Commuting and living pattern changes before and during COVID-19 in the Netherlands

Master thesis in partial fulfillment of the requirements for obtaining an MSc degree in Transport & Supply Chain Management

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Abstract:

The development of information and communication technologies (ICT) helped shift work from offices into our homes. It made offices a rarely seen place for workers before and during the pandemic. Commute distance, commute frequency, and residential preference may have changed accordingly. This descriptive, quantitative research aims to analyze the Dutch commuting distance, Dutch commute frequency, and the development of population density to understand to what extent they have changed through time. This is undertaken by calculating the weighted average of commuting distance at the city level and the total commute frequency, closely followed by an analysis of working population density concerning the distance to the city center, referencing the result of average commute distance. The findings show that both commuting distance and frequency decreased sharply during the pandemic in all cities involved in this research. Population density tends to increase more in areas that are closer to the city area; the result shows that even though people may consider moving, the location closer to the city is still relatively popular. It is advised for future research to repeat the analysis of the datasets of commute-related activities for the post-COVID period.

Keywords: Commuting, ICTs, Population density, The Netherlands

1. Introduction

Throughout human history, under rare circumstances, a disease affected multiple countries at the same time. The last outbreak can be traced back to 2003 in Asia when SARS emerged (Chen et al., 2007). The world, at this moment, is facing another challenge from the outbreak as World Health Organization (WHO) declared COVID-19 as a pandemic on the 11th of March, 2020 (World Health Organization, 2020). In the Netherlands, the government responded with a series of measures to contain the outbreak of the virus, including hard lockdowns. Introduced in December 2020 and 2021, residents were asked to stay home for work and education as much as possible. Under such circumstances, people will require to change their living and working pattern dramatically in a short period. Such dramatic change is possible because of the development of information and communication technologies (ICT). Recent studies from 14 EU countries prove that information and communication technologies (ICT) are associated with a significant increase in the share of employees who work from home (Vahagn et al.,2020). Undoubtedly, the technologies of ICT help to limit the spread of the virus and bring impact to where we need to live since people may not need to travel a long distance to work. The change in commute and travel behavior has always been a popular research topic (Abdullah et al.,2020, Mustafa et al.,2021, Mikiharu et al.,2020, Molloy et al.,2021), and has drawn more attention after the outbreak. In the Netherlands, research shows that 44% of workers started or increased the number of hours working from home, and 30% have more remote meetings than before. Most of these workers report positive experiences (Haas de et al., 2020). Another observation has shown that teleworking can significantly impact where people decide to reside as there are fewer restrictions considering the distance of commute (Muhammad, 2007.We also notice that there are few studies focusing on connecting the change in commute patterns and the possible residency preference change with recent data. Therefore, this thesis will aim to study the change in commute patterns and the potential change in housing preference through population density analysis based on the latest data available.

A series of hypotheses are developed to investigate the change in commute behavior (distance and frequency) and the residential location preferences and will be validated by the research questions. We assume that the commuting behavior will change since the measurement such as hard lock down suggests that people stay home as much as possible. Therefore, we expect different behavior to be observed in the data of 2019~2020 compared to the previous years, and the number of trips that people make are also expected to decrease significantly by the measurement. Finally, we assume that there will be changes in the population density centered in selected Dutch cities, as working populations may change their place reside due to pandemics and teleworking.

To validate those hypotheses, changes in the commute distance of people, commute frequency related to the pandemic, and spatial data with geographical characteristics will be analyzed. Furthermore, this research will provide a descriptive result with a detailed analysis of the essential data to further understand the change in communing behaviors and the population density changes during the pandemic.

The research area of this topic is the Netherlands, a country known for its high density of population in major cities and its modernized rail-way system that connects the entire country. Research indicates that 27% of home-workers also expect to work more from home in the future after corona (Haas de et al., 2020), making the Netherlands an ideal place for finding out what impact have the pandemic brings to the behavior of commuting and whether or not the urban development correlates with the commuting behavior.

In summary, this thesis aims to conclude by answering the following research questions:

> *Research Question 1: "How much has the average commuting distance changed in the year 2018~2020 between selected Dutch cities?"*

In this thesis, datasets of the commuting distance from Centraal Bureau Voor de Statistiek (CBS) are used as the base of analysis; this thesis will perform an analysis between the year 2018~2020. Due to the pandemic and the development of remote working, the distance and the amount of travel will be less than in the time before COVID, which is the first hypothesis in this thesis.

The second research question is as follows:

> *Research Question 2: "How much has the commuting frequency changed in the year 2018~2020 between selected Dutch cities?"*

This research question examines another crucial element in understanding the commuting behavior – the commute frequency. The dataset of "Onderzoek Onderweg in Nederland"

(ODiN) available from 2018 to 2020 will be used and analyzed in the research question. This research question is crucial as longer commute distance does not necessarily represent more commute frequency. It is expected that due to COVID regulation, people may commute less. Also, improving ICT devices and techniques do not require workers to commute at all or at least less nowadays.

The final research question is:

> *Research Question 3: "To which extent has the spatial distribution of the working population changed within selected Dutch cities between the year 2018~2020 in relation to their work location?"*

Lastly, the final research question is to research the change in population density in the Netherlands. CBS dataset: "Kaart van 100-meter bij 100 meters met statistieken" will be used in this research question. These shapefiles provide raster data on the scale of 100m to 100m. Analyzing with average commute distance will enable us to understand the change in the cities' working population and areas reached by commuters. This can help answer if people choose another residency place and if the urban development still follows what Wolff et al. (2018) proposed. Their research indicates that despite urban de-densification, other factors may still make large cities remain highly populated. Since the COVID outbreak is still relatively recent and ongoing, the observation period may be limited to finding a conclusive answer. However, recent research in New York City shows that it is possible to observe an immediate urban response in the short term (Yang et al.,2021), making it worth further examination for a potential change.

This thesis is structured as follows: *Literature Review* (Chapter 2) provides extensive background knowledge for this thesis, covering " Information and communication technologies," " Teleworking," and "Population development in the Netherlands." *Methodology, research design, and data description* (Chapter 3) provide a detailed overview of the datasets used in this thesis and the GIS & Statistic method used. *Results* (Chapter 4) demonstrate the results obtained from the previous chapter. *Discussion* (Chapter 5) compares the literature and the results of this thesis and interprets the outcome. The final chapter *Conclusions, limitations, and further research* (Chapter 6) discuss the limitations and potential future research.

2. Literature review

This literature review will discuss the development of ICT and teleworking with their connection between commuting behaviors. As the theoretical basis of our research question, the Dutch population development will also be covered in the following literature review.

Information and communication technologies (ICT)

With technologies evolving, the way we live and work changes. Based on the development of information and communication technology (ICT), remote working has become possible and has grown steadily in recent years (Vilhelmson et al.,2016). Since the Morse code was introduced in 1835 by Samuel F.B Morse, people started to transmit messages through signals faster and more reliable than the old fashion mail letter. Since the invention of computers and the internet, ICTs have evolved to the extent that people can facilitate their access to a wide range of opportunities and facilities: remote jobs, E-shopping, and online education (Muhammad, 2007). Especially during the outbreak of the COVID, the ICTs support workers and educators to deploy activities through the internet, reflecting the governmental lockdown in various countries (Wang et al., 2021).

Teleworking

The word 'telework' was first introduced in 1973 by Jack Nilles, who defined it as an activity that "includes all work-related substitutions of telecommunications and related information technologies for travel" (Collins, 2005). Telework constituted a 'hot' topic for researchers, policymakers, and practicians during the 1970s when digital networks and computers were widely introduced in business and work (Vilhelmson and Thulin, 2016).

