(0.0034)
Garden(yes)	-0.004	(0.0060)	0.008	(0.0056)	0.009 *	(0.0055)	0.007	(0.0055)
RB(yes)	0.079 ***	(0.0043)	0.076 ***	(0.0040)	0.078 ***	(0.0040)	0.081 ***	(0.0039)
Parking(yes)	0.077 ***	(0.0046)	0.104 ***	(0.0043)	0.104 ***	(0.0043)	0.101 ***	(0.0042)
Property type								
Single family property	0.178 ***	(0.0113)	0.185 ***	(0.0105)	0.187 ***	(0.0105)	0.280 ***	(0.0361)
Townhouse, canalside property	0.391 ***	(0.0142)	0.335 ***	(0.0133)	0.340 ***	(0.0132)	0.317 ***	(0.0419)
Bungalow, recreational house, houseboat	0.335 ***	(0.0271)	0.369 ***	(0.0252)	0.364 ***	(0.0252)	0.249 **	(0.1050)
Villa, country house, former farm	0.588 ***	(0.0155)	0.593 ***	(0.0144)	0.599 ***	(0.0144)	0.833 ***	(0.0472)
Groundfloor apartment	0.615 ***	(0.0131)	0.489 ***	(0.0123)	0.472 ***	(0.0123)	0.178 ***	(0.0405)
Upper-floor apartment	0.548 ***	(0.0130)	0.402 ***	(0.0123)	0.379 ***	(0.0124)	0.014	(0.0379)
Maisonnette	0.140 ***	(0.0157)	0.101 ***	(0.0146)	0.096 ***	(0.0146)	-0.206 ***	(0.0450)
Flat with porch	0.240 ***	(0.0135)	0.224 ***	(0.0126)	0.219 ***	(0.0125)	0.084 **	(0.0381)
Apartment with external access	0.110 ***	(0.0143)	0.113 ***	(0.0133)	0.105 ***	(0.0133)	0.090 **	(0.0414)
Duplex apartment	0.658 ***	(0.0300)	0.488 ***	(0.0280)	0.470 ***	(0.0280)	-0.046	(0.0948)
Temporal variables								
2015	0.075 ***	(0.0051)	0.080 ***	(0.0048)	0.080 ***	(0.0048)	0.081 ***	(0.0047)
2016	0.174 ***	(0.0051)	0.181 ***	(0.0047)	0.182 ***	(0.0047)	0.185 ***	(0.0046)
2017	0.281 ***	(0.0053)	0.290 ***	(0.0049)	0.291 ***	(0.0049)	0.294 ***	(0.0048)
Distance to transit								
250-500			0.018 **	(0.0079)	0.015 *	(0.0079)	-0.080 ***	(0.0216)
500-750			0.031 ***	(0.0075)	0.027 ***	(0.0075)	-0.082 ***	(0.0207)
750-1000			0.050 ***	(0.0075)	0.044 ***	(0.0075)	-0.092 ***	(0.0207)
Overall TOD								
TOD			1.047 ***	(0.0150)	0.876 ***	(0.0205)	0.180	(0.1200)
Interactions								
Single family property*TOD							-0.323 ***	(0.1110)
Townhouse, canalside property*TOD							0.112	(0.1240)
Bungalow, recreational house, houseboat*TOD							0.364	(0.3790)
Villa, country house, former farm*TOD							-0.835 ***	(0.1500)
Groundfloor apartment*TOD							0.743 ***	(0.1160)
Upper-floor apartment*TOD							0.864 ***	(0.1110)
Maisonnette*TOD							0.861 ***	(0.1300)
Flat with porch*TOD							0.394 ***	(0.1140)
Apartment with external access*TOD							0.022	(0.1240)
Duplex apartment*TOD							1.182 ***	(0.2070)
250-500*TOD							0.270 ***	(0.0601)
500-750*TOD							0.319 ***	(0.0577)
750-1000*TOD							0.405 ***	(0.0576)
Control variable								
lnJobs per place of residence					0.018 ***	(0.0015)	0.022 ***	(0.0014)
Observations	32,926		32,926		32,926		32,926	
Prob > F	0,000		0,000		0,000		0,000	
Adjusted R^2	0.653		0,699		0.700		0,711	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Regression results of the first four models of Stage 1. Own work based on dataset.

General effect of TOD

This paragraph tests for a linear relationship between TOD and residential property values in North-Holland. Based on the results of Model 3, a positive linear relationship is found between *TOD* and logarithmic *Transaction price* in North-Holland on a level of 99%. An one tenth increase in *TOD*, results in an increase of 9.16% in transaction price. Conversely, an one tenth decrease in *TOD* translates into a 9.16% lower transaction price. In this way, if all else being equal, a property situated in, for instance, *Amsterdam Sloterdijk* has a higher predicted residential property value, compared to the same property in *Nieuw Vennep*'s station district. The higher residential property values in are casued by the added value of being located in central areas, such as *Amsterdam Sloterdijk*. Clearly, there is higher demand for residential properties as TOD-ness of a district increases, which is in accordance with the ongoing urbanization trend. Thus, according Model 3's output, overall TOD is positively correlated with the logarithmic *Transaction price* in North-Holland.

Effect of TOD on property types

However, when delving further into the effects of TOD on residential property values by interacting *TOD* with *Property type* and *Distance*, considerable variation is found between property types and distance bands. As such, Model 4 explores whether there are differences in the effect of *TOD* on logarithmic *Transaction price* for *Property type* and *Distance*. This paragraph tests for different linear relationships between TOD and residential property for property types. The first ten coefficients listed below *Interactions* concern the effect of *TOD* on the logarithmic *Transaction price* for various property types compared to the reference category, namely *Simple home*.

The effect of *TOD* on the logarithmic *Transaction price* of T*ownhouse & canal side property, Bungalow, recreational house & houseboat* and *Apartment with external access* is not significantly different from *Simple home* on a 95% level. In contrast, the effect of *TOD* on the logarithmic *Transaction price* of S*ingle family property, Villa, country house, former farm, Groundfloor apartment, Upper-floor apartment, Maisonnette, Flat with porch* and *Duplex apartment* are significantly different from the effect of *TOD* on logarithmic *Transaction price* of *Simple home* on a 99% level. Consequently, different linear relationships between TOD and residential property values for property types in North Holland is accepted.

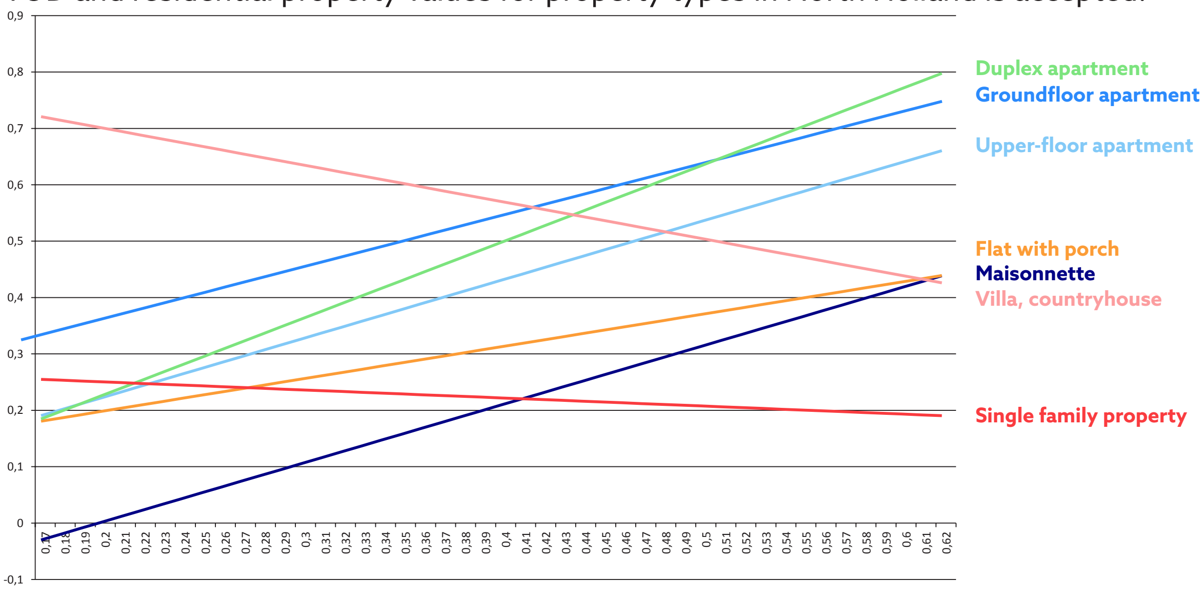

Figure 8: Significant interaction effects between property types and TOD on housing prices. Own work based on dataset.

It is interesting to shed more light on the signs and magnitude of the significant regression coefficients of the apartment-like and house-like properties (see Figure 8). In the case of *Duplex apartment, Groundfloor apartment, Upper-floor apartment, Maisonette* and *Flat with porch, TOD* is positively correlated with logarithmic *Transaction price*. Positive correlations entail higher willingness' to pay as TOD increases. Contrarily, *TOD* is negatively correlated with logarithmic *Transaction price of Single family property, Villa, country house* and *former farm*. Negative correlations entail lower willingness' to pay as TOD increases. Consequently, significant differences in the linear relationships exist between TOD and residential property values for apartment-like and house-like properties. Additionally, the interaction regression coefficient of a *Duplex apartment* differs significantly from a *Flat with porch* since the associated 95% confidence intervals do not overlap.

Lastly, the magnitude of the correlations suggest that an apartment-like property is generally more sensitive to *TOD*, than a *Single family property.* If all else being equal, the willingness to pay for a certain *Single family property* varies not as heavily when *TOD* changes as, for instance, a *Groundfloor apartment* varies. Therefore the willingness to pay for an apartment-like property depends to a larger extent on *TOD*. In this way, an increase in *TOD* affects logarithmic *Transaction price* of property types in North-Holland asymmetrically in terms of direction and magnitude.

Effect of TOD on distance bands

This paragraph tests for different linear relationships between TOD and residential property values for distance bands. According to Model 3's output, residential property values slightly depend on their proximity to stations. Willingness to pay is significantly higher for properties located from 500 to 1,000 meters from the station on a 95% level, compared to similar properties in 0 to 250 meters. When interacting with *TOD* in Model 4, the effects become even stronger, which indicate variation in the effects on distance bands. The last three coefficients listed below *Interactions* concern the effect of *TOD* on the logarithmic *Transaction price* for the three outer distance bands compared to the reference category, namely *0 to 250 meters*. Effects of *TOD* on logarithmic *Transaction price* for properties in distance band *250 to 500 meters, 500 to 750 meters and 750 to 1,000 meters* significantly differ from *0 to 250 meters* on a 99% level. Consequently, a difference in linear relationships is found between TOD and residential property values for properties situated within 250 meters and farther than 250 meters from the station.

