



ERASMUS SCHOOL OF ECONOMICS

MASTER THESIS

**The influence of the quality of the public  
transport system on modal choice**

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October 3, 2018

## **Abstract**

One of the key challenges for cities in the future is urban growth and the mobility problem accompanies this expansion. This paper investigates how the public transport system influences travel behavior by analyzing the relationship between the quality of public transport and modal choice using the data from the 2010 Netherlands National Travel Survey and the SNAMUTS framework. In this way it contributes to the limited research in this subject. The empirical analysis indicates that the quality of public transport does influence modal choice. A more frequent service and shorter travel times to other nodes increases the likelihood of people travelling via public transport.

# Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
<b>2</b>	<b>Literature Review</b>	<b>4</b>
2.1	<i>Introduction</i> . . . . .	4
2.2	<i>Spatial characteristics</i> . . . . .	4
2.3	<i>Personal characteristics</i> . . . . .	5
2.4	<i>Conclusion</i> . . . . .	7
<b>3</b>	<b>Data</b>	<b>10</b>
3.1	<i>Introduction</i> . . . . .	10
3.2	<i>Variables</i> . . . . .	10
<b>4</b>	<b>Research Design &amp; Results</b>	<b>12</b>
4.1	<i>Introduction</i> . . . . .	12
4.2	<i>Descriptive analysis</i> . . . . .	12
4.3	<i>Multinomial Logit Model</i> . . . . .	14
4.4	<i>Average Marginal Effects</i> . . . . .	17
<b>5</b>	<b>Conclusion &amp; Discussion</b>	<b>18</b>
5.1	<i>Conclusion</i> . . . . .	18
5.2	<i>Discussion</i> . . . . .	19
5.3	<i>Policy recommendations</i> . . . . .	19
5.4	<i>Limitations</i> . . . . .	19
	<b>References</b>	<b>20</b>
	<b>Appendix</b>	<b>24</b>

## List of Tables

1	Case studies . . . . .	8
2	Expected relation of variables relative to the use of public transport . . . . .	11
3	Modal split by quality of public transport, socio-economic factors, and urbanization rate . . . . .	13
4	Average quality of public transport by urbanization rate . . . . .	14
5	Multinomial logit model of modal choice . . . . .	16
6	Average marginal effect closeness centrality . . . . .	17
7	Average marginal effect degree centrality . . . . .	18
8	Average marginal effect nodal betweenness . . . . .	18

# 1 Introduction

A major topic in this fast-changing world is urbanization. More and more people are moving to cities to escape poverty. Cities across Africa, Asia and South-America are growing rapidly. Although this does not explain urbanization in Europe and the United States, the fast pace of people moving to the city is causing problems there too. In recent decades cities have spread and generated an excessive spatial growth, mostly caused by the preference to live in or close to a city but still reside in a house with a garden located in a quiet neighborhood. While cities are often praised for their connectivity and accessibility this can be threatened if the growth of cities is not accompanied by actions to increase mobility. Especially if the most inefficient transport mode, the car, is most prevalent (Schwanen, Dijst, & Dieleman, 2004). It was found that in the United States 76 percent of all workers drive alone to work and 25 percent of the total urban area in Europe is road (Burea, 2016; Camagni, Gibelli, & Rigamonti, 2002). Changing from the use of a car to a bus will consume 24 times less space per passenger (Servant, 1996). Distancing from car use is not only needed to sustain current mobility, it has more advantages in terms of environment and travel time (García-Palomares, 2010; Jansen, Hilbers, & Wilmink, 2002).

History has proven that reaching this goal is more difficult than it seems. Due to urban sprawl commuter numbers, commuting distance and car use has increased, the development of greenfield neighborhoods close to cities has not reduced commuting times, and there is only little evidence that spatial planning efforts in the 20th century have created efficient travel patterns in the Randstad area (García-Palomares, 2010; Schwanen et al., 2004). The rapid expansion of cities often causes a lack of accessibility in new areas. The results concerning this topic are small and sometimes contradicting. It is widely agreed that personal characteristics influence travel behavior, however the outcome of, for instance income and education, differs across studies (Lu & Pas, 1999; Wang, 2001). Other characteristics such as the presence of children, availability of the car and gender results in more corresponding outcomes (F. M. Dieleman, Dijst, & Burghouwt, 2002; Schwanen, Dijst, & Dieleman, 2002). Besides, the effect of the quality of the public transportation network and other aspects of the built environment on travel behavior seems to be neglected (Ewing & Cervero, 2001). Without a good understanding of how travel behavior is affected, planning the urban environment so that roads and modes of transportation are used most efficiently will be difficult. Therefore more knowledge is needed to assist mobility planners in the future to organize a sustainable transportation network.

The purpose of this study is to expand knowledge about the correlation between the objective accessibility of public transport and travel behavior, which in turn can help mobility planners to be more decisive in future projects. This study answers the question: What is the relationship between objective accessibility and travel behavior in the Randstad? This study uses a multinomial model where the supply of public transport in the Randstad, provided by the SNAMUTS framework of Curtis et al. (2010), is linked to travel behavior, provided by the Dutch Bureau of Statistics (Centraal Bureau voor de Statistiek (CBS) & Rijkswaterstaat (RWS), 2011).