During the 1970s and 1980s, telework was considered the future work arrangement (Illegems et al., 2001). Despite the optimistic predictions, the implementation of telework, mainly as an occasional work pattern, had proven slow until 2019, when the Covid-19 outbreaks, which organizations were requested to implement a system of remote work covering most of their personnel. (European Commission, 2020; Iscan and Naktiyok, 2005).

Although many researchers focus on the definition that links telework with working from home, telework mainly involves working outside of the employer's premises with the support of ICTs, and, therefore, it can occur from multiple locations (home, office, other places) using different kinds of technologies (smartphones, laptop). To gain a systemic perspective of the situation of teleworking, the ILO report (2017) characterizes teleworking into several different modalities. Table 1 presents the definitions for these types of telework.

Table 1:Different types of teleworking (ILO,2017)

Modality	**Place of work**
Regular home-based telework	From home at least, several times a month and in other locations less often than several times a month.
High mobile teleworks	At least several times a week in at least two locations other than the employer's premises or working days in at least one other location.
Occasional telework	Employees working in one or more places outside the employer's premises only occasionally and with a much lower degree of mobility than the high mobile group.

Besides providing new ways for people to work, teleworking also has a significant impact on the choice of residency. In the past, commuting distance to the physical workspace was strongly related to residential location preferences. (Van Ommeren et al. 2000). The link between them can be explained by workers' preference to limit their commuting distance and time (Horner 2004) since physical commuting is made less frequently in the case of teleworking. Therefore, the development of telework may affect a worker's perception of residential location priorities and decisions (Mokhtarian et al., 2003).

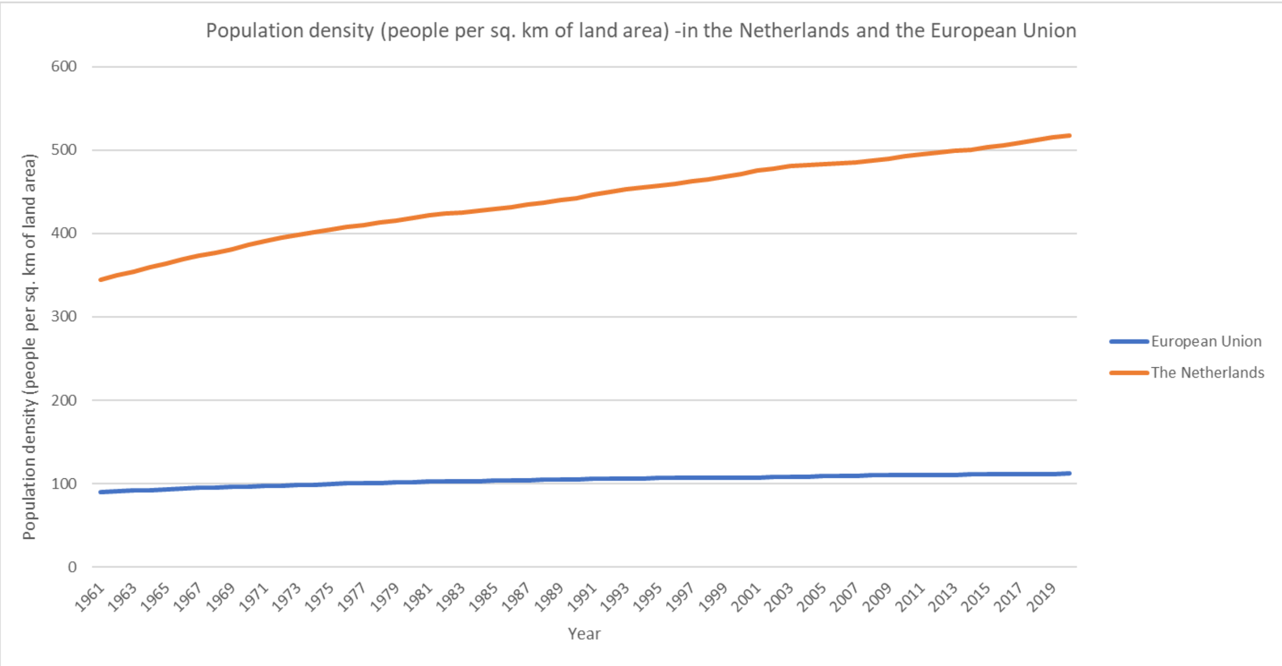
With the mentioned growth of teleworking, locational preferences for different types of residential environments are expected to change as trade-offs are made between commuting time and characteristics of the place of residency. In general, workers that are able to telework will have a spatially more comprehensive range of choices than traditional commuters.

Therefore, possible correlations between the commuting patterns and population development can be expected.

Population development in the Netherlands

The Netherlands is a densely populated country. According to the data from The World Bank (2022), the population density rose from 345 to 518 persons per square kilometer of land area from 1960 to 2020. This is much higher than the average for the European Union, which rose from 90 to almost 112 persons/km^2, as is shown in Figure 1.

Figure 1:Population density (people per sq. km of land area) -in the Netherlands (blue) and the European Union (orange).



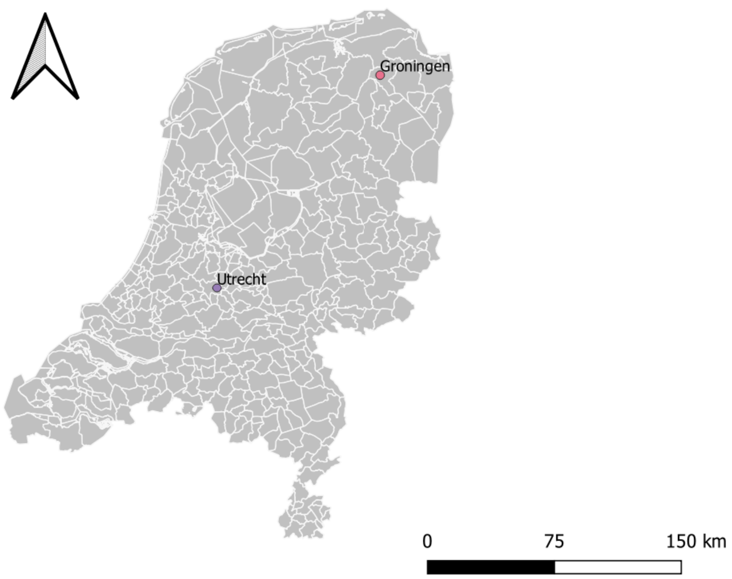
At a micro level, according to the research of Beenackers et al. (2018), compared to cities in the United States or Australia, where cities leaving downtown are generally widely set up, European cities are often more compact and, in many cases, are very densely populated. For example, Orlando, Florida, a middle-sized city of 200,000–250,000 inhabitants in the USA, has an average population density of around 1000 inhabitants per km^2. In contrast, in the Netherlands, a city of the same size will have a population density that is two times higher than cities in the United States; Eindhoven, the Netherlands, has 2596 inhabitants per km^2 in this case. Moreover, the dwelling density was still increasing (Broitman and Koomen, 2020) in many Dutch cities. For example: Utrecht has increase from 52.6 housing units/ha to 66.8 housing units/ha and Groningen increase from 45.7 housing units/ha to 73.3 housing units/ha in 2012 to 2017.

Whether on the scale of the whole country or gone into the city level, The Netherlands has proven to be a country with a high population density. Also, it possesses compact cities, which are all valuable geographical research material should we want to research population or urban development.