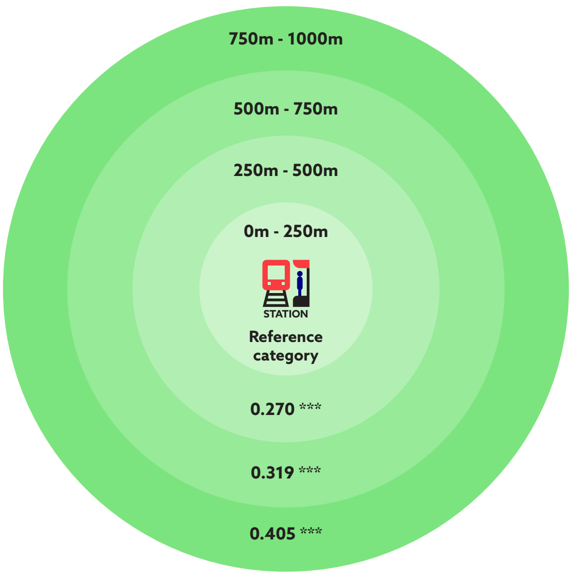

Figure 9: Interaction effects between distance bands and TOD on housing prices. Own work based on dataset.

From Table 7 and Figure 9, it is presented that interaction regression coefficients increase with distance. Although the three outer distance bands do not significantly differ from one another, it may be speculated that the effect of *TOD* on residential property values is increasingly heavier as distance to stations grow. As such, the more distant the residential property is located within station districts, the heavier the willingness to pay is affected by an upgraded station districts in terms of TOD, compared to properties adjacent to the station. This suggests that changes in TOD generates positive and negative externalities. It appears, however, that externalities are unevenly distributed across the distance bands. It may be that negative externalities primarily concentrate closely around stations and affect the quality of life of those inhabitants; for instance, this may be because of the nuisance produced by an ever-growing station, or the increased passenger flow in the main streets adjacent to the station. Contrarily, inhabitants farther away tend to reap the positive externalities, such as increased accessibility offered by the station, rather than the negative externalities. As a consequence, these property values are driven upwards.

Above described findings claim, with slight uncertainty, rising residential property values with higher *TOD* for apartment-like properties. Or formulated differently, an increase in overall TOD has an adverse effect for houses' residential property values. The merits in terms of residential property values resulting from an increase in *TOD* tend to rise with distance from stations. Altogether, an increase in overall TOD is more beneficial for residential property values of apartments more distant from a station. Consequently, the first three null hypotheses are rejected in Stage 1.

4.2.2. Stage 2

Earlier in this chapter, a positive relationship between TOD and residential property values is established. Yet, it is unknown which TOD-elements primarily account for this effect. By giving attention to the effect of the elements constituting TOD per subsample (*Low TOD, Medium TOD and High TOD*), it is possible to identify the drivers of the upward trend. Unfortunately, *High TOD* is supplemented by *Medium TOD*, due to violation of OLS assumptions (see Appendix C). For the same reason, *Economy* and *User-friendliness* are eliminated. In this form, the OLS models of Table 8 highlight the implicit value contribution of *Density, Diversity, Design, Accessibility* and *Parking* to residential property values per TOD environment. Also, the OLS models allow for statements pertaining the willingness to pay for houses or apartments in certain TOD environments. This may be regarded as either a confirmation or rejection of Stage 1's conclusions.

The three OLS models are better than no models, since the F-tests are significant. The adjusted R^2 of the OLS models are 73.8% for *Low TOD*, 76.4% for *Medium TOD* and 75.7% for *Medium & High TOD*. Interpretation of the regression coefficient is the same as in Stage 1.

Effect of TOD-elements
This paragraph tests for differences in the directions of the linear relationships between the various TOD-elements and residential property values. With regard to regression coefficients listed below *TOD*, it is first important to note that the TOD-elements' regression coefficients for the subsamples, thus TOD environments, are significant on a 99% level, thereby implying linear relationships between the elements and logarithmic *Transaction price*. At first glance, apart from *Parking* the OLS models do not exhibit inconsistencies across TOD environments with regard to the signs of the coefficients.

Stage 2

Variables	Low TOD Coefficient		Medium TOD Coefficient		Medium & High TOD Coefficient	
(Constant)	8.921 ***	(0.0574)	8.196 ***	(0.0559)	7.764 ***	(0.0432)
Physical house characteristics						
lnFloor area	0.947 ***	(0.0120)	0.887 ***	(0.0111)	0.938 ***	(0.0079)
Number of rooms	-0.004 *	(0.0026)	0.031 ***	(0.0029)	0.026 ***	(0.0021)
Number of bathrooms	0.078 ***	(0.0053)	0.084 ***	(0.0053)	0.065 ***	(0.0039)
Garden(yes)	-0.052 ***	(0.0079)	0.060 ***	(0.0076)	0.075 ***	(0.0055)
RB(yes)	0.073 ***	(0.0061)	-0.003	(0.0059)	0.001	(0.0043)
Parking(yes)	0.144 ***	(0.0058)	0.174 ***	(0.0065)	0.112 ***	(0.0052)
Property category						
Apartment	-0.114 ***	(0.0098)	0.051 ***	(0.0092)	0.097 ***	(0.0067)
Temporal variables						
2015	0.080 ***	(0.0075)	0.088 ***	(0.0071)	0.096 ***	(0.0054)
2016	0.148 ***	(0.0073)	0.198 ***	(0.0070)	0.220 ***	(0.0053)
2017	0.254 ***	(0.0076)	0.318 ***	(0.0073)	0.336 ***	(0.0055)
Distance to transit						
250-500	0.009	(0.0112)	0.008	(0.0121)	0.021 **	(0.0094)
500-750	0.029 ***	(0.0108)	-0.005	(0.0115)	0.035 ***	(0.0090)
750-1000	0.023 **	(0.0109)	0.038 ***	(0.0114)	0.067 ***	(0.0089)
TOD						
Density	1.529 ***	(0.0920)	1.526 ***	(0.0466)	0.532 ***	(0.0165)
Diversity	-0.319 ***	(0.0226)	-0.671 ***	(0.0298)	-0.883 ***	(0.0272)
Design	-0.807 ***	(0.0486)	-1.711 ***	(0.0403)	-1.057 ***	(0.0306)
Accessibility	1.259 ***	(0.0725)	1.091 ***	(0.0398)	0.784 ***	(0.0186)
Parking	-0.367 ***	(0.0160)	0.181 ***	(0.0154)	0.084 ***	(0.0146)
Control variable						
lnJobs per place of residence	-0.075 ***	(0.0043)	0.069 ***	(0.0022)	0.089 ***	(0.0016)
Observations	11,244		12,305		21,682	
Prob > F	0,000		0,000		0,000	
Adjusted R^2	0.738		0.764		0.757	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Regression results of the three models of Stage 2. Own work based on dataset.

However, contrarily to the expectation, not all 'improvements' in TOD-elements positively correlate with residential property values. Results to 'improvements' in TOD-elements are highly ambiguous. Namely, in station districts being categorized in *Low TOD*, an increase in *Density* and *Accessibility* is positively correlated with the logarithmic *Transaction price*, whereas *Diversity, Design and Parking* is negatively correlated. Similar coefficient signs are found for urban environment-related elements plus *Accessibility* in *Medium TOD*. However, the sign of *Medium TOD*'s *Parking* is reversed relative to *Low TOD*.

The coefficient signs of *Medium & High TOD* corresponds with *Medium TOD*. However, the differences in magnitudes provide insights on the relationships between the elements and logarithmic *Transaction price* in *High TOD*. In general, the relationships are slightly attenuated in *Medium & High TOD* compared with *Medium TOD*. Only *Diversity* correlates even more negatively with logarithmic *Transaction price* in *High TOD*. Furthermore, it may be assumed that, first, suddenly *Density* correlates negatively with logarithmic *Transaction price* in *High TOD*. This suggests that inhabitants of properties located in high TOD-districts appreciate less densified districts and are willing to pay for this. *Design* correlates less negatively with residential property values in *High TOD* relative to *Medium TOD*. *Accessibility* remains positively correlated, but is of less importance in explaining residential property values in *High TOD* compared to *Medium TOD*.

Despite marginal differences in coefficient signs, two clear patterns with regard to the magnitude are found in Stage 2 when shifting from *Low TOD* to *High & Medium TOD*. First, TOD increases, the stronger the negative correlation between *Diversity* and residential property values. *Diversity* can be thought of as proxy for calmness. The higher *Diversity*, the less calm or restful the environment. The negative correlations for *Diversity*, suggest that the willingness to pay increases for properties nested in higher TODs as the district is less diversified. Second, as TOD increases, the weaker the correlation between *Accessibility* and residential property values. In fact, high TOD districts are already situated in urban centers. Inhabitants of high TOD district rely therefore less on transit accessibility and therefore possibly attribute less value to it. Theoretically, increases in *Accessibility* could even distort residential enjoyment as negative externalities arise.

The heterogeneous correlations of the TOD-elements with residential property values render it debatable to determine the core of TOD or which TOD-strategy best to pursue. Even though higher walkability and cyclability, more diverse places or greater parking opportunities constitute TOD, it is not necessarily appreciated by residents wherefore it is not leading to higher residential property values. Yet, in spite of this, *Accessibility* correlates positively with residential property values on 99% level across the three TOD environments. *Density* positively correlates with residential property values in *Low TOD* and *Medium TOD*, but it remains highly uncertain whether *Density* positively correlates in *High TOD*. As such, *Accessibility* could be appointed as the primary driver of the upward trend in residential property values. Thus, providing sufficient *Accessibility* could be a catalysator for the development of successful TOD. Important to keep in mind though, the findings are correlations, which merely tell how strongly the variables of interest are linearly related and change together. On the basis of correlation, it is hazardous to point out cause and effect, since the direction of causation may be the opposite of what is assumed. Panel data is required in order to claim causality (see chapter 5.3.).

Lastly, due to the incorporation of temporal effects in Stage 2, it is possible to monitor in which kind of TOD environment the residential property values increased the quickest. From the Table 8, it follows that the willingness to pay for residential properties nested in *Medium TOD* rose quicker between 2014 and 2017, than in *Low TOD*. Even when including observations nested in *Medium TOD*, the output results concerning *Medium & High TOD* display on its turn even stronger increases in residential property values than is the case for properties in *Medium TOD*. Therefore, on a more speculative note, it is likely that the willingness to pay for properties in high TOD environments have experienced even steeper increases than *Medium TOD*. As such, the results mirror the urbanization wave, since the willingness to pay for more TOD, thus centrally and urbanized districts with higher accessibility, increased over the time. This indicates healthier demand for residential properties in moderate to high TOD environments, rather than low TOD- environments.

Sensitivity analysis

Previously, in Stage 1, a twofold conclusion is drawn. On one hand, an increase in *TOD* causes a general upward shift in logarithmic *Transaction price*. On the other hand, an increase in *TOD* is more beneficial for apartment-like properties and for properties located more distant from stations. In this subsection, the aim is to confirm or reject the findings of Stage 1. Through distinguishing TOD environments, it is possible to identify differences when environments become more transit-oriented. For this purpose, a dummy variable provides insight into whether the willingness to pay differs for houses or apartments, and if so in which TOD environment. Also, this subsection illustrates which distance bands tend to be more attractive in terms of residential property values.

Again, in Stage 1, apartment-like properties' prices respond stronger to an increase in *TOD* than house-like properties. On the basis of the OLS models of Stage 2, this can be confirmed. Namely, when interpreting the dummy variable *Apartment* in *Low TOD*, it becomes clear that the willingness to pay for apartments is significantly lower than for regular houses on a 99% level. Next, if the environment is moderately oriented to transit, the sign of the significant regression coefficient is reversed, meaning that the willingness to pay for apartments is significantly higher in *Medium TOD* than for houses on a 99% level. Naturally, even a stronger effect favoring apartment-like properties in *High TOD* is expected. This is indeed confirmed by *Medium & High TOD*'s regression coefficient. Even when including properties nested in *Medium TOD*, it reflects once more a higher willingness to pay for apartment-like properties than for houses on level 99%. Hence, it is confirmed that the willingness to pay for apartments is higher in moderate to high TOD environments.