The remainder of the paper starts with a brief review of the literature considering the relationship between household attributes, residential environment, and modal choice. The data and the variables are explained in section 3 followed by the research design and results. The paper is completed with a conclusion and discussion.

## 2 Literature Review

### 2.1 Introduction

Travel behavior is affected by various attributes. These can be categorized into two main areas: spatial and personal characteristics. Spatial characteristics focus mainly on the built environment at the origin and destination of the trip. This encompasses components such as density, land-mix use, and supply of public transport. Personal characteristics are about individual attributes including gender, income and household composition. Both are proven to influence travel behavior. Findings are however somewhat contradictory and depend on the research location. This chapter will summarize the most important findings of these studies.

### 2.2 Spatial characteristics

Cities across the world have grown over the past decades and those in Asia and Africa are the most well known with extreme examples such as Lagos and Shenzhen. Although most cities in Europe do not reach the same level of growth, urban areas have changed (Eurostat, 2017). Cities have grown spatially in recent decades caused by people's preference to live in or close to a city but still reside in a house with a garden located in a quiet neighborhood. This has led to an excessive spatial growth, defined as urban sprawl. Important to note is that the growth is excessive, despite the fact that cities must grow spatially to accommodate the people, the claim is that too much spatial growth occurs (Brueckner, 2000). This has an extreme impact on the environment. The sprawl results in a stark increase in transport-related CO<sub>2</sub> emissions, more so than other CO<sub>2</sub> contributors such as population growth or GDP per capita growth (Bart, 2010).

One of the major concerns with urban sprawl is therefore its effect on mobility and the associated consequences. Several case-studies have been conducted in different European cities and areas. García-Palomares (2010) found that in the Madrid area, municipalities affected by the recent metropolitan expansion made more frequent use of the car, at the expense of public transport and travel on foot. Travel time is not however longer than expected which might be caused by this increased use of cars. These results are contradictory to what has been found in the Netherlands and the United States. The increase in car use caused more severe road congestion in both the Netherlands and Chicago which leads to longer commuting times (Jansen et al., 2002; Prevedouros & Schofer, 1991). Travisi, Camagni & Nijkamp (2010) conclude in their study on Italy that less compact cities result in a greater dispersion of activities and therefore increase the dependency on cars. Moreover, it makes it necessary to spend more time travelling. Car use itself also encourages sprawl since it requires more land for transportation facilities and accordingly development at the outskirts of the city. Public transport is also impacted by the sprawl of cities, especially in cases where the new neighborhoods are less structured. This causes a less efficient network, which is less competitive and therefore results in a lower share in total mobility (Camagni et al., 2002). Urban planning is suggested as effective in promoting other modes of transport than cars and to get a hold on urban sprawl, although timing is key in this matter and the impact can be insignificant if the investment is too late (Acharya & Morichi, 2007). In the case of the Netherlands, the lack of planning was expected to lead to more sprawl and therefore to more negative outcomes on environmental aspects (F. Dieleman & Wegener, 2004). Schwanen et al. (2004) conclude that the development of greenfield neighborhoods close to cities do not appear to have reduced the commuting times in the Netherlands and they find little evidence that spatial planning efforts created efficient travel patterns. This could be caused by the fact that most public transport services were provided only after most residential units were already completed. Hajer & Zonneveld (2000) do agree following an investigation into the

second half of the 20th century that Dutch planning should rethink some of the basic features of the planning system.

This broader concept of dispersion growth became a popular topic in Europe around the millennium, however the characteristics that stereotype these neighborhoods, such as lower density, no mixed land use, and lower supply of public transport, have long been researched. The influence of density and land-use on travel is most predominantly researched and to a lesser extent the other effects of the built environment such as the supply of public transport (Ewing & Cervero, 2001). The relationship between density and mass-transit is in general found to be positive and larger than the impact of land-mix use (Cervero, 1996). Cervero (1994) concludes that commute by rail is more common in areas with a high density of workers and highly residential areas than areas of lower density. Frank and Pivo (1994) contribute to this idea, positing that modal choice is more dependent on the employment density at the destination than on the residential origin. The transit share is compounded by a transit oriented design and vice versa (Cervero & Gorham, 1995). Schimek (1996) concludes that a higher density is accompanied to a greater concentration of jobs in the central business district and the inner suburbs, which leads to better public transport and therefore higher usage. The discussion about the influence of density on modal choice raised the question by Handy (1997) whether it was really density that matters. It may be that what's important is what goes along with density. The urban design provides choices for people but the design does not change behavior. Correspondingly the availability of more parking spaces per employee leaves the commuter the choice to come by car and therefore decreases the use of public transport (Morrall & Bolger, 1996). Furthermore, the high-quality public transport system in the Netherlands tempts people to use this mode of transport as opposed to walking or biking (F. M. Dieleman et al., 2002). The likelihood of going by train also increases as train stations become more accessible (Limtanakool, Dijst, & Schwanen, 2006). This is also the conclusion of Mulalic, Pilegaard and Rouwendal (2016) in their research about the extension of the metro network in the greater Copenhagen area. They predict a 2.3 percent decrease in the overall car ownership after the project is finished.