3. Methodology, research design, and data description

This chapter consists of a description of the data used for the analysis, an explanation of the research design, and a general description of the methodology to answer the research questions. The targeted study area in this thesis is The Netherlands (Figure 2).

Figure 2:Study area (The Netherlands) and selected city for population density analysis



3.1 Data description

3.1.1 Commuting distance data

The "Woon-werkafstand werknemers; regio" dataset from the Dutch statistical office (CBS) contains data reflecting commuting distance between all possible combinations of municipalities from 2014 to 2019. Based on the information from the Dutch tax authorities and data from the civil register, CBS could draw a connection between the place of living and the place of work with a unique Gemeente code for each city. The dataset assumes that daily commuting occurs if an individual resides in city i and works in city j. For example, the first row in Table 2 shows the commuting distance from Aa en Hunze to Aalten. In this thesis, for alignment with the ODiN dataset used in the upcoming analysis, which only contains a period from 2018 to 2020, the commute dataset will also focus on the same period.

Table 2: Structure of Dutch commuting distance data in the period 2018-2020 (CBS,2018~2020)

Gemeente code i	Gemeente code j	Commute Distance from Gemeente i to Gemeente j	Year
1680	197	$x_{1680\ 197}$	2018
2	34	$x_{2\ 34}$	….
…..	…..	…..	….
412	1	$\mathbf{x_{4121}}$	2020

3.1.2 Commute frequency data

The second dataset used in this thesis is the commute frequency dataset extracted from "onderzoek Onderwegin Nederland (ODiN). " As the continuation of the "Onderzoek Verplaatsingen in Nederland (OViN)" after 2017, the dataset only contains records after 2018. Unfortunately, the methodology between ODiN and OViN is entirely different; merging them is impossible. Therefore, this thesis focuses on the more recent ODiN dataset. Table 3 is a sample of information used in this thesis extracted from ODiN. The first row shows the reason for travel is "work" (Code: 2) and the travel trips from city i to j, which follows the same Gemeente code logic as the previous dataset.

Table 3: Data structure of Dutch commuting frequency in the period 2018-2020(ODiN,2018~2020)

Reason of travel	Commute trips from Gemeente i to Gemeente j	Year	Gemeente code i	Gemeente code j
2	$Y_{1680\ 197}$	2018	1680	197
2	$Y_{2\ 34}$	….	2	34
…..	…..	….	…..	…..
2	$\mathbf{Y_{1\ 412}}$	2020	1	412

3.1.3 Dutch Population data

The last dataset used in this thesis is "Kaart van 100-meter bij 100 meters met statistieken". This dataset divides the Netherlands into squares of 100 meters by 100 meters. A variety of information is there within these squares. In addition to information on population compositions, these squares also contain ages, ethnicities, incomes, information on the number of dwellings, etc. This dataset is provided by the Dutch statistical office (CBS).

3.2 Research Design & Methodology

This chapter explains the procedure and methodologies used to be able to answer the research questions proposed in the previous section.

3.2.1 Commuting distance data

In this thesis, the classification of municipalities is based on the classification of the Dutch statistical office (CBS). This classification is based on administrative boundaries between municipalities. The authority divides cities into urban agglomerations and regions and labels them with a unique Gemeente code. Based on this and a different selection process, Vliegen (2005) conducted a classification of city hierarchy, taking population and level of development into account. In subsequent years, the authority updated the classification to reflect changes in the composition of some municipalities. The 421 municipalities in the dataset were classified as cities, suburbs, and others.

Unfortunately, it is challenging to analyze commuting distance in all the municipalities on a municipality basis with the method mentioned above. The reason is that the data for suburbs and others have a lot of missing data, which the flow is simply absent. Therefore, this thesis will target the 22 cities classified by Vliegen (2005), as shown in Table 4. Utilizing only 22 cities cannot obtain a national-wise overview. If the dataset permits in the future, the area other than these should be included so that a national-wise result can be obtained.

To gain a more sensible calculation result, a weighted average will be calculated with the commute frequency, the commute frequency dataset used for the next research question will also be involved for this purpose.

Table 4:Name and Gemeente code labeled as "Cities"

City code	City name	City code	City name	City code	City name
14	Groningen	344	Utrecht	772	Eindhoven
80	Leeuwarden	363	Amsterdam	796	's-Hertogenbosch
153	Enschede	392	Haarlem	855	Tilburg
193	Zwolle	505	Dordrecht	917	Heerlen
200	Apeldoorn	518	's-Gravenhage	935	Maastricht

202	Arnhem	546	Leiden	1883	Sittard-Geleen
268	Nijmegen	599	Rotterdam		
307	Amersfoort	758	Breda		

There are two central portions: the in-commute distance and the out-commute distance.

The in-commute distance is calculated as follows:

$$Incommute_j = \frac{\sum_{i \in All\ Gemeente} Distance_{ij} * Commute\ frequency_{ij}}{\sum_{i \in All\ Gemeente} Commute\ frequency_{ij}} \quad , \quad \forall j \in City$$

Where:

$Distance_{ij}$: Commuting distance from municipality *i* to municipality *j*

$City$: 22 cities classified as "Cities" in the study of Vliegen (2005).

$All\ Gemeente$: All the 412 gemeente available in the dataset.

$Commute\ frequency_{ij}$: Amount of commute trips made from *i to j*.

The in-commute measures the weighted average commute distance of people working in municipality j coming from other regions. It can determine the distance that people commute to work in municipality j from any area recorded in the dataset. This calculation can help us understand how far workers from a city travel to work, and we can utilize the result to observe the change in commute distance over time.

The out-commute distance is calculated as follows:

$$Outcommute_i = \frac{\sum_{j \in All\ Gemeente} Distance_{ij} * Commute\ frequency_{ij}}{\sum_{j \in All\ Gemeente} Commute\ frequency_{ij}} \quad , \quad \forall i \in City$$

Where:

$Distance_{ij}$: Commuting distance from municipality i to municipality j

$City$: 22 cities classified as "Cities" in the study of Vliegen (2005).

$All\ Gemeente$: All the 412 gemeente available in the dataset.

$Commute\ frequency_{ij}$: Amount of commute trips made from i to j.

The Out-commute measures the weighted average commuting distance of people residing in municipality i and performing their work elsewhere.

To better understand the level of impact brought by the time of Covid outbreaks, the Panel regression method is involved in this thesis.

Panel data is a two-dimensional concept, where the same individuum are observed repeatedly over different periods in time. If the data is collected randomly, the random effect model needs to be applied. If the model is not collected randomly, the fixed-effect model will be the choice. In this thesis, all data were not collected randomly; hence the fixed effect model is applied.

Continue with the in-commute and out-commute calculations; the panel data regression will also be performed with in-commute and out-commute.

The in-commute panel regression will be analyzed as follow:

$$Incommute_j \ = \ \beta_0 * Year2019 + \beta_1 * Year2020 + city\_fixed\_effect\_incommute_j$$

Where
$\beta_0 \in \{0,1\}$: Coefficient of the year variable of 2019.
$\beta_1 \in \{0,1\}$: Coefficient of the year variable of 2020.
$City\_fixed\_effect\_incommute_j$: Fixed effect estimated for every 22 cities.

The input for this regression is the result of the previous in-commute distance calculation. The regression model will estimate the coefficient of 2018~ 2020 and calculate a fixed effect for every 22 cities. The coefficient will provide a number of the impact of the different years on each city. While β_0 and β_1 are both 0, the model will represent the year 2018, if β_0=1 and β_1=0, the model will represent the year 2019. The model will represent the year 2020 while β_0=0 and β_1=1.