In addition, Stage 1 displays positive linear relationship between logarithmic *Transaction price* and *TOD* as distance to a station grows. This relation can only be partially confirmed on the basis of Stage 2. In *Low TOD*, the willingness to pay for residences located in the outer two distance bands is significantly higher than the willingness to pay for properties nested in the inner distance band (reference band). However, the results of *Medium TOD* render interpretation somewhat complicated. Just the most outer distance band significantly differs from the reference band. *Medium & High TOD* in turn confirms the sketched linear relationship, since the impact of being located in one of the outer distance bands differ significantly from the reference band. Hence, the willingness to pay for properties located on increasingly greater distances appears to be higher, although this cannot be fully confirmed.

5. Conclusion & discussion

After having presented the results, the final answers to the research questions are provided in the following sequence in this chapter. First, the elements constituting and determining TOD are addressed. Afterwards, the TOD-ness of station districts in North-Holland is presented. Lastly, the relationship between the TOD-ness and residential property values is evaluated. The findings are reflected upon with respect to the existing academic literature. Finally, policy implications and further research recommendations on transit-oriented development are drawn up.

But first, time to discuss the value added. This thesis contributes to the literature in several respects: First, this thesis fills an academic gap by evaluating TOD as an overall concept and by its elements individually in order to find the direction of the various effects. Second, since commuter railway stations in North-Holland function as the study area, this thesis adds on one hand to the empirical evidence on TOD-ness in the province of North-Holland, while on the other hand it is a continuation of Singh's TOD-Index. Thereby, it attempts to understand which TOD-elements are accountable for value creation in terms of residential property values. These findings, which are summarized in the next subsection, might be of practical use for a variety of urban stakeholders, such as researchers, urban planners, policy makers, and real estate developers and investors.

1. Which elements determine the degree of TOD in a commuter railway station district?

TOD is an urban planning concept which integrates land use and transit systems in order to support transit use. It relates to the quality of the transit and to what extent the urban environment is oriented to it. As long as it theoretically supports TOD, all sorts of subjects, indicators and criteria could be measured and quantified. Despite TOD's rise, measuring and quantifying TOD is in a preliminary stage. Singh (2015) is one of the first who carried out attempts to quantify TOD around existing railway stations through an index. Singh's TOD-Index builds further on earlier work. For instance, on the work of Cervero (1997, 2009) who argued that high urban densities, high diversity in land use, pedestrian and cycling accustomed urban design and excellent accessibility are crucial for TOD, together with user-friendliness of transit and parking facilities.

2. What is the degree of TOD of commuter railway station districts in the Province of North-Holland?

Ideally, TOD is a varied program of moderate to high densities, mixed use and well-designed public space near user-friendly transit with excellent accessibility and sufficient parking space. Derived from the TOD assessment, all station districts appear to be rather unique with their associated strengths and weaknesses. Overall, one easily interprets a relatively weak performing North-Holland on TOD. However, the results provide a somewhat wrong message because all criteria's outcomes are offset to the best performing district, mostly *Amsterdam Centraal*. In this capacity, station districts are often poorly depicted, but perform fairly well relative to their function.

Therefore it is fairer to consider the typology of TOD, namely being either barely, moderately or highly oriented to transit. In this way, the distribution of districts across the

TOD environments is more comprehensive. An image arises wherein the bulk of station districts is barely oriented to the transit present. These kinds of stations are often located in towns and on the outskirts of midsized cities. Districts which are moderately oriented to transit are generally located within midsized cities or on the outskirts of Amsterdam. Then, the larger agglomerations, such as Amsterdam, Haarlem, Hilversum and Alkmaar, accommodate the station districts which are highly oriented to transit. Unsurprisingly, there are not as many high TOD districts as there are those of lesser TOD. Overall, the degree of TOD in North-Holland as a whole is moderate.

3. What is the relationship between TOD and residential property values in North-Holland's station districts?

The empirical findings of the hedonic pricing analysis suggests a positive linear relationship between TOD and residential property values. An environment oriented to a greater extent to transit nodes offering excellent accessibility, is found to drive up the value of residential properties. Indeed, the attractiveness is being capitalized into higher residential property values. Not surprisingly, since urban living is in high demand. Such findings are greatly in line with the prediction of Belzer and Autler (2002) and Bartholomew et al. (2011).

However, more interestingly, there are differences between TOD's effect on residential property values between property types and distance bands which are not reflected in the general relationship. Apartment-like properties respond positively to an increase in TOD. Houses, however, respond negatively to an increase in TOD, i.e. the willingness to pay for apartment-like properties in an environment on the higher end of the TOD-spectrum is significantly higher than house-like properties in a similar environment. Moreover, the willingness to pay for an apartment-like property is generally more sensitive to TOD, than a *Single family property*. These findings are in accordance with Atkinson-Palombo (2010), whose study differentiated between condominiums and single family properties, and finds that condominium prices are more sensitive to alterations of TOD-elements.

Additionally, locations within station districts play a role in determining residential property values. Distance bands have marginal impacts on residential property values, but slightly grows as distances expand. Impact of distance bands on property values is much stronger when interacted with TOD. Moreover, the impact is increasingly heavier as distance from the station grows. The more distant the residential property is located within station districts, the heavier the willingness to pay is affected by an upgraded station districts in terms of TOD, compared to properties adjacent to the station. This suggest there are unequal distribution patterns of externalities active in this respect. Mohammad et al. (2013) find similar unequal distribution patterns of externalities.

TOD is disaggregated into elements to gain a deeper understanding of the individual impact on residential property values. Consequently, impact of the elements on residential property values appear to be heterogeneous in terms of direction and magnitudes. Only *Accessibility* consistently correlates positively with residential property values, whereas *Diversity, Design and Parking* consistently correlate negatively. This rejects the synergistic effects between transit proximity on one hand, and pedestrian and amenity-dominated mixed-use environments on the other hand to an extent (Atkinson-Palombo, 2010; Duncan, 2010). Important to note furthermore, it is problematic to appoint crucial TOD-elements, since the findings concern correlations and not causations. However, it may be stated that *Density* and *Accessibility* are crucial for the creation of successful TODs. Singh (2015), as well, attributed the highest weights to *Density* and *Accessibility*. As such, *Density* and *Accessibility* are elements which could be targeted in order to improve TOD, while not being detrimental to residential property values.

Overall, TOD plays a role in explaining residential property values around commuter railway stations in the Province of North-Holland, as residential properties situated in districts more oriented to transit display higher residential property values. The main driving force behind the upward trend of residential property values is accessibility. Important to note, TOD's impact is asymmetric across property types and distance bands. First, apartment-like properties respond positively to an increase in TOD, whereas house-like properties respond negatively. Second, properties farther away from the station are affected heavier, compared to nearer properties.

5.1. Policy implications

The Netherlands is in the initial phase of a large-scale building task. Between today and 2030, over one million houses will have to be built in order to meet the national housing demand. TOD is a possible strategy and this thesis supports the concept of TOD. Apart from benefits such as the economic added value, positive health effects and ecological advantages, TOD appears to be appreciated by residents as it indicates a market-potential for more TOD. As such, local governments may embrace and propagate TOD as one of the strategies to pursue the forthcoming building task. However, it is important to develop TODs alongside other urban development types since there are a few disadvantages. Pursuing merely TOD, for instance, leads to scarcity in non-TOD locations, and inner-city developments are also known as time and cost intensive relative to developing expansion locations.

Moreover, due to the popularity of cities and subsequent urbanization wave, housing affordability and accessibility to the housing market is at stake. An upgraded urban district is generally perceived as positive, but, as indicted in this thesis, urban redevelopment also leads to rising property values and ultimately displacement of certain segments of the urban population. Not merely because of housing affordability, but also the worsening provision of basic services to lower income residents lead to displacement effects, since neighborhood-serving commercial areas switch from serving basic needs to more luxurious items (Bates, 2013). Therefore, policy makers are advised to formulate anti-gentrification strategies to prevent displacement effects. Incorporating fixed minimum shares of social housing and essential basic services into transit-oriented development is an interesting start (Belzer and Autler, 2002; Hochstenbach, 2016). In principal, inclusive revitalization of urban districts along the lines of the TOD-concept has priority.

Nevertheless, empirical findings signal, healthy market demand for high TOD location, because of sharper increases in willingness to pay over time for properties nested in environments characterized as highly TOD compared to lower TOD. It is then advised to largely take up apartment-like properties in development plans for environments on the higher end of the TOD-spectrum. Contrarily, house-like properties have price premiums on the lowest end of the spectrum, wherefore these development programs arguably must largely consist of house-like properties. Furthermore, the search scope for building locations could be enlarged since the effects geographically widespread. Due to the wide-ranging benefits of TOD, its market potential and widespread effects, it appears to be realistic to create high TOD districts.

It is recommended to not merely concentrate investment efforts in the already better performing TOD environments where development opportunities are scarce and costs high. Instead, also target seemingly more peripheral station districts, such as Halfweg and Haarlem-Spaarnwoude, in order to support and relieve pressure on the main transit hubs. Development of these districts could contribute to the solution for mobility and housing dilemma, while at the same time offering new sorts of living environments at relatively low development costs. Providing or improving accessibility is presumably of foremost importance for catalyzing such inner-city developments.

Nevertheless, in order to accelerate urban development along the lines of TOD, it is necessary to identify common interests and objectives of the stakeholders. If TOD is successfully implemented, local governments could recapture value through higher tax revenues from increased property values (Belzer an Autler, 2002). Also, the introduction of additional duties on private individuals and enterprises who benefit from investments in public transit may be considered, which in turn could be reinvested into transit (Clahsen, 2019). Lastly, transit investments could be partly covered through the development of housing by the transport company in the station district, for example as is the case in Singapore and Hongkong (Jager, 2019). Sharing the costs and benefits equally among stakeholders could accelerate the development of transit and associated inner-city developments.

5.2. Limitations & research recommendations

This thesis employs cross-sectional data. In this capacity, it cannot display behavior over time or determine cause and effect. Also, hedonic pricing analysis has disadvantages as well, for instance, it cannot incorporate all external influencing factors into the analysis. Moreover, correlation is not necessarily causation, wherefore claiming causality must be handled with care. Given the approach in this thesis, several improvements and recommendations for future research are advised.

First of all, the findings of this thesis concern correlations. Therefore, it is complicated to claim causations. This renders it interesting to delve further into the elements of TOD and their effects on residential property values. Namely, the findings of this thesis state that mainly accessibility correlates positively with residential property values but it is impossible to identify the direction. Hypothetically, the following is likely: Accessibility could be the foremost catalyst determining residential property values and thereby could cause densification of scarce and highly demanded space around the station. Through the application of a Granger causality method on panel data about the implemented TOD-variables, it would be possible to derive causations. This would be incredibly beneficial for a future TOD-investment strategy.

Second, if a follow-up study were to be conducted, it is recommended to measure and quantify TOD on different scale levels rather than just one, which is the case in this thesis.