Although most of these studies use data from cities in the United States, it can be assumed that these findings are also applicable to European cities. Noulas, Scellato, Lambiotte, Pontil, and Mascolo (2012) found in their study on cities across the world that differences in movement in cities are predominantly caused by differences in the distribution of places, defined as the number of opportunities (e.g. coffee shops, airport terminals or libraries), across the urban environments and therefore identify a universal law for human mobility. This is in line with Gil's (2016) reasoning that each urban environment seems to have its natural modes of transport supported by its infrastructure and its urban morphology. Backed by the findings of Schwanen et al. (2004) in their study in the Netherlands where they found that the differences are bigger within certain areas than between.

The growth of the cities accompanied by a disproportionate increase in the space cities occupy has led to undesirable outcomes both socially and environmentally. The sprawl and thereby the increasing use of cars has caused unsustainable outcomes in the mobility framework. Urban planning seems the key to reverse or at least divert this path of growth into a more viable solution. Travel choices are however not only influenced by spatial variables. Other determinants of travel behavior are personal characteristics such as income, education and gender.

### **2.3** *Personal characteristics*

It is debatable how personal characteristics affect travel behavior and past studies have had contradicting outcomes. Lu and Pas (1999) found in a case study on Portland that higher income leads to longer travel times and Turner and Niemeier (1997) conclude that this effect is even bigger when it comes to men. F. M. Dieleman et al.'s (2002) results are in line with

these scholars in their case study on the Netherlands. This can be explained by the tendency for workers with higher incomes to choose to live outside the city center where rents are lower (Gordon, Kumar, & Richardson, 1989). Another proposed theory is that high-income households have a stronger incentive to economize on commuting and therefore commute less. This is supported by the findings of Gordon et al. (1989). Closely related to income is education level. In line with Gordon et al. (1989) are the findings of Wang (2001) who suggests that more highly educated individuals are expected to make more informed decisions when choosing their residence and hence minimize their commuting time. Contradicting results were found in a case-study in the Netherlands where researchers concluded that travelling by car increased travel time and those that were more highly educated were more likely to travel by car (Schwanen et al., 2002). F. M. Dieleman et al. (2002) supports the findings that more highly educated individuals travel more by car, however the difference compared with other levels of education is very small. Limtanakool et al. (2006) found opposing results; explicitly that the likelihood of someone traveling by train was higher as education levels increased, however this did not mean that those that were highly educated would choose to travel by train. This can be explained by accessibility; the majority worked in high density office parks which are easily accessible by train.

Studies on the effects of income and education level on travel behavior result in contrasting outcomes. Conclusions about other attributes seem to be more in line. Most studies agree that the use of public transport is higher in households without children than with children (Schwanen et al., 2002; Turner & Niemeier, 1997). There is however a difference between the findings of Limtanakool et al. (2006) and F. M. Dieleman et al. (2002). The first found that car dependency does not appear to increase for business travel when the couple has children, the latter mentions that families use the car the most for commuting. The results of Kim, Horner and Marans (2005) are in line with Dieleman and both conclude that the different life-cycles of one's family does have an influence on travel behavior. It seems to be a trade-off where people with children choose to live in a better natural environment for their children but must as a result commute longer. On the other hand, people without children choose a residence with good job accessibility but end up in smaller housing with different neighborhood characteristics. Most scholars agree on the fact that men have longer travel times than women (Schwanen et al., 2002; Simma, 2003; Turner & Niemeier, 1997; Wang, 2001), except for Hanson and Johnston (1985). Furthermore, it has been found that people with a part-time job commute longer than people with a full-time job. It can be said that this is a bit surprising assuming the traditional household division between men and women. There is a consensus that car ownership is the strongest predictor of travelling by car, which is what you would expect.

The results of previous studies are often not significant and besides the effects are small. This makes a legitimate case for the findings of Hamilton and Röell (1982), who conclude that people in the United States and Japan chose their place of residence and jobs at random and therefore make no effort to economize on commuting. Mode of travel is however largely a reasoned decision (Bamberg, Ajzen, & Schmidt, 2003).

The effects of previously discussed spatial variables on travel behavior cohere between European cities and cities in the United States, in contrary to personal attributes. The suggestion of Noulas et al. (2012) of a universal law of human mobility is therefore dubious. Additionally, there are no clear findings to discern which attributes have the strongest effect on travel behavior, personal or spatial characteristics. Simma (2003) mentions after his study on Austria that personal attributes have a stronger effect on travel behavior than spatial characteristics, so does Schwanen et al. (2002). F. M. Dieleman et al. (2002) disagree and conclude that the residential environment has a strong influence on work trips.

## 2.4 *Conclusion*

The literature discussed gives an indication of the diverse outcomes within this field of research. It shows that the effect of certain attributes on travel behavior is hard to measure and mixed results regularly emerge. These studies research numerous attributes and often density is often accounted for, which is strongly correlated with the quality/supply of public transport. The direct link between the quality/supply of the public transportation network and travel behavior seems however to have been neglected in the research. Nonetheless, in a world where cities account for 70 percent of global CO2 emissions and congestion is a considerable problem a better understanding of this link is urgent to ensure cities remain livable in in the future (Narayan, 2014).