The out-commute panel regression will be analyzed as follow:

$$Outcommute_i \ = \ \beta_0 * Year2019 + \beta_1 * Year2020 + city\_fixed\_effect\_outcommute_i$$

Where
$\beta_0 \in \{0,1\}$: Coefficient of the year variable of 2019.
$\beta_1 \in \{0,1\}$: Coefficient of the year variable of 2020.
$City\_fixed\_effect\_Outcommute_i$: Fixed effect estimated for every 22 cities.

The input for this regression is the result of the previous out-commute distance calculation. The regression model will estimate the coefficient of 2018~ 2020 and calculate a fixed effect for every 22 cities. Similar to the previous model, the coefficient will provide a number of the impact of the different years on each city. While β_0 and β_1 are both 0, the model will represent the year 2018, if β_0=1 and β_1=0, the model will represent the year 2019. The model will represent the year 2020 while β_0=0 and β_1=1.

3.2.2 Commute frequency data

A very similar method as described in section 3.2.1 will be applied in analyzing the commute frequency data. The commute frequency data will focus on the 22 cities characterized by Vliegen (2005) study in order to align with the result obtained in section 3.2.1.

There are two central portions of calculation with this data: the in-commute frequency and the out-commute frequency.

The in-commute frequency is calculated as follows:

$$Total\_Incommute\_freq_j \; = \sum\nolimits_{i \in All\ Gemeente} Commute\ frequncy_{ij} \;\; , \forall j \in City$$

Where:

$Commute$ frequency $_{ij}$: Commuting trips from municipality *i* to municipality *j*.

$City$: 22 cities classified as "Cities" in the study of Vliegen (2005).

$All\ Gemeente$: All the 412 gemeente available in the dataset.

The total in-commute frequency measures the total commute frequency of people working in municipality j coming from other regions. It can estimate how often people commute to work in municipality j from any other places available in the dataset.

The out-commute frequency is calculated as follows:

$$Total\_Outcommute\_freq_i \; = \sum\nolimits_{j \in All\ Gemeente} Commute\ frequncy_{ij} \;\; , \forall i \in City$$

Where:
$Commute$ frequency $_{ij}$: Commuting trips from municipality *i* to municipality *j*.
$City$: 22 cities classified as "Cities" in the study of Vliegen (2005).
$All\ Gemeente$: All the 412 gemeente available in the dataset.

The total out-commute frequency measures the total commuting frequency of people residing in municipality i and performing their work in other places available in the dataset.

The panel regression analysis will also apply to the result of the commute frequency data with in-commute frequency and out-commute frequency.

The in-commute frequency and out-commute frequency are modeled as follows:

$$Incommute\_freq_j = \beta_0 * Year2019 + \beta_1 * Year2020 + city\_fixed\_effect\_incommute_j$$

$$Outcommute\_freq_i = \beta_0 * Year2019 + \beta_1 * Year2020 + city\_fixed\_effect\_outcommute_i$$

Where
$\beta_0 \in \{0,1\}$: Coefficient of the year variable of 2019.
$\beta_1 \in \{0,1\}$: Coefficient of the year variable of 2020.
$City\_fixed\_effect\_incommute_j$: Fixed effect estimated for every 22 cities for in-commute
$City\_fixed\_effect\_outcommute_i$: Fixed effect estimated for every 22 cities for out-commute.

The input for this regression is the result of the previous commute frequency calculation. The regression model will estimate the coefficient of 2018~ 2020, calculate a fixed effect for every 22 cities, and provide a number of the impact of the different years on each city. Same as section 3.2.1, while β_0 and β_1 are both 0, the regression will represent the year 2018, if β_0=1 and β_1=0, the regression will represent the year 2019. The regression will represent the year 2020 while β_0=0 and β_1=1.

3.2.3 Dutch population data

Inspired by Broitman & Koomen (2020), a research method with ring-shaped buffers will be used to analyze the working population data. According to Organization for Economic Co-operation and Development (OECD,2022), the working population generally refers to those aged 25 to 64. To prevent the potential overlapping of the ring buffer if the target area is close to each other, this thesis will focus on the city of Utrecht and Groningen. Due to the historical development of the cities in scope, the large marketplace or the city hall was defined as the city center (Lemoy & Caruso, 2020). With this idea, the targeted city center of this study is shown in Table 5:

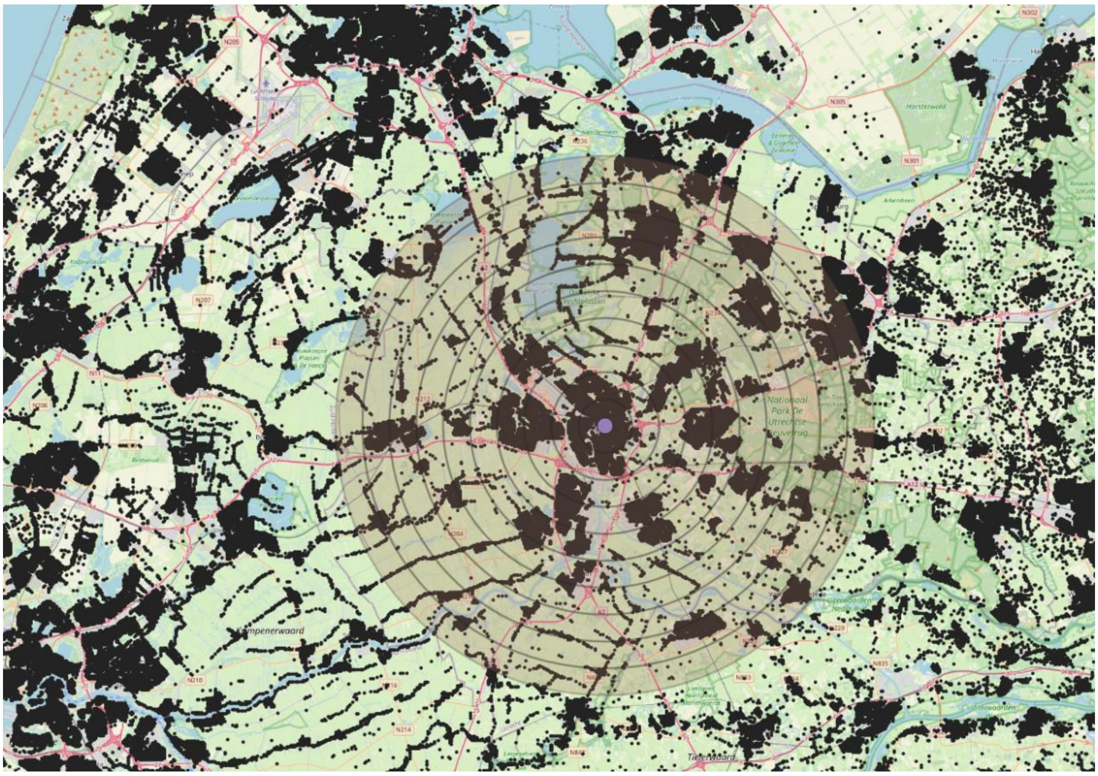
Table 5: Names and coordinates of the selected city center and maximum buffer distance

Name	latitude	longitude	Maximum buffer distance
Dom Utrecht	52.0908338	5.121381708	20700 meters
Grote Markt Groningen	53.21925445	6.566809566	15300 meters

Furthermore, rings were defined around the city center. The ring buffer size will correspond to the result of the out-commute distance analysis in section 3.2.1. Since the out-commute distance represents how far the city residents travel to work, the radius will cover area outside of the cities itself. This can be used to check if there is a potential connection between the change of population distribution and the commute distance.