For instance, the measurement of urban environment related variables could be re-centered around individual properties, whereas transit related variables could continue to be measured for the entire station district. Variation in independent variables on at least two, or perhaps, even more scale levels would likely reflect the actual situation better, it would then be possible to conduct a multilevel linear regression, which ultimately leads to more accurate estimations.

Third, a follow-up study could expand in terms of study area. For instance, a nationwide study of all commuter railway station districts. Through capturing more station districts, reexamination of the found patterns is made possible. Moreover, due the inclusion of other major stations in Rotterdam, Utrecht and The Hague, the dominant position of Amsterdam could be counter-balanced. A nationwide study could result in more robust TOD environments too. Perhaps a few station districts would be categorized into *Extraordinary high TOD*, alongside with *Amsterdam Centraal*. In contrary, reducing the study to a functional or city region, such as Amsterdam Metropolitan Area, could lead to the inclusion of all sorts of transit modes (bus, tram, metro and train), rather than only commuter railway stations.

Lastly, similar kind of studies can be executed for other submarkets as well. Due to the fact that this thesis merely concentrates on residential real estate, commercial real estate remained unchartered territory. As a consequence, it leaves space for further research into the question whether TOD influences Dutch commercial property values as well. Then, at the same time, it is recommended to include further variables, for instance demographics, to control for differences in station districts apart from the TOD concept. Such findings would contribute to the literature on TOD.

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Appendix A

Assessment of TOD across the stations districts

This following appendix elaborately introduces the sixteen indicators and the source of the data in Table 10. Furthermore, a discussion is given of the relevance of the indicators, the computation of the indicators and lastly the interpretation through an example. Associated maps are attached to the description of the indicators when it concerns spatial information and when it is possible.

Population density (persons / sq.km)
Densities in terms of population indicate the degree of support for the transit system and imply shorter average distances travelled between residency, work and services (Cervero and Lee, 2007). Additionally, it adds to the vibrancy of a place. Higher densities are thus important for TOD. Information on population is available for 2018 on neighborhood level from CBS. Since the area of analysis does not entirely corresponds with the boundaries of the neighborhoods, an intersection operation is carried out in GIS. In this way, the population of a neighborhood is proportionally divided according to the aerial size of the neighborhood falling in the area of analysis. Next, the individual neighborhood populations are aggregated and expressed in population densities per square kilometer.

Thus, in the case of Amsterdam-Amstel, the population density is 4,957 inhabitants per square kilometer.

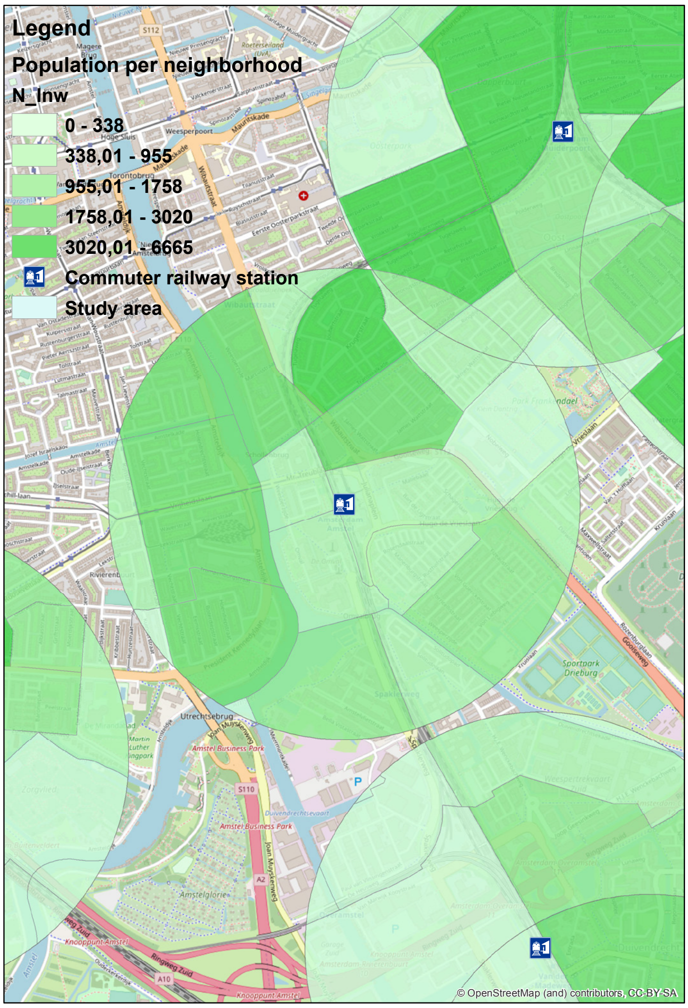


Figure 10: Geographical overview of populations around station Amsterdam-Amstel.

Land use Diversity / Mixed-ness of residential land use with other land uses

In the subsequent subsection, two indicators related to urban diversity and design are introduced, namely land use diversity and mixed-ness of residential land use with other land uses. Although the indicators belong to different criteria, similar techniques are applied to obtain outcomes. The importance of land use diversity can be explained in two ways: In the first place, diversity in land use positively affects the balance of the passenger flows, since diversified areas attract passenger and visitors throughout the day and for different motives. Besides, and in the second place, inhabitants of diversified land use generally have lower travel demand since amenities and services for daily use are relatively close by. As a result, inhabitants make shorter travel movements. In order to assess land use diversity, the 'Entropy' measure of Singh (2015) is used. It results in an outcome varying between 0 and 1, where 0 represents absolutely homogenous land use. The equation of the formula is shown here:

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

Where

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

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

Mixed-ness of residential land use with other land uses is the second indicator and is an important precondition of walkable and cyclable urban environments. It is suggested that multifunctional districts (residential land use sufficiently mixed) improve the likelihood of making short leisure trips by foot or bicycle (Zhang and Guindon, 2006; Bach et al., 2006). In order to assess mixed-ness, the measure of Zhang and Guindon (2006) is used. It results in an outcome that varies between 0 and 1, where 0.5 implies an equal share of residential and other land use. The equation of the formula is shown here:

$$MI(i) = \frac{\sum_{ni} S_c}{\sum_{ni}(S_c + S_r)} \quad \forall i$$

Both indicators demand information on the size of the various land use classes in the station districts; such information is retrievable for individual objects in BAG. Through the use of GIS, the land use class for an individual's object is determined as accurate as possible. Subsequently, the objects are categorized into residential, industrial, commercial, office, health, education, sport and other classes. Subsequently, the total size of each land use class is calculated which ultimately serves as an input for the above outlined equations.

Thus, in the case of Amsterdam-Amstel, the diversity of land use is indicated with 0.55. With regard to mixed-ness, Amsterdam-Amstel is characterized as 0.39.

Total length of walkable/cyclable paths (meters)

Important for walkability and cyclability is the length of total walkable and cyclable paths. It indicates the embeddedness of a node within the infrastructure network, and thus whether the node is directly reachable. Up-to-date information on the entire Dutch road network is available through OSM. However, a significant share of the road network is unsuited for pedestrians and cyclists. It is thus necessary to adjust the road network in such a way that major roads inaccessible for pedestrians and cyclists, such as motorways and primary roads, are excluded from the analysis. Based on information on the various road types on Wiki.openstreetmap.org, a selection is made of those roads accessible for slower transportation modes: cycleway, footway, living street, path, residential, pedestrian and unclassified.

In this manner, the length of each of these distinct walkable and cyclable roads is known. Through the use of the intersection tool in GIS, all walkable and cyclable roads within the stations district are selected. Subsequently, with GIS it is possible to compute the total length of the selected road types within the station districts. In this way, the total length of walkable and cyclable path is found.

Thus, in the case of Amsterdam-Amstel, the station district contains just over 155 kilometers of these pedestrian and cyclist friendly road types.

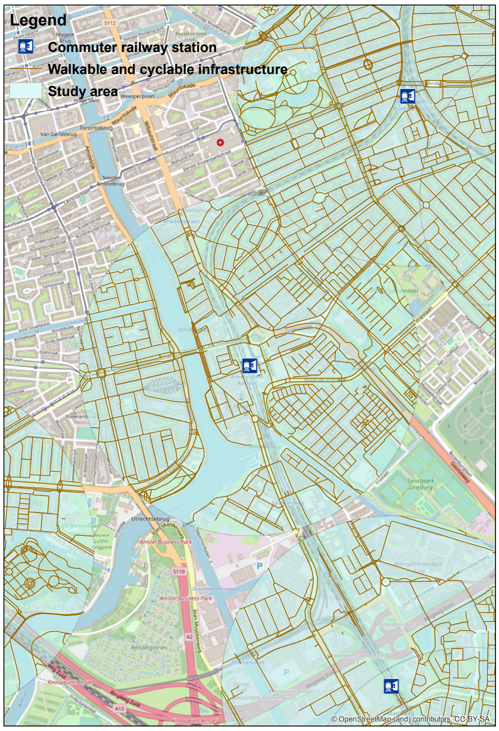


Figure 11: Geographical overview of walkable and cyclabe infrastructure around station Amsterdam-Amstel.

Intersection density (number of intersections / sq.km)

Walkability and cyclability is affected by intersection density, since it indicates the degree of meshing. Finer infrastructure networks enhance walkability and cyclability. Similar to the computation of walkable/cyclable paths, information about the Dutch road network is required in order to measure intersection densities. For this purpose, however, data from the NWB is used for the analysis. Through the use of the intersection tool in GIS, the intersections of roads within the stations' districts are identified and subsequently merged into one intersection by the dissolve tool. Lastly, the station districts' road intersections are aggregated through GIS' spatial join tool and expressed in intersection densities per square kilometer.

Thus, in the case of Amsterdam-Amstel, the station district has a density of 84 intersections per square.

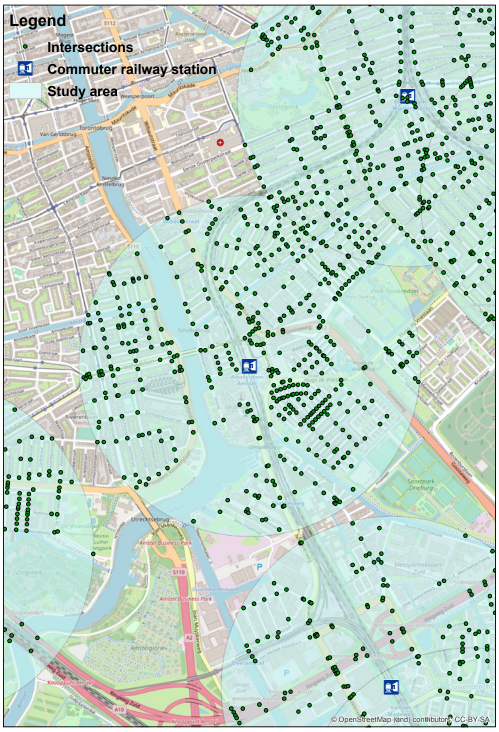


Figure 12: Geographical overview of tha various intersections around station Amsterdam-Amstel.