**Table 1.** Case studies

Authors	City/region	Indicator variables	Data	Conclusions
<i>Spatial characteristics</i>				
Camagni, Gibelli, & Rigamonti (2002)	Milan, Italy	1. Urban expansion	Census data (transformed into EIC <sup>1</sup> )	1. The more dispersed the development, the lower the share of public transport on the mobility market
Cervero (1996)	Bay area, California	1. Proximity to railway stations 2. Residential density	Travel survey	1. Proximity to the station and density are the strongest predictors of rail modal split (people going by train) 2. Free parking discourages people to take the public transport
García-Palomares (2010)	Madrid, Spain	1. Distance to the center 2. Population growth	Census data	1. Urban sprawl increases commuting, in numbers, distance, and car use
Schwanen, Dijst, & Dieleman (2004)	Netherlands	Four planning policies	Travel survey	1. Urban sprawl has increased commuting times 2. No evidence is found that urban sprawl has increased the use of public transport
Travisi, Camagni, & Nijkamp (2010)	Italy	1. Density 2. Diversity of land use 3. Consumption of ex-urban agricultural land	Census data (transformed into EIC)	1. Urban sprawl intensifies travel movements

*Personal characteristics*

Dieleman, Dijst, & Burghouwt (2002)	Netherlands	1. Personal characteristics	Travel survey	1. People with higher incomes are more likely to use and own a car 2. People with children are more likely to use the car
Schwanen, Dijst, & Dieleman (2002)	Netherlands	1. Personal characteristics	Travel survey	1. The number of workers in the household, age and education are positively correlated to travel time 2. The use of public transport is the highest with households without children
Limtanakool, Dijst, & Schwanen (2006)	Netherlands	1. Personal characteristics	Travel survey	1. The likelihood of someone traveling by train to be highly educated is the biggest

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<sup>1</sup>Equivalent impact commuters

## 3 Data

### 3.1 Introduction

This section will describe the different data resources and the variables used in the analysis. Some variables are more thoroughly explained with the purpose of giving you a better understanding during the results section, this is particularly important for the indices representing the quality/supply of public transport.

### 3.2 Variables

The data used in this research comes from two data resources. First, the Netherlands National Travel Survey (Onderzoek Verplaatsing in Nederland (OVIN)). This survey, started in 2010, is conducted in almost 80.000 households in the Netherlands across the year. Only people aged over 18 years old are selected considering that they can make their travel choices independently and in addition have more choices available to them (e.g. car). Due to the scope of the research only trips within the province of South- Holland are considered.

The main dependent variable is modal choice and is categorized into ‘private car’ (as driver), ‘public transport’ (bus, tram, metro, or train), and ‘bicycle/walking’. Additional to this dataset are five personal characteristics: gender, age, disposable income, car ownership, and education (elementary; High school, low level; High school high level; college and higher). The household type an individual belongs to is categorized by two characteristics: if the person is working over 12 hours a week and household composition, which is distinguished as families (have children under the age of 12), couples and singles. This gives us six different household types: family, working and non-working; couple, working and non-working; and single, working and non-working. These are common household types and often used in the literature in this subject (F. M. Dieleman et al., 2002; Limtanakool et al., 2006; Schwanen et al., 2004). The residential environment is categorized by urbanization rate, from very strongly urbanized to a little urbanized (4 categories). The urbanization rate depicts the urbanization rate at the origin of the trip. These categories are given by CBS and are capricious, given that these values are based on the municipality and therefore zip codes located in a remote area can still be assigned as very urbanized. South-Holland is relatively urbanized and connected and as such there are no observations which fall under the category of no urbanization.

Second are the indices that describe the quality/supply of the public transport in the county of Zuid-Holland (Curtis et al., 2010). These are the main independent variables and are used to answer the research question as to whether there is a relation between objective accessibility and travel behavior. Three indices seem to be plausible to influence travel behavior. These are titled by Curtis and Scheurer (2010) as closeness centrality, degree centrality, and nodal betweenness and will be addressed the same in this paper. *Closeness centrality* describes the ease of movement along the public transport network and is calculated using the travel time and service frequency between nodes. A relative low indicator is better and means that the node offers a fast and/or frequent service. *Degree centrality* describes the directness of journeys along the public transport network. The index is an average of the number of transfers that are needed to reach another node. *Nodal betweenness* shows whether the station is located at a favorable position within the transportation network. This combines the number of paths that pass through the node, the number of jobs and residents in the catchment areas, and the travel time and frequency. A high index will therefore mean that a node is located at the crossroads of the system. Even though most indices are linked and sometimes the same variables are used in the calculation, it does not mean that if the station performs well in one aspect it necessarily performs well on the other indices. Closeness centrality is related to time and frequency, whilst degree centrality and nodal betweenness indicate more about the location. An extensive formula of the indices is

presented in the Appendix. In the remainder of the paper the term *quality of public transport* is used to address these indicators.

These indices correspond to the area in which the individual starts their trip and ends their trip. This analysis will make use of the modal choice of the person, the quality of the public transport system at the location of departure and destination, and controls for personal/household characteristics and the residential environment. Finally, the analysis is done on a total of 3,490 observations. Variables that are said to be important in influencing travel behavior, such as the amount of parking lots and land-mix use, are not available and therefore not included. Table 2 demonstrates the expected direction of the variables within the analysis based on the literature. For example, it is expected that as you grow older the likelihood of travelling by car becomes higher. The expected effects of the quality of public transport on modal choice is based on previous research about density and their influences, since this is regarded as closely related to the quality of public transport.