The radius of the buffer will be the number obtained from section 3.2.1. Subsequently, this thesis will further divide the radius into 10 to create ten donut-like buffers surrounding the city center, as shown in Figure 3. Moreover, Rings in this analysis are all independent; for example, the ring that ranges from the center to 2070 meters and the ring between 2070 to 4140 has no cumulative relationship. With the QGIS 3.16.16 operation joining attributes by location and the ring buffer plugin, the number of inhabitants aged 25 to 65 was counted for every ring. These inhabitants represent the working population (OECD,2022) that directly contributed to the commuting behavior.

Figure 3: Sample of analysis with the center of Utrecht



To calculate the working population density, the area of every ring in hectare was calculated:

$$Area_{rd} = \frac{\pi * r_{rd}^2 - \pi * r_{rd-1}^2}{1000}$$

where

$Area_{rd}$ is the area of the ring with radius d in city r

r_{rd} is the radius of the ring with radius d in city r

Finally, the inhabitants per hectare were calculated:

$$H_{rd} = \frac{I_{rd}}{Area_{rd}}$$

Where

I_{rd} is the total number of inhabitants in the ring with the radius d in city r.

H_{rd} is the number of inhabitants per hectare in the ring radius d in city r.

4. Result

The following chapter presents the results of the analysis introduced in chapter 3.

4.1 Commuting distance data

Table 6: Result of Incommuting and Outcommuting distance calculation 2018~2020

	In-Commute distance (KM)			Out-Commute distance (KM)		
Cities	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Groningen	12.4	15.9	13.8	16.6	14.6	14.7
Leeuwarden	16.6	15.9	13.4	11.2	13.0	12.5
Enschede	12.4	13.6	11.2	11.0	14.4	11.2
Zwolle	22.3	20.9	21.7	24.4	23.4	18.0
Apeldoorn	17.0	16.7	18.5	24.4	14.2	12.9
Arnhem	18.1	19.4	15.5	21.1	20.5	19.1
Nijmegen	13.4	14.9	8.7	20.2	21.1	14.3
Amersfoort	24.5	22.6	14.9	22.2	28.9	15.3
Utrecht	26.2	29.0	19.0	19.0	25.2	18.1
Amsterdam	22.0	25.4	21.3	16.2	15.9	13.4
Haarlem	13.6	15.0	11.4	16.1	17.2	13.4
Dordrecht	14.2	17.6	10.7	17.7	22.1	12.1
's-Gravenhage	20.5	16.2	14.9	17.0	14.9	13.3
Leiden	14.7	15.8	16.9	18.7	14.0	20.2
Rotterdam	18.5	15.2	13.8	17.1	18.7	14.1
Breda	17.2	16.9	13.7	18.9	18.3	13.8
Eindhoven	18.7	19.3	16.6	15.4	13.3	10.2
's-Hertogenbosch	18.1	20.9	16.1	17.8	24.1	14.0
Tilburg	15.6	15.1	14.0	17.1	15.8	10.6
Heerlen	10.0	10.0	6.9	10.2	11.9	10.8
Maastricht	18.0	17.0	13.7	9.3	12.1	12.0
Sittard-Geleen	14.8	11.7	10.9	13.0	13.0	12.9

Table 7: Result of change in Incommuting and Outcommuting distance calculation 2018~2020

	Change of In-Commute distance (KM)		Change of Out-Commute distance (KM)	
Cities	**2018-2019**	**2019-2020**	**2018-2019**	**2019-2020**
Groningen	28%	-13%	-12%	1%
Leeuwarden	-5%	-16%	16%	-4%
Enschede	10%	-18%	32%	-23%
Zwolle	-7%	4%	-4%	-23%
Apeldoorn	-2%	11%	-42%	-9%
Arnhem	7%	-20%	-3%	-7%
Nijmegen	12%	-42%	4%	-32%
Amersfoort	-8%	-34%	30%	-47%
Utrecht	11%	-34%	32%	-28%
Amsterdam	16%	-16%	-2%	-16%
Haarlem	11%	-24%	7%	-22%
Dordrecht	24%	-39%	25%	-45%
's-Gravenhage	-21%	-8%	-12%	-11%
Leiden	8%	6%	-25%	44%
Rotterdam	-18%	-9%	9%	-25%
Breda	-2%	-19%	-3%	-25%
Eindhoven	3%	-14%	-14%	-23%
's-Hertogenbosch	15%	-23%	35%	-42%
Tilburg	-3%	-7%	-8%	-33%
Heerlen	0%	-31%	16%	-9%
Maastricht	-6%	-19%	30%	0%
Sittard-Geleen	-21%	-7%	0%	-1%
Overall	2%	-18%	3%	-21%

Table 6 and Table 7 present the result of the method calculation mentioned in section 3.2.1. Generally speaking, we can see a positive increase of up to 3% in both in-commute and out-commute distance if we look at all 22 cities from 2018 to 2019. However, the trend decreases significantly from 2019 to 2020, up to 21%. Individually speaking, several cities observe a significant growth in the commute distance between 2018 and 2019. For example, Groningen recorded a 28% increase in in-commute distance, and Utrecht reported a 32% increase in out-commute distance. Between 2019 and 2020, when the pandemic outbreaks occurred, almost all cities observed a considerable decrease individually. Nijmegen observes the most decrease of 42% in the in-commute distance. The city of Amersfoort sees a 47% decrease in the out-commute distance.

Table 8:Panel regression for out-commute distance

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
factor(Year)2019	0.28126	0.56220	0.5003	0.6195
factor(Year)2020	-2.78216	0.56220	-4.9487	1.257e-05 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-Squared: 0.46351

City fixed effect (Kilometers):

's-Gravenhage	's-Hertogenbosch	Amersfoort	Amsterdam	Apeldoorn	Arnhem
15.935	19.467	23.011	16.044	17.991	21.058
Breda	Dordrecht	Eindhoven	Enschede	Groningen	Haarlem
17.848	18.138	13.799	13.029	16.13	16.43
Heerlen	Leeuwarden	Leiden	Maastricht	Nijmegen	Rotterdam
11.81	13.089	18.5	11.979	19.385	17.493
Sittard-Geleen	Tilburg	Utrecht	Zwolle		
13.807	15.343	21.594	22.787		

Table 9:Panel regression for in-commute distance

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
factor(Year)2019	0.53375	0.82029	0.6507	0.5187972
factor(Year)2020	-3.08264	0.82029	-3.7580	0.0005224 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-Squared: 0.3504

City fixed effect (Kilometers):

's-Gravenhage	's-Hertogenbosch	Amersfoort	Amsterdam	Apeldoorn	Arnhem
18.0138	19.2339	21.5203	23.7266	18.2535	18.5027
Breda	Dordrecht	Eindhoven	Enschede	Groningen	Haarlem
16.7771	15.0172	19.0468	13.2242	14.8857	14.1645

Heerlen	Leeuwarden	Leiden	Maastricht	Nijmegen	Rotterdam
9.7851	16.1339	16.6274	17.0555	13.1579	16.6842
Sittard-Geleen	Tilburg	Utrecht	Zwolle		
13.3132	15.6974	25.5989	22.4766		

With the result of the previous analysis and the help of Rstudio, a panel regression model is created. Table 8 and Table 9 show the result of the analysis. We can easily observe that 2020 truly has a negative impact on the commute distance. On the other hand, 2019 positively impacts the commute distance from different cities. The interpretation is that the estimated reduction in commute distance due to variable 2020 is 2.782 kilometers in out-commute distance and 3.08 kilometers in in-commute distance. The factor 2020 in both models are statistically significant, meaning that 2020 has strong relationship between the commute distance and the year factor. Both regression models have a relatively low R-square, which is a statistical measure of fit that indicates how much variation of a dependent variable is explained by the independent variables in a regression model. Low R-square indicates that more independent variables other than city and years need to be involve in order to gain more explanatory power towards the variation of the dependent variable.