The road network of NWB is preferred over OSM, because OSM is to a certain extent inadequate to compute intersection densities. In many cases OSM depicts various road functions by separate polygons in GIS, while it is one road in reality. All these polygons intersect each other at a point and GIS counts all these intersections. For instance, a four-leg intersection consisting of primary roads, cycle lanes and pathways would be counted as numerous intersections. Analysis on the basis of OSM therefore leads to an overestimation of intersections densities per station. The NWB road network depicts the infrastructure by one polygon, even though it has different road functions. Hence, double-counting of intersections is avoided. Also, the NWB road network has disadvantages; NWB for instance does not take the little unofficial go-throughs for pedestrian and cyclists into account, but after all, disadvantages of NWB are expected to be small.

Impedance Pedestrian Catchment Area (IPCA)

Walkability and cyclability is partly affected by the Impedance Pedestrian Catchment Area, which represents the total area that is reachable for pedestrian within a certain distance based on a street network around a given location. Large IPCAs contribute to TOD. In this analysis, the given distance is 800 meters, the given locations are railway stations and the street network is a derivative of the Dutch road network from OSM.

In order to obtain the ultimate street network, the high-speed roads were removed from the Dutch road network. Based on Wiki.openstreetmap.org and Google Streetview, the following road types are selected: pedestrian, cycleway, footway, living street, path, residential, secondary(-link), tertiary(-link), unclassified and steps. Through GIS' network analysis, it is possible to calculate a polygon representing the area that is reachable. Subsequently, the geometries of the various polygons area calculated, which in turn made it possible to compute the ratio of the reachable area relative to the study area.

Thus, in the case of Amsterdam-Amstel, a pedestrian can reach almost 2,7 square kilometers or 33.4% of the particular study area after having walked 800 meters.

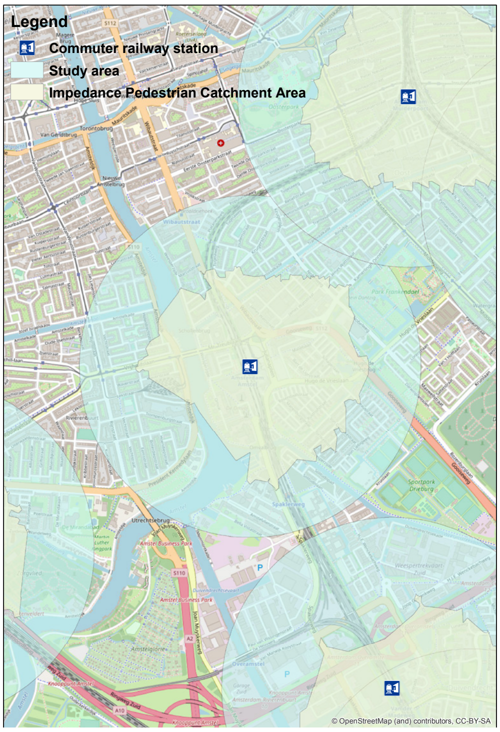


Figure 13: Geographical overview of area which can be covered after having walked 800 meters from station Amsterdam-Amstel.

Commercial density / Density of business establishments (number of business establishments/sq.km)

Apart from population densities, densities in terms of economic development indicate the size of the possibly generated passenger flows. Besides, higher densities of economic development improve the vibrancy of a place which in turn attracts visitors. Densities thus affect TOD. 2016 is the most recent information on establishments where paid work information is provided by LISA. LISA contains information on the level employment and the type of economic activity for all establishments. Pertaining to economic activity, LISA classifies the various establishments according to the Standard Industrial Classifications (SIC), which consists of 22 sectors in total.

However, obtaining commercial and business densities is the purpose of this indicator. Hence, all LISA-establishments have to be converted into commercial establishments, business establishments and others. Thereby two steps have to be taken. Firstly, locations from establishments, such as locations of the government, education and health care are categorized into 'Other establishments'. Then, secondly, commercial and business establishments are separated from one another. Herein commercial establishments represent those sectors related to services, retail and recreation and tend to be consumer-oriented, business establishments, contrarily, refer to primary and secondary industries which are more business to business-oriented.

It is important to note here, that despite of the aim to make an adequate and accurate distinction, it is slightly arbitrary; provided below is an overview of the division made across the three themes:

Commercial establishments	*Business establishments*		*Other establishments*
1. Wholesale and retail trade	1. Agriculture, forestry and fishing	7. Renting, buying and selling of real estate	*1. Education*
2. Accommodation and food service activities	2. Mining and quarrying	8. Renting / leasing of tangible goods and other business support services	*2. Public administration, public services and compulsory social security*
3. Culture, sports and recreation	3. Manufacturing	9. Transportation and storage	*3. Human health and social work activities*
4. Extraterritorial organizations and bodies	4. Electricity, gas, steam and air conditioning supply	10. Information and communication	*4. Unknown*
5. Other service activities	5. Water supply	11. Consultancy, research and other specialized business services	
	6. Construction	12. Financial institutions	

Table 9: Overview of the division between business activities related to commercial, business or other establishments.

As mentioned, information on the commercial and business establishments is available on the micro level with XY-coordinates for each establishment. Hence, it is possible to depict the establishments in GIS. Since merely commercial and business establishments are of interest, one layer for each category is created. Next, GIS' spatial join tool is used for both layer in order to find out the aggregate number of LISA-establishments falling within the study area. Lastly, the total number of commercial and business establishments is expressed in densities per square kilometer.

Thus, in the case of Amsterdam-Amstel, the commercial and business densities are respectively 94 and 276 establishments per square kilometer.

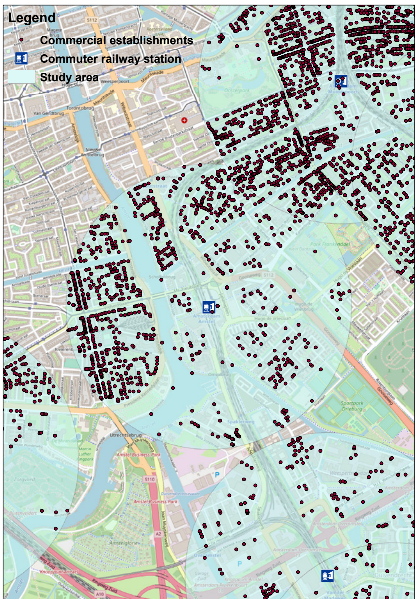


Figure 14: Geographical overview of commercial establishments around station Amsterdam-Amstel.

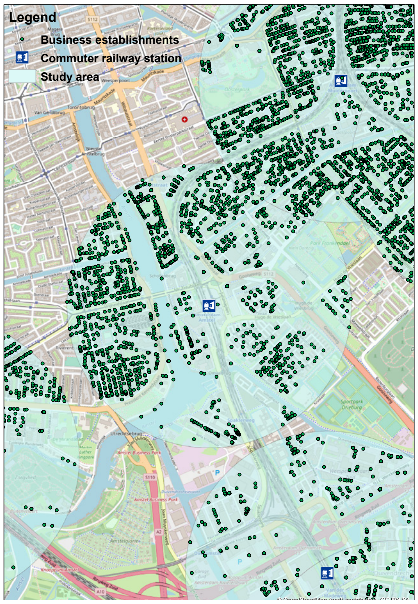


Figure 15: Geographical overview of business establishments around station Amsterdam-Amstel.

Safety of commuters at the transit stop

Feeling of safety is greatly important for the user-friendliness of the transit system. Also, unfortunately, safety is one of the hardest indicators to quantify, since it is determined by a variety of factors, such as the presence of people and factors related to design. Relevant information on the number of people in stations and design-related factors are unobtainable, Singh (2015) therefore uses the number of shops and eateries as proxy indicator for safety. Singh argues that the abovementioned facilities have the ability to retain passengers somewhat longer in stations, and this ultimately enhances the safety level.

Information on shops and eateries is available online and is provided by the NS on the station level. Important to note here, is that merely the shops and eateries exploited by the NS are known. Other shops and eateries in the station district are not taken into account. Therefore, this indicator merely states information about the number of shops and eateries at the transit node itself.

Thus, for example in the case of Amsterdam-Amstel, there are eleven shops and eateries, wherefore safety of commuters at the transit stop is indicated with eleven.

Basic Amenities at the station

Besides shops and eateries, other – more basic – amenities and services are necessary to improve user-friendliness of a station and make it more attractive for use, like sitting benches, ramps, elevators and bicycle parking for instance. Like the previous indicator, information on basic amenities is available online and is provided by the NS on the station level.

Thus, as an example in the case of Amsterdam-Amstel, the station offers thirteen basic amenities and services which make improve the user-friendliness of the station.

Frequency of transit service (number of trains operating / hour)

Access to transit is affected by the frequency of the service. Higher frequency of departing trains positively affects the access to transit network. Information on the frequency of service is retrieved from the NS via Rijdendetreinen.nl/treinarchief. Their archive contains information about the total number of trains departing per day at a certain station. An entire week (mon 18-02 to sun 24-02) is considered to compute the number of trains operating per hour. Operating hours of the train system is in general between 5AM and 1AM, wherefore the total number of trains departing is subdivided by twenty operational hours and seven days.

Thus, for instance, at Amsterdam-Amstel a total number of 2,137 trains depart in a time frame of 140 hours spread across the entire week. In this way, the frequency of transit service is just over fifteen per hour on average.

Interchange to different routes of same transit

Access is affected by the number of different routes. Multiple routes result in higher access to transit than just a sole route, because more destinations are within reach. Information on interchange to different routes of same transit are retrieved from the NS via Wiki.ovinnederland.nl. Officially these routes are called train series. Wiki.ovinnederland.nl lists the various train series that call at the particular stations. A train series always runs between two end destinations and therefore it is possible to enter train series (route) in two directions from an intermediate station. To avoid double counting however, train series are counted just once per station. Besides, even though this indicator is about the same transit, various types of train are operative on the rail network, namely so-called night trains, Sprinters, Intercitys, intercity Directs and international trains.

Not all train types represent the same user value due to differences in speed and action radius. The faster the type of train and the larger the action radius, the higher the user value of a particular train. Therefore, the user value of the train types has to be differentiated. In order to apply a differentiation, the approach of and Ruimte en Lijn (2006) and Deltametropool (2013) is largely followed. These studies attach user values of the trains in a similar order as in the table below.

Type of train	*User-value*
Night train	*0.50*
Sprinter	*0.75*
InterCity	*1.00*
Intercity Direct	*1.25*
International	*1.50*

Table 10: Scorecard for train types (Ruimte en Lijn, 2006) and (Deltametropool, 2013).

A score pertaining to interchange to different routes of same transit can be derived by multiplying the number of routes at a certain station with the user-value of the particular train. Thus, for instance, at Amsterdam-Amstel a total number of six routes call for a stop. Hereof, there are four InterCitys and the two Sprinters. Therefore Amsterdam-Amstel scored 5.5 on interchange to same transit.

Interchange to other transit modes

Access is affected by interchange to other transit modes. Presence of other high-quality transit modes increases the access to transit, since it helps passengers to get to stations or continue their onward trip. Information on interchange to other transit modes are retrieved from 9292.nl and Wiki.ovinnederland.nl. A double check is conducted through the use of Google Maps. The public transit network is the most extensive in the municipality of Amsterdam. Apart from the commuter train network, this region generally has a bus network, tram network and a metro system. Passenger may also use the ferry to cross the river 't IJ in the case of Amsterdam Central. Other municipalities along the Zaancorridor are less well-off in terms of interchange possibilities to other transit modes, since their network remains virtually limited to busses.