**Table 2.** Expected relation of variables relative to the use of public transport

	Car use to public transport	Biking/walking to public transport
<i>Quality of public transport indicators</i>		
Closeness centrality	+	+
Degree centrality	+	+
Nodal betweenness	-	-
<i>Personal attributes</i>		
Female	+	?
Age	+	?
Disposable income	+	+/-
Car ownership	+	?
Education	+/-	+/-
Household type (relative to family, worker)		
Family, worker	+	?
Family, non-worker	?	?
Couple, worker	-	?
Couple, non-worker	-	?
Single, worker	-	?
Single, non-worker	-	?
<i>Urban environment</i>		
Urbanization	-	+/-

## 4 Research Design & Results

### 4.1 Introduction

This section starts with a brief overview of the determinants relating to modal choice. These are divided by quality of public transport, personal attributes, and residential environment. There is also a short examination of the quality of public transport by the level of urbanization. These are represented in Table 3 and Table 4. Following this the results of the analysis are presented which will provide an answer to the research question whether the quality of public transport influences modal choice. The model will be explained and will include several examples as to how the results should be interpreted. In addition, a marginal analysis of the indices depicting the quality of public transport will give a deeper understanding of the effects.

### 4.2 Descriptive analysis

**Modal Choice.** The modal split by percentages are presented in Table 3. The majority of the sample lives in a very strongly urbanized environment (70 percent) and in total almost half live in either Rotterdam or The Hague. This is coherent considering a sample size of South-Holland, the most densely populated province in the Netherlands. The total share of public transport is 18 percent. People are more likely to travel by public transport if they start their journey in an area where public transport is relatively better, this is mostly at the expense of taking a car or going by bike. This is consistent with the results of F. M. Dieleman et al. (2002), who found that people use good public transport in the Netherlands as a substitution for biking or walking. Car use is more common for men than for women, who make more trips by bicycle or foot. An explanation for this is that women often work closer to home or are predominantly responsible for childcare. Singles use public transport more regularly than other kinds of households. There is an increase in car use from low to high income. Education levels reveal a similar pattern to income; more highly educated individuals travel more often by car, assuming that people with a higher education level earn more. Most trips are made using public transport when the purpose of the trip is work related. As expected, the car is the most frequent option in areas that are a little urbanized and people starting their trip in a very urbanized area travel more often by public transport. Notably the share of bicycle trips and trips by foot does not vary substantially between the different urban environments. This may reflect that only certain trips are made on foot and by bike and that distance of these trips tends to be similar across the different urbanization rates, for example groceries or bringing your children to school.

**Table 3.** Modal split by quality of public transport, socio-economic factors, and urbanization rate (%)

	Car driver	Public transport	Bicycle	Walking	Other
<b>Quality of public transport</b>					
<i>Closeness centrality (at origin)</i>					
Bad performers	29.3	10.0	28.8	19.9	12.0
Good performers <sup>1</sup>	21.5	26.4	18.0	25.9	8.1
<i>Degree centrality (at origin)</i>					
Bad performers	26.8	12.9	26.3	22.8	11.1
Good performers	23.0	28.0	18.4	22.8	8.1
<i>Nodal betweenness (at origin)</i>					
Bad performers	29.1	11.6	26.0	21.3	12.1
Good performers	22.2	24.0	21.4	24.2	8.2
<b>Personal attributes</b>					
<i>Gender</i>					
Male	30.8	18.8	21.3	21.2	7.9
Female	22.1	17.3	25.1	23.9	11.6
<i>Household type</i>					
Family	30.3	14.1	24.5	20.1	11.1
Couple	24.9	17.8	22.7	23.7	10.9
Single	18.3	24.8	23.4	26.2	7.3
<i>Disposable income</i>					
To €10.000	21.9	24.4	24.4	25.2	4.2
€10.000 to €20.000	15.4	25.2	24.9	23.4	11.1
€20.000 to €30.000	20.1	19.9	20.5	30.1	9.3
€30.000 to €40.000	28.5	15.3	21.7	24.1	10.5
€40.000 to €50.000	29.7	17.2	22.7	18.5	12.0
€50.000 or higher	30.7	14.1	27.7	17.9	9.5
<i>Level of education</i>					
Lower	18.9	22.3	16.9	29.4	12.6
Middle, lower	27.0	11.6	21.1	23.1	16.5
Middle, upper	24.9	20.3	25.1	21.6	8.1
High	26.8	17.7	24.6	22.3	8.7
<i>Car owner</i>					
No	6.9	26.8	29.4	23.4	13.5
Yes	43.2	9.4	18.1	22.3	7.0
<i>Trip purpose</i>					
Work	25.5	35.8	25.6	8.5	4.6
Shopping	19.6	10.0	28.7	33.5	8.2
Leisure	29.1	13.7	19.2	21.8	16.2
Other	30.2	17.4	20.1	23.1	9.2
<b>Urban environment</b>					
<i>Urbanization</i>					
Very strong	23.2	22.2	21.6	23.3	9.7
Strong	31.8	8.9	26.1	21.9	11.3
Average	28.5	5.9	32.6	20.9	12.2
Little	46.8	0.0	23.6	26.8	4.8
<b>Total modal split</b>	<b>25.5</b>	<b>18.0</b>	<b>23.6</b>	<b>22.8</b>	<b>10.1</b>