4.2 Commute frequency data

This section focuses on the commute frequency data analysis proposed in section 3.2.2.

Table 10:Result of Incommuting and Outcommuting frequency calculation 2018~2020

	Total in-commute trips/year			Total out-commute trips/year		
Cities	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
Groningen	1391	936	736	1229	792	633
Leeuwarden	964	551	363	703	412	308
Enschede	844	590	401	690	538	355
Zwolle	806	701	492	803	542	329
Apeldoorn	686	588	425	653	488	343
Arnhem	882	700	535	756	574	381
Nijmegen	1064	740	613	1007	750	609
Amersfoort	895	659	667	767	789	836
Utrecht	3301	2595	2381	2556	2068	1997
Amsterdam	8409	6420	3614	5229	3375	2051
Haarlem	680	646	421	999	719	437
Dordrecht	431	439	329	439	412	299
's-Gravenhage	3121	4597	2513	2476	4045	2306
Leiden	924	852	445	992	658	412
Rotterdam	3735	5002	2711	2850	4597	2596
Breda	831	781	479	711	655	392
Eindhoven	1656	1104	839	1204	832	680
's-Hertogenbosch	965	636	491	805	535	361
Tilburg	811	736	541	814	824	499
Heerlen	570	351	311	399	270	314
Maastricht	630	459	369	418	294	213
Sittard-Geleen	431	343	320	341	304	214

Table 11:Result of change in Incommuting and Outcommuting frequency 2018~2020

	Change in total in-commute trips/year		Change in total out-Commute trips/year	
Cities	**2018-2019**	**2019-2020**	**2018-2019**	**2019-2020**
Groningen	-33%	-21%	-36%	-20%
Leeuwarden	-43%	-34%	-41%	-25%
Enschede	-30%	-32%	-22%	-34%
Zwolle	-13%	-30%	-33%	-39%
Apeldoorn	-14%	-28%	-25%	-30%
Arnhem	-21%	-24%	-24%	-34%

Nijmegen	-30%	-17%	-26%	-19%
Amersfoort	-26%	1%	3%	6%
Utrecht	-21%	-8%	-19%	-3%
Amsterdam	-24%	-44%	-35%	-39%
Haarlem	-5%	-35%	-28%	-39%
Dordrecht	2%	-25%	-6%	-27%
's-Gravenhage	47%	-45%	63%	-43%
Leiden	-8%	-48%	-34%	-37%
Rotterdam	34%	-46%	61%	-44%
Breda	-6%	-39%	-8%	-40%
Eindhoven	-33%	-24%	-31%	-18%
's-Hertogenbosch	-34%	-23%	-34%	-33%
Tilburg	-9%	-26%	1%	-39%
Heerlen	-38%	-11%	-32%	16%
Maastricht	-27%	-20%	-30%	-28%
Sittard-Geleen	-20%	-7%	-11%	-30%
Overall	-11%	-34%	-9%	-32%

Tables 10 and 11 show the total trips made for working purposes by city level. Overall, all cities have a decreasing trend in commute frequency. Between 2018 and 2019, this thesis observes an overall 11% decrease in in-commute frequency and a 9% decrease in out-commute frequency. From 2019 to 2020, a significant decrease of 34% overall in-commute frequency and 32% in out-commute frequency are recorded. Individually speaking, Rotterdam could be the reflection of the impact caused by the pandemic. The city reports a 34% increase in in-commute frequency and 61% increase in out-commute frequency during 2018 to 2019, but reports a significant loss of 46% of in-commute frequency and 44% decrease in out-commute frequency during 2019 to 2020.

Table 12:Panel regression for in-commute frequency

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
factor(Year)2019	-163.68	172.93	-0.9465	0.3493008
factor(Year)2020	-637.77	172.93	-3.6880	0.0006432 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-Squared: 0.25894

City fixed effect (Trips):

's-Gravenhage	's-Hertogenbosch	Amersfoort	Amsterdam	Apeldoorn	Arnhem	Breda	Dordrecht
1288.15	893.15	878.82	933.48	833.48	972.82	1072.82	1007.48
Leiden	Maastricht	Nijmegen	Rotterdam	Sittard-Geleen	Tilburg	Utrecht	Zwolle
4083.15	964.15	1466.82	964.48	963.15	677.82	753.15	631.82
Eindhoven	Enschede	Groningen	Haarlem	Heerlen	Leeuwarden		
3026.15	6414.82	849.48	666.82	3677.48	1007.48		

Table 13:Panel regression for out-commute frequency

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
factor(Year)2019	-107.64	133.68	-0.8052	0.425238
factor(Year)2020	-467.09	133.68	-3.4942	0.001135 **

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-Squared: 0.24177

City fixed effect (Trips):

's-Gravenhage	's-Hertogenbosch	Amersfoort	Amsterdam	Apeldoorn	Arnhem	Breda	Dordrecht
1076.24	665.91	719.24	749.58	686.24	761.91	980.24	988.91
Leiden	Maastricht	Nijmegen	Rotterdam	Sittard-Geleen	Tilburg	Utrecht	Zwolle
3539.24	777.58	1096.91	758.58	903.91	519.24	499.91	477.91
Eindhoven	Enschede	Groningen	Haarlem	Heerlen	Leeuwarden		
2398.58	3743.24	909.91	574.91	3133.91	878.91		

Similar to the commute distance data analysis, a panel regression is executed. Table 12 and Table 13 show the result of the regression analysis. The interpretation of these models is that the estimated reduction in commute frequency due to variable 2019 is 164 trips in in-commute frequency and 107 trips in out-commute frequency. The same logic applies to 2020, where the estimated reduction in commute frequency due to the year variable is 637 trips in in-commute and 467 trips in out-commute. The model derived from the commute frequency reports a low

R-square and a statistical significance of the factor 2020. The factor 2020 in both models are statistically significant, meaning that 2020 has strong relationship between the commute frequency and the year factor. Same as the conclusion from the panel regression of commute distance, more independent variables other than city and years need to be involve in order to gain more explanatory power towards the variation of the dependent variable.