As set out in the above paragraph, various transit modes exist in the province but not all modes represent the same user value due to differences in speed, frequency, capacity and comfortability. The faster the transit, the more comfortable the transit the higher the user value of a particular transit mode. Therefore, the user values of the transit modes have to be differentiated. Similarly as in the previous indicator, the approach of and Ruimte en Lijn (2006) and Deltametropool (2013) is largely followed. These studies attach user values of the transit modes in a similar order as provided in the table below.

Transit mode	*User-value*
Ferry	*0.50*
Bus	*0.75*
Tram	*1.00*
Metro	*1.25*

Table 11: Scorecard for transit modes (Ruimte en Lijn, 2006) and (Deltametropool, 2013).

Furthermore, the number of lines calling at the particular transit node is of importance for the interchange to other transit modes. By multiplying the user value of a particular transit mode with the number of lines, a score pertaining to the interchange to other transit modes can be derived.

Thus, for instance, Amsterdam-Amstel scored 15.5 on interchange to other transit modes since it is connected to thirteen bus lines, two tram lines and three metro lines.
Access to opportunities within walkable distance from train station (number of jobs)
Apart from access to train routes and other transit modes, a transit node provides access to employment opportunities as well. Presence of large numbers of jobs in the station district enlarges passenger flows and thus contributes to TOD. LISA is used in order to measure the employment opportunities in the study areas, since it contains information on the number of jobs per establishment. Due to the XY-coordinates, it is possible to depict the geographical locations of the establishments in GIS. Lastly, the total number of jobs is found with help of GIS's spatial join tool.

Thus, for instance, Amsterdam-Amstel is characterized as an area with 11,305 job opportunities within walkable distance from the station.

Parking facilities for cars and bicycles
Sufficient amount of parking facilities is an important condition for TOD. On the one side, proper car accessibility is important for transit passengers from farther distances. The presence of sufficient parking space improves the likelihood of park and ride ridership (P&R). On the other side, a vast share of transit passenger arrives at the transit node by bicycle, wherefore sufficient storage space is of great importance. In order to examine whether parking facilities are sufficient, the actual parking capacities is offset against the total number of daily passengers. Herefore information, provided by the Province of North-Holland, on P&R's and bicycle parking is used. Information on the passenger comes from the NS. In this way it is possible to compare the parking facilities between the various station districts.

Thus, for instance, Amsterdam-Amstel is characterized as an area without a P&R and solely 4,129 bicycle storage spaces relative to its 31,688 daily passengers (13%).

Appendix B

The typology of the stations districts

Station district subject to investigation must be categorized in order to obtain more accurate estimations and to answer the initial research objectives. During the typology analysis it became clear that the extraordinary TOD-performance of Amsterdam Centraal is incompatible with the other station districts subject to the analysis. A fourth TOD-category wherein Amsterdam Centraal stands alone would have been necessary, but running multiple linear regressions with solely Amsterdam Centraal as an observation would have been without value. Another option is the inclusion of Amsterdam Centraal withinn the high TOD-category, but this is expected to distort observed relationships and leads to efficiency losses. Besides, Schiphol-Airport contains no residences and is therefore uninhabited. As such, it appeared better to eliminate Schiphol-Airport beforehand since including it might have distorted the outcomes of the typology analysis.

Three typologies are considered to obtain the categorization for the remaining 58 station districts: These are a 3-level typology based on the TOD and criteria, another 3-level typology based on the indicators and lastly a 2-level typology based on TOD and indicators. The typology analysis is conducted through GIS's tool 'Grouping Analysis'.

3-Level TOD & Criteria

The first typology is based on the final and overall TOD-score plus the seven criteria. An interesting distribution of station districts across the levels results is 28 low TOD-districts, 22 medium TOD-districts and eight high TOD-districts. The group sizes are not entirely equal but there are less medium and high TOD-stations present, wherefore the grouping depicted below appears to correspond with the actual situation. Yet again, the distribution is roughly equal with regard to residential property types over the TOD-levels.

TOD Low = 28
TOD Medium = 22
TOD High = 8

Figure 16: Overview of station districts across the categories, resulting from grouping analysis based on TOD and criteria.

	2014	2015	2016	2017	Total
Low TOD	3.409	1.924	2.170	1.875	*9.378*
Medium TOD	2.785	3.191	3.345	2.906	*12.227*
High TOD	2.702	2.021	2.152	1.748	*8.623*
Total	*8.896*	*7.136*	*7.667*	*6.529*	*30.228*

Table 12: Observations tabularized by year and TOD environment.

	Apartment	House	Total
Low TOD	1.945	7.433	*9.378*
Medium TOD	6.357	5.870	*12.227*
High TOD	6.018	2.605	*8.623*
Total	*14.320*	*15.908*	*30.228*

Table 13: Observations tabularized by property category and TOD environment.

3-Level Indicators

Second typology is based on the sixteen indicators. Again, a distribution of station districts across the levels results with thirteen low TOD-districts, 34 medium TOD-districts and eleven high TOD-districts. Not equal but the large medium TOD-category could function as relevant base category, wherefore the grouping depicted below appears to correspond with the actual situation. However, the number of observations has shrunken drastically due to a lower number TOD-districts.

TOD Low = 13

TOD Medium = 34

TOD High = 11

Figure 17: Overview of station districts across the categories, resulting from grouping analysis based on indicators.

	2014	2015	2016	2017	Total
Low TOD	710	662	811	697	*2.880*
Medium TOD	5.036	3.895	4.182	3.647	*16.760*
High TOD	3.150	2.579	2.674	2.185	*10.588*
Total	*8.896*	*7.136*	*7.667*	*6.529*	*30.228*

Table 14: Observations tabularized by year and TOD environment.

	Apartment	House	Total
Low TOD	781	2.099	*2.880*
Medium TOD	6.333	10.427	*16.760*
High TOD	7.206	3.382	*10.588*
Total	*14.320*	*15.908*	*30.228*

Table 15: Observations tabularized by property category and TOD environment.

2-Level TOD & Indicators

A further attempt is the 2-level typology and is based on the final and overall TOD-score plus the sixteen indicators. A distribution of 47 low and eleven high TOD-districts appears, this would not be ideal since the stations districts with the lowest TOD-scores are grouped with the top twenty station districts. Once again, the distribution of observations is somewhat unbalanced.

TOD Low = 47

TOD High = 11

Figure 18: Overview of station districts across the categories, resulting from grouping analysis based on TOD and indicators.

	2014	*2015*	*2016*	*2017*	*Total*
Low TOD	5.746	4.557	4.993	4.344	*19.640*
High TOD	3.150	2.579	2.674	2.185	*10.588*
Total	*8.896*	*7.136*	*7.667*	*6.529*	*30.228*

Table 16: Observations tabularized by year and TOD environment.

	Apartment	*House*	*Total*
Low TOD	1.945	7.433	*9.378*
Medium TOD	6.357	5.870	*12.227*
High TOD	6.018	2.605	*8.623*
Total	*14.320*	*15.908*	*30.228*

Table 17: Observations tabularized by property category and TOD environment.

Appendix C

Data preparation and assumptions linear regression

1. Outliers

Ideally, all observations of the sample would be included within the regression. However, it is unlikely that the sample contains perfect data. Therefore, all observations are subject to scrutiny in order to reduce the measurement errors. Residential properties are analyzed on potential outliers which would affect the results, as first step in the data preparation. Only those observations with highly unlikely results are removed. In case of transaction prices, 32 observations with transaction prices of €1,- are removed. Regarding the floor area, seven more observations with floor areas of five or less m^2 are removed.

2. Transformations

When a variable is skewed to the left or right, a natural logarithmic transformation may be the solution to normalize the data. Transaction price and floor area are transformed into natural logarithmic format as second step in the data preparation, since both variables then appear to be more equally distributed. The adjusted R^2 of regression models including these variables is higher, which entails that a larger proportion of the variance is explained. Below, the normal distribution before (left) and after (right) transformation is depicted.

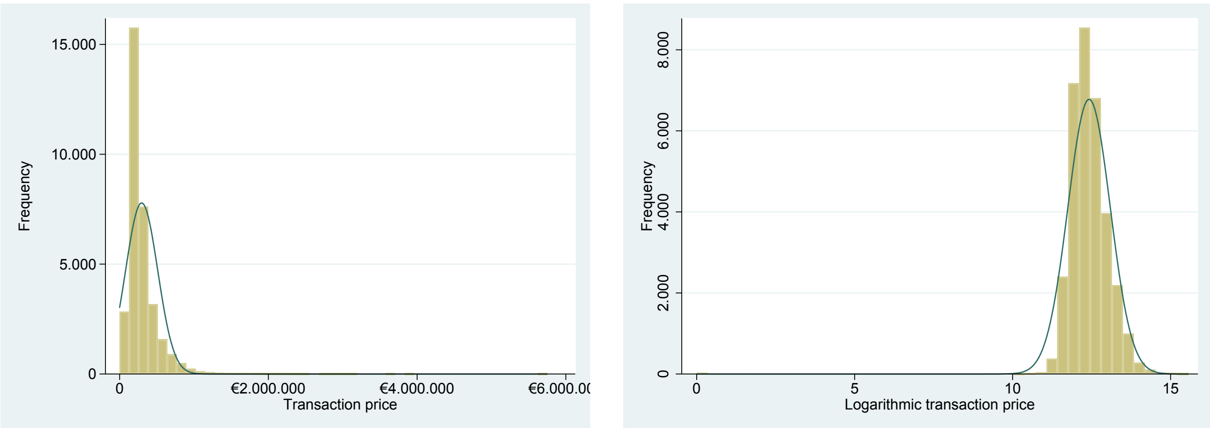


Figure 19: Transformation of the variable transaction price; left: before transformation and right: after transformation. Based on NVM dataset.

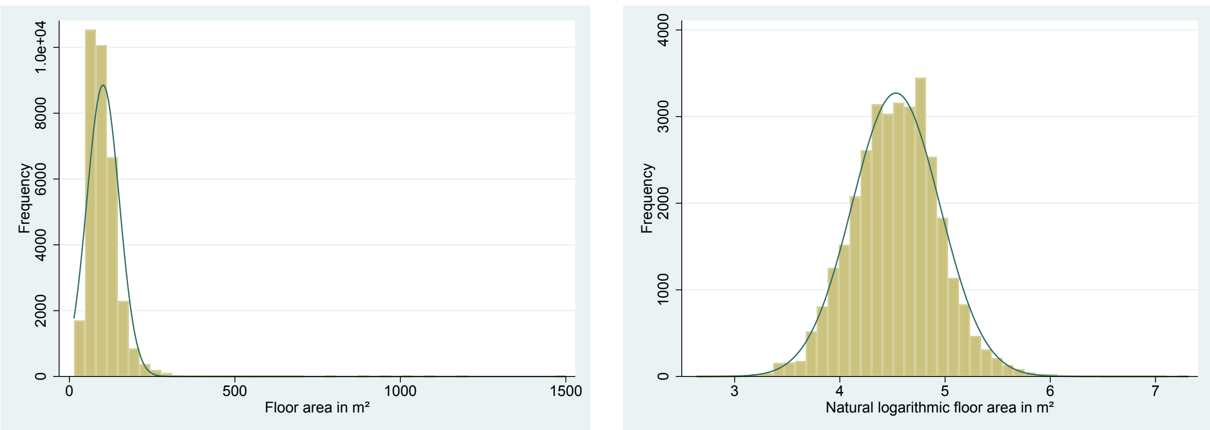
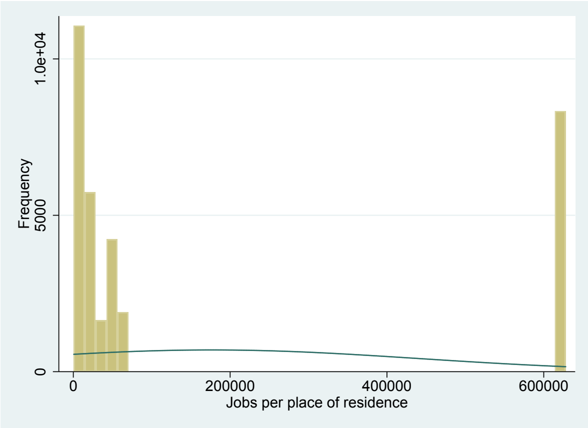


Figure 20: Transformation of the variable floor area; left: before transformation and right: after transformation. Based on NVM dataset.