<sup>1</sup>Station that performs above the median

**Public Transport.** Table 4 gives an overview of the average quality of public transport by different urbanization rates. In general, public transport in the more urbanized environments is better than in the less urbanized environments. There are more stations in the strongly urbanized areas and the differences can become substantially large when compared to the less urbanized parts. The indices of the best performers for closeness centrality, degree centrality and nodal betweenness are 41, 0.7, and 291, respectively. The average of the urbanized areas is considerably lower than these best performers, which indicates that the stations in this area cannot perform closely to the high standard set by the central stations. These urbanized areas are however still outperforming the less urbanized areas by far.

**Table 4.** Average quality of public transport by urbanization rate (indices)

	Closeness centrality	Degree centrality	Nodal betweenness
Very strong	53.1	1.5	44.3
Strong	68.5	1.6	25.9
Average	92.4	1.9	4.6
Little	114.4	2.1	3.3
Median	57	1.5	14

### 4.3 Multinomial Logit Model

This research used a multinomial logit model to find the effects of the various attributes on modal choice. The independence of irrelevant alternatives (IIA) can be disrupted if additional choices, for instance the possibility to travel with Uber, will change behavior in favor of choices already existing in the model. Nevertheless, all other modes of transport are available to choose and these modes of transport are very distinct from one another so it will comply with the IIA and therefore the multinomial logit model is sufficient for this analysis. Besides, this model is a common practice in the field of mobility research (Cervero, 2002; F. M. Dieleman et al., 2002; Schwanen, Dieleman, & Dijst, 2001).

The results of the analysis are presented in Table 5. The dependent variable is modal choice and here public transport is taken as the point of reference. All the coefficients are relative to the reference category. For example, parameter 0.162 indicates an increase in the likelihood of using the car relative to public transport as age increases. The categorical variables also have a reference category. The parameters of the other categories are expressed with respect to this reference category. For instance, the parameter of 0.422 as *high* on the variable education level indicates that those with a higher level of education are much more likely to go to work by foot or bike than people with a *lower* level of education (the reference group). As this is a regression model, other influences are taken into account (e.g. income, gender, car ownership). The odds ratio expresses the effect of the independent variable on the likelihood of using that mode of transport - private car, foot or bike - to the reference transport mode. For example, the ratio of 0.67 for household type indicates that an employed individual without children is almost half as likely to travel by car than an employed individual with children.

Although at a very small magnitude, the quality of public transport seems to influence travel behavior. People become more likely to travel by car, foot or bike when the travel time to other nodes becomes longer and the frequency decreases. The closeness centrality at both the origin as well as at the destination of the trip seems to affect this. This makes sense since longer travel times will have a disadvantage over private car use and slower modes of transport. Similarly, waiting time is often seen as a nuisance, which is increased by lower

frequency. People are less likely to travel via public transport if the average transfer to other nodes in the system from their origin is high. This result is however not significant. A result was expected here since a direct connection reduces waiting times and is far more convenient. People are less likely to travel by car, foot or bike if nodal betweenness is better, implicating that the likelihood of travelling via mass transit increases if the station at the origin and/or at the destination of the trip is positioned in a favorable position within the network. This should however be interpreted with great caution since most stations positioned in a favorable position have also a great catchment area in terms of employees which is not controlled for.

All the parameters within household variable and private car are significant. This is in line with previous research and indicates that couples and singles without children are more likely to travel via public transport. When you have children and are not employed the likelihood of travelling by car, foot or bike strongly increases. This can be explained as stay-at-home men and women have more trips where public transport is not the optimal mode of transport (e.g. bringing children to school, groceries).

Unsurprisingly, car ownership increases the likelihood of travelling by car considerably. Car ownership also increases the likelihood of travelling by slow transport. The unfamiliarity with the public transport system might explain this result. More specifically, a car can substitute for long public transport trips, but the car is often a poorer option when it comes to shorter trips, where travelling by foot or by bike is also suitable. You might rather travel by foot or bike when the public transport system is unknown. On the other hand, public transport can also be a substitute for short trips. This might create a tendency to go by public transport if you are familiar with the system, also for these shorter trips. Women are more likely to travel by foot or bike than men. The analysis implies that urbanization rate only has a small impact on travel mode; people living in a strongly urbanized environment are more likely to travel by car.