4.3 Dutch population data

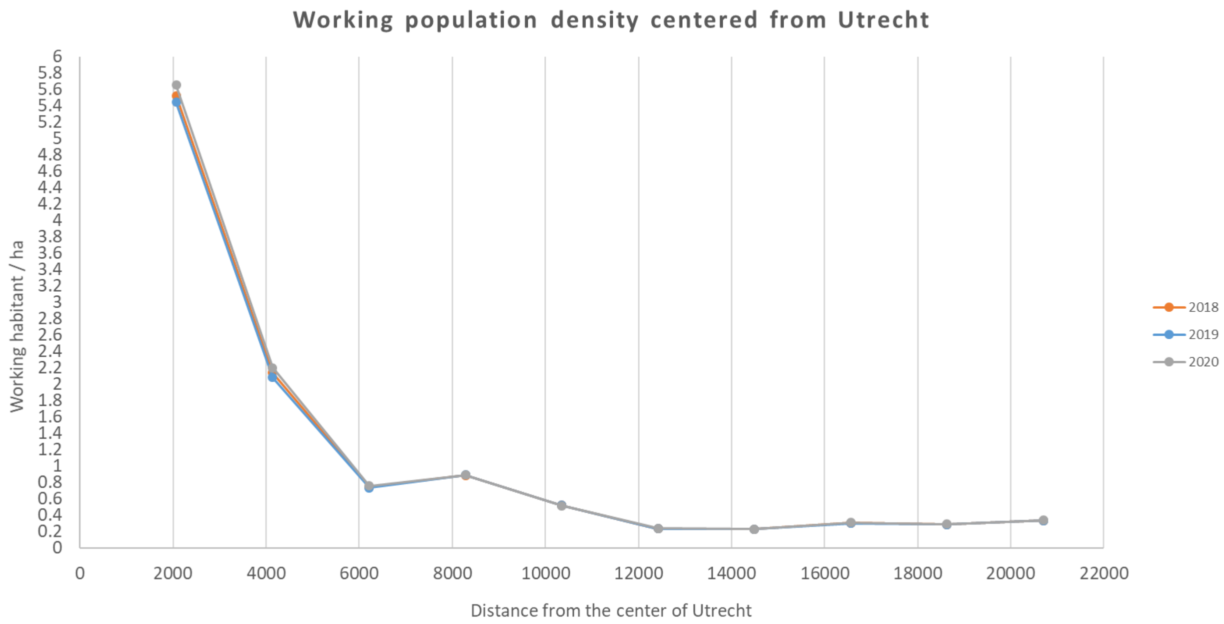
This section focuses on the population density of the cities of Utrecht and Groningen concerning the out-commute distance obtained in section 4.1.

Figure 4 and Table 14 shows the working population density distribution from 2018 to 2020, originated from the city center of Utrecht. With the result of section 4.1, in 2018, the weighted average of commute distance was, on average, 19 kilometers. In 2019, the weighted average commute distance was, on average, 25.2 kilometers; and in 2020, the weighted average commute distance was, on average, 18.1kilometers. We take the average of these results as the radius, which is 20.7 kilometers. As a result, a series of donut-like rings that ranges up to 20700 meters were derived.

Table 14:Result of working population density in city of Utrecht

		Population density/ha		
	Utrecht	2018	2019	2020
Distance from city center(meters)	2070	5.526914	5.445199	5.65283
	4140	2.14007	2.080022	2.202223
	6210	0.745093	0.731648	0.757054
	8280	0.886981	0.889315	0.892658
	10350	0.516993	0.517653	0.513691
	12420	0.234036	0.232382	0.2364
	14490	0.22786	0.228631	0.230231
	16560	0.303881	0.301306	0.307794
	18630	0.287948	0.286156	0.288931
	20700	0.3347	0.333292	0.33597

Figure 4: City of Utrecht - Working population density



Overall, the working population density does not seem to change much across the entire radius around Utrecht. Ring number 1, which ranges from the center of Utrecht to 2070 meters away, observes an increase in working population density from 5.52 inhabitants/ha in 2018 to 5.65 inhabitants/ha in 2020. The second ring ranges from 2070 meters from the origin to 4140 meters and records another increase from 2.14 inhabitants/ha to 2.2 inhabitants/ha from 2018 to 2020. The fifth ring ranges from 8280 meters from the origin to 10350 meters and reports a slight decrease from 0.516 inhabitants/ha to 0.513 inhabitants/ha. The last ring ranges from 18630 meters from the origin to 20700 meters and reports another increase from 0.334 inhabitants/ha to 0.335 inhabitants/ha.

Table 15:Result of working population density in city of Groningen

		Population density/ha		
	Groningen	2018	2019	2020
Distance from city center(meters)	1530	5.312648	5.390835	5.411912
	3060	1.763177	1.774509	1.800345
	4590	0.77752	0.774393	0.766506
	6120	0.159385	0.166087	0.170361
	7650	0.071993	0.071539	0.074032
	9180	0.107175	0.107855	0.107175
	10710	0.082266	0.082214	0.082266
	12240	0.061281	0.060374	0.061145
	13770	0.087946	0.087826	0.086906
	15300	0.157018	0.156589	0.154621

Figure 5: City of Groningen - Working population density

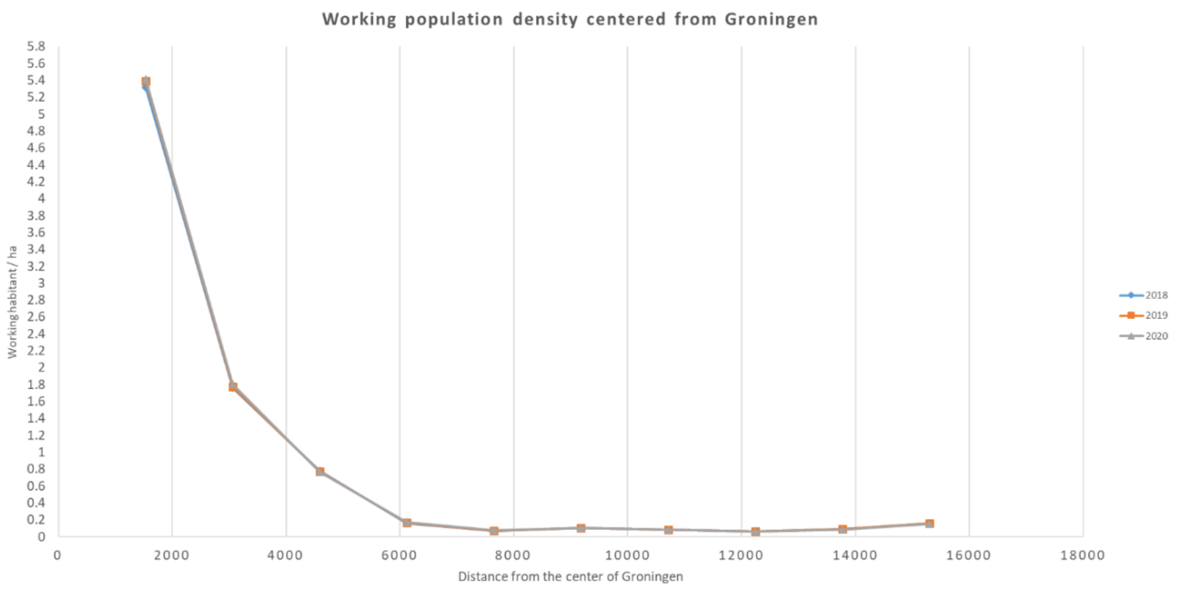


Figure 5 and Table 15 shows the working population density distribution from 2018 to 2020, originating from the city center of Groningen. According to the result from section 4.1, in 2018, the commute distance was, on average, 16.6 kilometers. In 2019, the commute distance increased to 14.6 kilometers, and in 2020, the commute distance was, on average, 14.7 kilometers. Like the city of Utrecht, we derive a series of rings that range up to 15300 meters, which is the weighted average of the commute distance between 2018 to 2020 from Groningen.

The first ring, which ranges from the center of Groningen to 1530 meters, observes an increase in working inhabitants from 5.31 inhabitants/ha in 2018 to 5.41 inhabitants/ha in 2020. The third ring ranges from 3060 meters up to 4590 meters from the city center. It reports a decrease in working inhabitants from 0.77 inhabitants/ha in 2018 to 0.76 inhabitants/ha in 2020. The forth ring ranges from 4590 meters to 6120 meters from the city center. Reports an increase in working inhabitants from 0.159 inhabitants/ha in 2018 to 0.17 inhabitants/ha in 2020, which is a 7% increase.

5. Discussion

The analysis results show that commuting distance, commute frequency, and working population density are highly volatile.