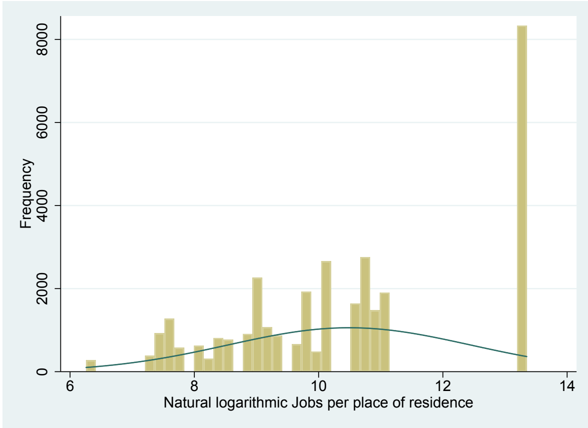


Figure 21: Transformation of the variable Jobs per place of residence price; left: before transformation and right: after transformation. Based on NVM dataset.

3. OLS assumptions

Furthermore, linear regression comes with assumptions, which are the following:

1. Linearity between dependent variable (Y) and the independent variable (X's).
2. Error terms of the observed and predicted values are normally distributed;
3. Independent variables (X') are not highly correlated with each other;
4. Variance of error terms are similar across the values of the independent variables;
5. Little or no autocorrelation between the observations

Several tests are conducted for the last model of Stage 1 and Stage 2.

1. Linearity: In order to comply to linearity, the average value of the residuals has to be zero. Then, the relationship between the dependent variable and independent variables is linear. Due to the fact a constant term is included in the regression, this assumption is not violated (Brooks and Tsolacos, 2010). Furthermore, this assumption may be tested by creating scatterplots to check for linearity between the dependent variable and independent variables. Below, four scatterplots with linearity are shown.

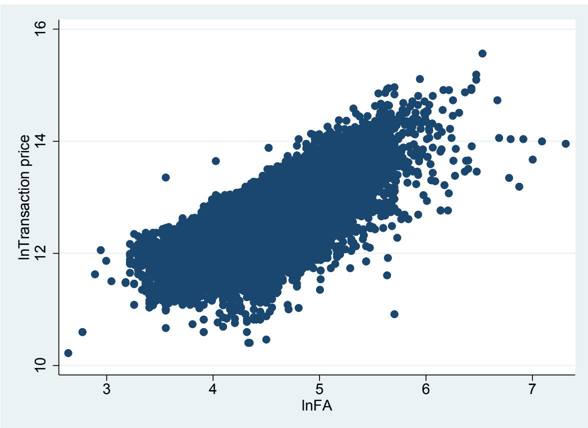


Figure 22: Scatterplot of logarithmic floor area and logarithmic transaction price.

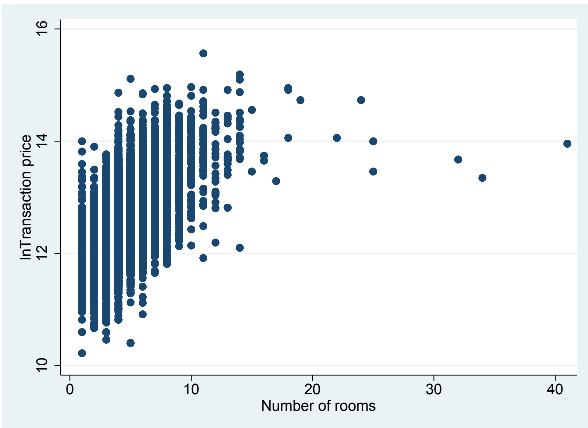


Figure 23: Scatterplot of number of rooms and logarithmic transaction price.

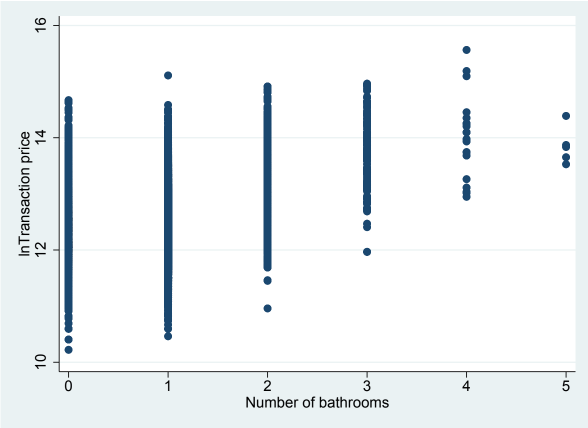


Figure 24: Scatterplot of number of bathrooms and logarithmic transaction price.

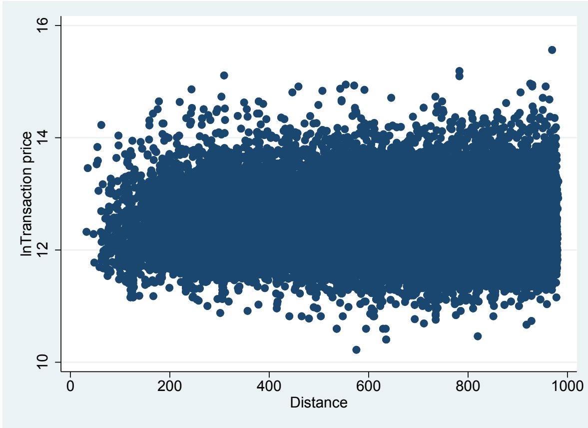


Figure 25: Scatterplot of distance and logarithmic transaction price.

2. Error terms normally distributed: In order to comply to the normally distributed assumption, the residuals (errors) of the regression line are approximately normally distributed. For this purpose, a histogram is used. Below, four normal distribution of the residuals of each model is shown. Apparently, the residuals of the first three models are normally distributed, whereas the last model is not.

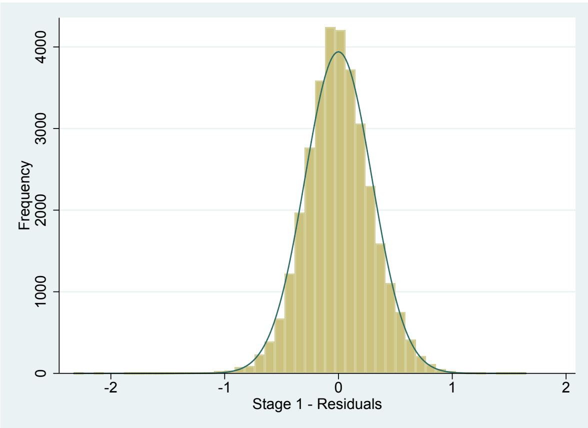


Figure 26: Normalilty of residual distribution of Model 4 in Stage 1.

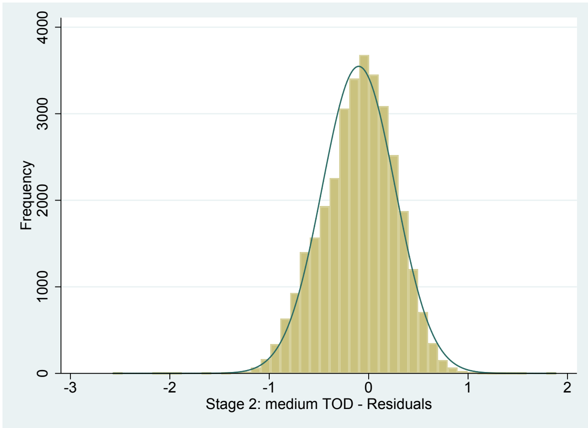


Figure 27: Normalilty of residual distribution of Medium TOD in Stage 2.

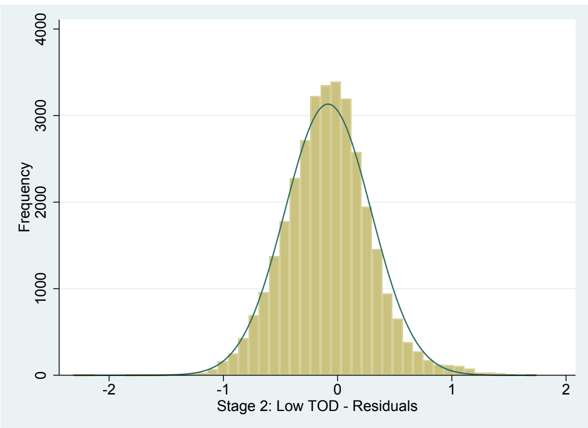


Figure 28: Normality of residual distribution of Low TOD in Stage 2.

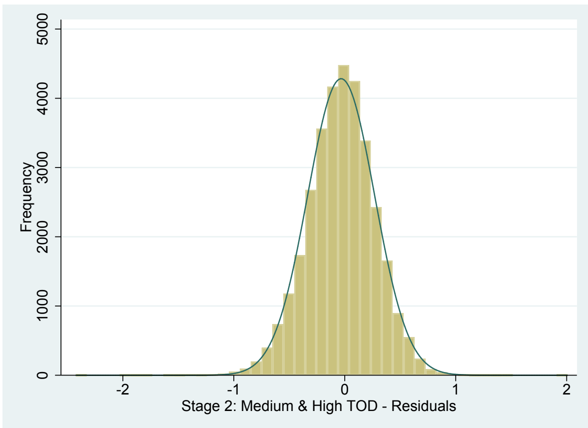


Figure 29: Normality of residual distribution of Medium & High TOD in Stage 2.

3. Multicollinearity: In order to test for multicollinearity, Variance Inflation Factor (VIF) is used, which can be applied after having ran multivariate regressions. Apart from the OLS assumption, it is also relevant as it helps to create a robust model and it gives insight whether indicators or criteria lend themselves better for the OLS model. VIF larger than 5 is evidence of severe multicollinearity.