**Table 5.** Multinomial logit model of modal choice (reference category = public transport)

	Private car			Cycling Walking		
	<i>B</i>	Standard error	Odds ratio	<i>B</i>	Standard error	Odds ratio
<i>Quality mass transit at origin</i>						
Closeness centrality	0.023**	0.009	1.02	0.025***	0.008	1.03
Degree centrality	0.254	0.336	1.28	0.242	0.289	1.27
Nodal betweenness	-0.003*	0.002	1.00	-0.002	0.001	1.00
<i>Quality of mass transit at dest.</i>						
Closeness centrality	0.015*	0.008	1.02	0.021***	0.007	1.02
Degree centrality	0.117	0.330	1.12	-0.174	0.281	0.84
Nodal betweenness	-0.006***	0.002	0.99	-0.004***	0.001	0.99
<i>Personal attributes</i>						
Female	0.158	0.126	1.17	0.249**	0.106	1.28
Age	0.162***	0.029	1.18	0.104***	0.023	1.11
Disposable income	-0.016	0.053	0.98	-0.049	0.044	0.95
Car ownership	2.843***	0.147	17.16	0.746***	0.114	2.11
<i>Level of education</i>						
Lower (=ref)						
Middle, lower	0.407	0.288	1.50	0.484**	0.230	1.62
Middle, upper	-0.083	0.267	0.92	0.189	0.208	1.21
High	-0.067	0.275	0.94	0.422*	0.217	1.53
<i>Household type</i>						
Family, worker (=ref)						
Family, non-worker	0.774**	0.347	2.17	1.145***	0.301	3.14
Couple, worker	-0.408**	0.179	0.67	-0.133	0.154	0.88
Couple, non-worker	-0.686***	0.208	0.50	-0.123	0.175	0.88
Single, worker	-0.469**	0.219	0.63	0.119	0.176	1.13
Single, non-worker	-0.921***	0.247	0.40	-0.269	0.193	0.76
<i>Urbanization</i>						
Very strong (=ref)						
Strong	0.414**	0.209	1.51	0.269	0.190	1.31
Average	-0.034	0.309	0.97	-0.027	0.278	0.97
Little	13.826	812.4	1.01E+6	13.284	812.4	587,5
Constant	-4.550***	0.729	0.01	-2.709***	0.644	0.07

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

#### 4.4 Average Marginal Effects

The average marginal effects are predicted by giving all the observations in the data the same index for the quality of public transport and looking at what mode of transport was chosen. Following this the average of these outcomes was calculated. However, improved public transport will not necessarily influence everybody's choice, other attributes are still of importance. In this model public transport is used again as the reference category.

For example, the parameter 0.299 in Table 6 indicates that for those living in an area where closeness centrality has a score of 28, it is predicted that almost 30 percent of them will travel via public transport. This is considerably higher than in the area with a closeness centrality of 130, meaning that in an area where the transport is more frequent and the distance to other nodes in the system is shorter, more people will use it. This counts for both the origin and the destination of the trip.

Table 7 demonstrates that people are much more likely to travel via public transport if they start their trip in an area where it takes on average of 0.7 transfers to reach the other nodes in the system. The likelihood gradually increases as degree centrality increases. Of note is that people who end their trip in an area with a high average are more likely to travel via public transport than people who end their trip in an area with a low average. This might mean that people travel from places where public transport is relatively good to less connected areas, which is counter intuitive since you would assume that offices and shopping areas are in the city center. Lastly people are less likely to use public transport if the nodal betweenness, the overall score of the area, is low. This applies especially to the 50 percent worst performing nodes in the sample (see Table 8). Besides, the differences are more present at the destination of the trip than at the origin. This could be explained by the fact that offices and shopping areas are often located near accessible stations, which makes it easier for workers and visitors to come via public transport.

**Table 6.** Average marginal effect closeness centrality

Value	Origin		Destination	
	Margin	Standard error	Margin	Standard error
28 Min	0.229***	0.022	0.222***	0.019
57 Median	0.169***	0.007	0.171***	0.006
80	0.112***	0.020	0.121***	0.018
100	0.076***	0.025	0.087***	0.024
130	0.040*	0.023	0.051**	0.025
155 Max	0.023	0.018	0.032	0.022

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 7.** Average marginal effect degree centrality

Value		Origin		Destination	
		Margin	Standard error	Margin	Standard error
0.7	Min	0.200***	0.029	0.168***	0.025
1.1		0.188***	0.014	0.174***	0.013
1.5	Median	0.177***	0.006	0.180***	0.006
1.9		0.167***	0.016	0.185***	0.016
2.3		0.156***	0.027	0.191***	0.029
2.7	Max	0.147***	0.038	0.196***	0.043

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 8.** Average marginal effect nodal betweenness

Value		Origin		Destination	
		Margin	Standard error	Margin	Standard error
1	Min	0.161***	0.009	0.153***	0.009
14	Median	0.166***	0.008	0.160***	0.008
80		0.191***	0.008	0.198***	0.009
150		0.216***	0.020	0.242***	0.022
220		0.240***	0.035	0.291***	0.039
291	Max	0.265***	0.052	0.344***	0.059

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## 5 Conclusion & Discussion

### 5.1 Conclusion

One of the key challenges for cities in the future is urban growth and the mobility problem accompanies this expansion. This paper focused on how the public transport system influences travel behavior. This research analyzed the relationship between the quality of public transport and modal choice in Zuid-Holland using the data from the 2010 Netherlands National Travel Survey and the SNAMUTS framework.

The results demonstrate that the quality of public transport does influence modal choice. A more frequent service and shorter travel times to other nodes increases the likelihood of people travelling via public transport. The location of the node within the network is also of importance for someone when choosing their mode of travel. The analysis confirmed that these effects are prevalent at the origin and destination of the trip. This is at the expense of not only cars but also trips by bicycle or foot. This analysis cannot confirm that the amount of transfers influence modal choice.