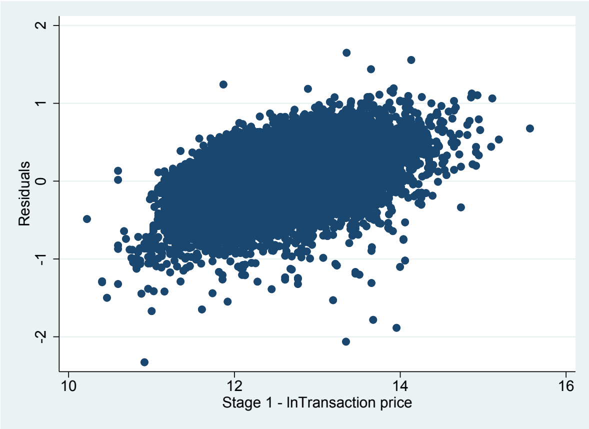
Variance Inflation Factor	**Indicators**				**Criteria**				**Criteria excl. Economy & Userfriendliness**			
	All	*Low*	*Medium*	*High*	*All*	*Low*	*Medium*	*High*	*All*	*Low*	*Medium*	*High*
Urban environment												
Density					28,85	7,06	7,82	684,79	3,05	3,25	1,99	241,96
Population density per km²	22,49	11,99	10,70	47,96								
Commercial density per km²	35,47	23,37	26,66	2185,80								
Diversity					1,66	1,63	2,31	35,99	1,63	1,45	1,56	34,65
Land use Entropy	13,21	25,09	15,24	36,14								
Design					3,79	3,22	1,65	22,05	2,76	3,04	1,39	4,59
Mixedness of residential land use	9,03	35,92	5,29	513,01								
Length walkable paths in meters	6,14	6,57	7,33	700,41								
Intersection density per km²	5,66	17,99	3,96	204,24								
Impedance Pedestrian Catchment Area	1,87	16,15	2,34	30,35								
Economy					27,90	3,56	8,68	56,81				
Business density per km²	66,19	19,51	47,09	Omitted								
Transit												
Accessibility					7,09	1,70	5,90	126,83	2,05	1,50	1,54	80,09
Frequency of train service	12,27	16,35	21,58	Omitted								
Interchange to train routes	12,50	11,21	29,32	Omitted								
Interchange to other transit modals	7,59	5,08	6,52	Omitted								
Accessibility to opportunities (jobs)	11,20	4,94	4,01	Omitted								
User-friendliness					3,16	1,27	4,06	16,69				
Safety	3,39	6,87	17,34	Omitted								
Service	5,12	16,46	11,63	Omitted								
Parking					1,51	1,24	2,88	94,74	1,47	1,11	1,40	64,86
Car parking	1,83	4,96	4,25	Omitted								
Bicycle parking	1,60	9,78	7,00	Omitted								
Mean VIF	7,79	7,93	7,88	131,58	5,38	2,57	3,43	53,62	2,47	2,33	2,38	25,57

Table 18: VIFs of variables related to the property and the TOD assessment.

Multicollinearity among the potential independent variables is detected. As presented in the left column in Table 14, VIFs for indicators are extremely high which suggest severe multicollinearity. Moreover, when looking at the TOD environments, multicollinearity clearly increases when the number observations decreases. Contrarily to indicators, in the middle column, solely Density and Economy appear to be multicollinear. After having removed Economy from the regression model, not a single criteria is characterized as severe multicollinear (see right column).

Solving the multicollinearity issue for a model with criteria is easier than for indicators. This is one of the reasons why the ultimate model specification uses criteria. Unfortunately, the regression model of high TOD in Stage 2 still contains multicollinearity due to the small sample of station districts.

4. Variance of error terms are similar across regression lines: to check this, a scatterplot of residuals versus predicted values is used. Ideally the plot should look like random scatter of points. Although randomness varies, it seems the data is homoscedastic. Heteroscedasticity tests confirm homoscedasticity of the models.

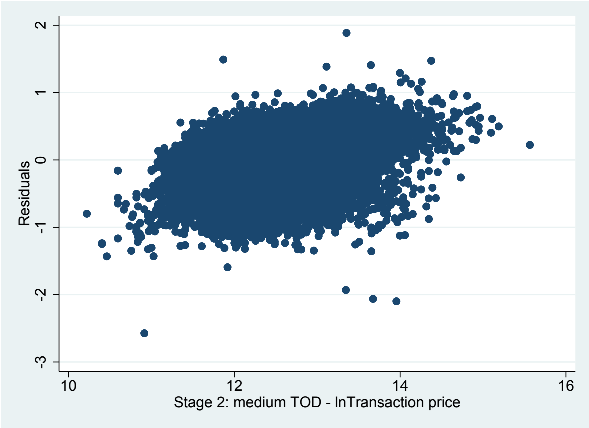



```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of lnPRIJS

         chi2(1)      =   938.26
         Prob > chi2  =   0.0000
```

Figure 30: Scatterplot of residuals versus predicted values of Model 4 in Stage 1, followed by heteroscedasticity test.

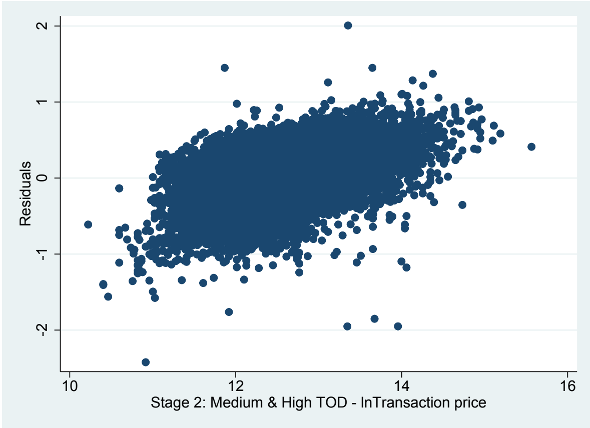

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of lnPRIJS

         chi2(1)      =   398.61
         Prob > chi2  =   0.0000
```

Figure 31: Scatterplot of residuals versus predicted values of Low TOD in Stage 2, followed by heteroscedasticity test.




```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of lnPRIJS

         chi2(1)      =   214.76
         Prob > chi2  =   0.0000
```

Figure 32: Scatterplot of residuals versus predicted values of Medium TOD in Stage 2, followed by heteroscedasticity test.




```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of lnPRIJS

         chi2(1)      =   349.12
         Prob > chi2  =   0.0000
```

Figure 33: Scatterplot of residuals versus predicted values of Medium & High TOD in Stage 2, followed by heteroscedasticity test.

Appendix D

STATA

Values of TOD assessment are processed in GIS and Excel. Further standardization of the values occurred in Excel. From there, the statistical analyses were conducted in STATA, of which the applied commands are presented here.

Data preparation

```
***Data cleansing***
Keep if Category==0 | Category==1
drop if Year<2014
drop if Transactieprijs≤1
drop if missing (Transactieprijs)
gen lnTransactionPrice = ln(Transactieprijs)
drop if Woonopp≤10
gen lnFA = ln(Woonopp)
drop if Nkamers<1
drop if Nbakd<0

***Data transformation***
hist Transactieprijs, freq
gen lnTransactionPrice = ln(Transactieprijs)
hist lnTransactionPrice, freq

hist Woonopp, freq
gen lnFA = ln(Woonopp)
hist lnFA, freq

hist WerkgelegenheidWoonplaats, freq
gen lnJobs = ln(WerkgelegenheidWoonplaats)
hist lnJobs, freq

gen PropertyType = 1
replace PropertyType = 2 if Soortwonin==5
replace PropertyType = 3 if Soortwonin==6 | Soortwonin==7
replace PropertyType = 4 if Soortwonin==4 | Soortwonin==9 | Soortwonin==3
replace PropertyType = 5 if Soortwonin==10 | Soortwonin==11 | Soortwonin==12 | Soortwonin==8
replace PropertyType = 6 if Soortwonin==21
replace PropertyType = 7 if Soortwonin==22
replace PropertyType = 8 if Soortwonin==23
replace PropertyType = 9 if Soortwonin==24
replace PropertyType = 10 if Soortwonin==25
replace PropertyType = 11 if Soortwonin==27
label define PropertyType 1 «Simple home» 2 «Single family property» 3 «Town house, canalside property» 4 «Bungalow, recreation home, houseboat» 5 «Villa, country house, country estate, former farm» 6 «Ground floor apartment» 7 «Upper-floor apartment» 8 «Maisonette» 9 «Flat with porch» 10 «Apartment with external access» 11 «Duplex
```

apartment»

gen CDISTANCE = 1
replace CDISTANCE = 2 if Distance≥250 & Distance<500
replace CDISTANCE = 3 if Distance≥500 & Distance<750
replace CDISTANCE = 4 if Distance ≥750 & Distance<1000
label define CDISTANCE 1 «0-250» 2 «250-500» 3 «500-750» 4 «750-1000»

gen RB = 0
replace RB = 1 if Nbalkon≥1 | Ndakterras≥1
label define RB 0 «No» 1 «Yes»

gen Parking = 0
replace Parking = 1 if Parkeer==2 | Parkeer==3 | Parkeer==4 | Parkeer==6 | Parkeer==8
label define Parking 0 «No» 1 «Yes»

gen Garden = 0
replace Garden = 1 if Tuinlig≥1
label define Garden 0 «No» 1 «Yes»

label define Category 0 «House» 1 «Apartment»
label define TODL 1 «High TOD» 2 «Low TOD» 3 «Medium TOD»

Descriptive statistics
Stage 1
sum Transactieprijs WOONOPP NR NBR Garden RB Parking Distance Category TOD PropertyType WerkgelegenheidWoonplaats

Stage 2
Low TOD:
sum Transactieprijs WOONOPP NR NBR Garden RB Parking Distance Category Density Diversity Design Accessibility WerkgelegenheidWoonplaats if TODL==2
Medium TOD:
sum Transactieprijs WOONOPP NR NBR Garden RB Parking Distance Category Density Diversity Design Accessibility WerkgelegenheidWoonplaats if TODL==3
Medium & High TOD:
sum Transactieprijs WOONOPP NR NBR Garden RB Parking Distance Category Density Diversity Design Accessibility WerkgelegenheidWoonplaats if TODL==2 | TODL==3

Regression models & assumption test
TOD results 1
corr Density Diversity Design Economy Accessibility Userfriendliness Parking
Stage 1
Model 1:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType b2014.Year
Model 2:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType b2014.

```
Year b1.CDISTANCE TOD
Model 3:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType b2014.
Year b1.CDISTANCE TOD lnJobs
Model 4:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType b2014.
Year b1.CDISTANCE TOD PropertyType##c.TOD CDISTANCE##c.TOD lnJobs
vif
predict a, res
hist a, normal freq
graph twoway scatter a lnTransactionPrice
estat hettest

***Stage 2***
Low TOD:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType
b2014.Year b1.CDISTANCE Density Diversity Design Accessibility Parking
lnWerkgelegenheidWoonplaats if TODL==2
vif
predict b, res
hist b, normal freq
graph twoway scatter b lnTransactionPrice
estat hettest
Medium TOD:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType
b2014.Year b1.CDISTANCE Density Diversity Design Accessibility Parking
lnWerkgelegenheidWoonplaats if TODL==3
vif
predict c, res
hist c, normal freq
graph twoway scatter c lnTransactionPrice
estat hottest
Medium & High TOD:
reg lnTransactionPrice lnFA NR NBR b0.Garden b0.RB b0.Parking b1.PropertyType
b2014.Year b1.CDISTANCE Density Diversity Design Accessibility Parking
lnWerkgelegenheidWoonplaats if TODL==2 | TODL==3
vif
predict d, res
hist d, normal freq
graph twoway scatter d lnPRIJS
estat hettest

graph twoway scatter lnTransactionPrice lnFA
graph twoway scatter lnTransactionPrice NR
graph twoway scatter lnTransactionPrice NBR
graph twoway scatter lnTransactionPrice Distance
```