## 5.2 Discussion

Most of the results are consistent with the expected direction of the variables (see Table 2) and with previous research about the influence of density on modal choice. In particular, the outcomes of nodal betweenness suggest that in the center of the network with the largest catchment area of jobs and residents, use of public transport is the highest. This was also proposed by Schimek (1996). However, the quality of public transport is calculated using different components. In concurrence with location it seems that frequency and time also influence the people's choices. This analysis cannot confirm that the amount of transfers affects modal choice, which might be caused by people with more transfers planning their journeys better such that they have no unnecessary waiting.

Other attributes researched in this study generate the same outcomes as previous research. More highly educated people are more likely to travel by bike or foot, which implicates shorter distances and time, and therefore supports the theory of Gordon et al. (1989) that more highly educated people economize on their commuting. Moreover, the modes of transport used by the different household types correspond with the literature; the effect of people travelling by car when they have children is especially apparent. One surprising result is that car ownership increases the likelihood of travelling by slow transport. This might be caused due the unfamiliarity with the public transport system. Car is often a poorer option when it comes to shorter trips and therefore someone who is unknown to the public transport system might prefer to travel by foot or bike.

## 5.3 Policy recommendations

The expected growth of cities puts more pressure on how a city's mobility functions. Action is needed to maintain the current accessibility level. Substantial results can be accomplished by extending the current public transport network (Mulalic et al., 2016) and finishing additional lines at the same time as residential neighborhoods are completed (Acharya & Morichi, 2007). However, improvements can also be made on the current network. Increasing the frequency and shortening travel times will attract more customers and therefore contribute to finding a more sustainable solution. Adding more substantial hubs so the overall system is better connected will increase the use of public transport and get cars off the road.

The sprawl has spread residents, but most jobs remain in city centers. Commuters can use multiple modes of transport by parking their car on the outskirts of the city and continue via public transport. This could be an ideal solution if transfers do not influence travel mode. The city center is often least accessible by car but most accessible by public transport. More frequent and faster services will respond to the sensitivity of people on frequency.

## 5.4 Limitations

The conclusions must be interpreted with caution since the analysis was restricted by lack of data. Quality of public transport was linked to the observations by zip code and the actual distance to the stations and the nature of the destination were not included, which might be of importance (Cervero, 1996). Besides, availability and number of parking spaces can also have a negative influence on car use and this might be of even more importance in highly-dense counties such as Zuid-Holland than in car-oriented cities such as Los Angeles. (Morrall & Bolger, 1996).

Another point to highlight is that travel behavior is also determined by other factors besides personal attributes and the urban environment, not included in this research. Willingness to use public transport is also influenced by self-congruity. Meaning that how people see themselves, or want to be seen, should match with the image of the product (Sirgy, Grzeskowiak, & Su, 2005). Steg (2003) found that fervent car users choose to travel by car not only because it was more convenient than public transport, but also because the car

represents cultural and psychological values such as freedom and independence. The results of research that does not include these attitudes might therefore be biased.

It would be interesting to include these cultural values in future research investigating how they influence modal choice. Values changes and in this era where peer-to-peer economy is on the rise it becomes increasingly important that these are understood in order to adjust mobility in the city for the future generations and their values rather than being based solely on current beliefs.

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## Appendix

### a. Quality of public transport formulas

#### Closeness centrality

$$C_i = \sum_{i=1, j \neq i}^N \frac{L_{min,ij}}{N-1} \quad (1)$$

Where:

$C_i$  = Closeness centrality of node  $i$

$L_{min,ij}$  = Minimum cumulative impediment between nodes  $i$  and  $j$

$N$  = Number of activity nodes in the network

Travel impediment

$$d_{ij} = 4 * \sqrt{\frac{t_{ij}}{f_{ij}}} \quad (2)$$

Where:

$d_{ij}$  = Impediment value of route segment between nodes  $i$  and  $j$

$t_{ij}$  = Travel time between nodes  $i$  and  $j$  in minutes

$f_{ij}$  = Service frequency in departures per hour per direction between nodes  $i$  and  $j$

#### Degree centrality

$$P_i = \sum_{i=1, j \neq i}^N \frac{P_{min,ij}}{N-1} \quad (3)$$

Where:

$C_{ij}$  = Degree centrality of node  $i$

$P_{min,ij}$  = Minimum number of transfers between nodes  $i$  and  $j$

$N$  = Number of activity nodes in the network

#### Nodal Betweenness

$$B_k = \frac{\sum_{i=1, j=1, j \neq i}^{N(N-1)} \frac{P_{ij}(k) * act_i * act_j}{L_{min,ij}}}{1000 * \sum_{i=1, j=1, j \neq i}^{N(N-1)} \frac{act_i * act_j}{L_{min,ij}}} * B_g \quad (4)$$

Where:

$B_k$  = Betweenness centrality of node/ segment  $k$

$P_{ij}(k)$  = Paths between nodes  $i$  and  $j$  that pass through node/ segment  $k$

$act_i$  = Number of residents and jobs in catchment area of node  $i$

$act_j$  = Number of residents and jobs in catchment area of node  $j$

$L_{min,ij}$  = Minimum cumulative impediment between nodes  $i$  and  $j$

$B_g$  = Global betweenness index

$N$  = Number of activity nodes in the network