Concerning the commute distance, because of ICT development, longer distances can be expected before covid outbreaks as the distance to work is no longer critical. However, with the covid restriction publicly applied, the commute distance is expected to decrease sharply. In regards to the in-commute distance, the overall commute distance decreased by 18% between 2019 to 2020. However, there are still cities such as Apledorn and Leiden that observe an increase, Apeldorn even increased by over 10 %. One possible explanation is the infection fear of using public transportation (Graham et al., 2021). Not all the lines of work can be supported by the ICT to enable working from home. Should commuters desire to travel to work during the pandemic, they can shift from taking public transportation to car driving. The distance will increase since, in most cases, public transport such as trains have a specialized route that optimizes the distance. In terms of the out-commute distance, the overall out-commute distance decreases by 21% from 2019 to 2020. Most cities record a decrease in change during pandemics (2019 to 2020). This matches the expected outcome of the covid-related restriction that banned workers from traveling.

In terms of the commute frequency, the result is in line with our hypothesis that the pandemic outbreaks will negatively affect the frequency of commuting. Most cities are experiencing a different level decrease in the frequency of both in-commute and out-commute from 2018 to 2019. Cities such as 's-Hertogenbosch and Eindhoven decreased by 34% regarding in-commute frequency. Leeuwarden even reports a 43% decrease in in-commute frequency. This is expected before the pandemic, with ICT development as a potential factor. We can easily observe that almost every city included in the analysis of commute frequency shows the level of decrease even further from 2019 to 2020, regardless of in-commute or out-commute. The behavior matches the huge impact brought by the covid restriction. However, the study from Schoenmaker (2021) indicates that Dutch commuters, especially ICT professionals, want to remain remote working at higher levels than before the pandemic, yet, to a lesser degree than during the pandemic. It would be interesting to verify this when the data of the post-pandemic period is available.

Regarding the population density development dependent on the commute distance from the city center, working populations were expected to reconsider their place of residence, resulting in a change in population density.
In the case of Utrecht, most areas of study do not demonstrate a significant change in working population density. However, different area shows different result of development. The first ring, which ranges from the center of Utrecht to 2070 meters away, observes a 2.3% increase in working inhabitants' density from 2018 to 2020. The second ring ranges from 2070 meters from the origin to 4140 meters and records another increase of 2.9% in working inhabitants' density from 2018 to 2020. The eight ring ranges from 16560 meters from the origin to 18630 meters, reports another increase of 1.3% of total working inhabitants from 2018 to 2020. A potential reason for this urban development can be found in the study of the CBS (2021) that shows a record-breaking number of households moved away from the Randstad conurbation in 2020. However, the population was compensated by international migration to urban areas since 2015, which can be the potential reason for the population still steadily increasing. Moreover, the most populated area is still the city itself and the outskirt area around it.
In the case of Groningen, most areas of study do not demonstrate a significant change in working population density as well. The area around ranges up to 1530 meters from the center of Groningen shows a slight increase in total working inhabitants of 1.9%. The fourth ring that ranges from 4590 meters to 6120 meters reports a 6.9% increase of working population density between 2018 and 2020. This is also reflected in the calculation of CBS (2021) that the number of immigrants exceeds the decrease of inhabitants around Groningen. The last 3 ring, which ranges from 12240 meters to 15300 meters, all showed a decrease in working population density up to 1.5%. A potential reason is the report by CBS (2021). As the area of Drenthe observed a decrease in the growth of total inhabitants but did not acquire enough immigrants to compensate for the loss. The fact that urban areas or large cities seem to gain attractiveness even during Covid is in line with recent findings by Wolff et al. (2018). Lastly, Urban development will show very different behavior and reaction depending on the different cities selected. The research of Yang (2021) involves the city of New York, which is one of the most populous cities in the world, consisting of 11232 inhabitants/ sq. km in 2020(United States Census Bureau, 2022). Utrecht, on the other hand, only consists of 3811/sq. Km during 2020, according to the calculation of CBS (2022). The level of difference in the population can be the potential factor why there is a short-term urban response in the research of Yang (2021).

6. Conclusions, limitations, and further research

6.1 Conclusions

This thesis used both descriptive and quantitative approach to investigate the weighted average of commuting distance and frequency in the Netherlands on a city level. Furthermore, it was analyzed how working population density develops with increasing distance to the city center in Utrecht and Groningen.

Regarding the first research question:

> *" How much has the average commuting distance changed in the year 2018~2020 between selected Dutch cities? "*

It can be concluded that 2020 has a much more significant impact on the overall commute distance than the other years, as this is expected because of the Covid restriction. This is derived from the regression model developed for both in-commute and out-commute; year factor 2020 shows statistical significance and a much more substantial effect on the commute distance. In terms of the commute data analysis, the same phenomenon is observed. Between 2018 and 2019, the overall increase of the in-commute distance is 2% and 3% in the out-commute distance. Cities such as Dordrecht even show a 24% increase in in-commute distance. The result is in line with the fact that the Dutch labor market is steadily growing and shows a record-low unemployment rate of 3.6% in 2019 (ING, 2019). However, the increase has not been evenly distributed across all urban areas can also be observed. In 2020, while the pandemic outbreaks, the overall economic growth rate of the Netherlands shrunk by 3.7% (European Commission,2021). The recession also matches the observation from the analysis as the in-commute distance shows an overall decrease of 18%. The out-commute distance also demonstrates an overall decrease of 21%, which Covid restriction can be derived as a potential factor. The impact also shows an uneven distribution toward different cities. Amersfoort, for example, shows a 47% decrease in the out-commute distance during 2020, while Groningen reports a 1% increase in the same year. To sum up, the general development of the commuting distance from 2018 to 2020 is decreasing overall. The pandemic outbreaks could be one of the major drivers as the year 2020 shows a very significant impact.

Looking at the second research question:

> *"How much has the commuting frequency changed in the year 2018~2020 between selected Dutch cities?"*

It can be generally said that the commute frequency is overall decreasing, 2020 decrease even more than the previous years. Most cities are experiencing a different decrease in the frequency of both in-commute and out-commute from 2018 to 2019. Cities such as Enschede and Nijmegen decreased by 30% regarding in-commute frequency. Leeuwarden even reports a 43% decrease in out-commute frequency. We can easily observe that almost every city included in the analysis of commute frequency decreased even further from 2019 to 2020, regardless of in-commute or out-commute. The most increase is observed in Rotterdam, which reports a 46% decrease in in-commute frequency and a 44% decrease in out-commute frequency. The panel regression analysis of the commute frequency also demonstrates the same result. Similar to the result of commute distance, Year factor 2020 shows statistical significance and a much more substantial effect on the commute frequency. The year 2020 genuinely demonstrates a different behavior compared to the previous year and also shows that how much time people want to commute is highly volatile.

To answer the last research question:

> *" To which extent has the spatial distribution of the working population changed within selected Dutch cities between the year 2018~2020 in relation to their work location?"*

The working population distribution has different behavior in different regions of the Netherlands. The area centered on Utrecht shows no significant change in the distribution of the working population in the range up to 20.7km. Most of the area shows a level of increase in working population density from 2018 to 2020. The first ring, which ranges from the center of Utrecht to 2070 meters away, observes a 2.3% increase in working inhabitant's density from 2018 to 2020. The second ring ranges from 2070 meters from the origin to 4140 meters and records another increase of 2.9% in working inhabitants density from 2018 to 2020. These 2 rings cover the city of Utrecht and the outskirt of the city, which reports the most increase in this analysis. The second ring shows a more increase comparing to the first ring. The area closer to the city center still tends to attract more residents in this case.

The area centered by Groningen also shows some increase in the working population density. Unlike the result of Utrecht that the most increase happened around the city. The most increase is found in the fourth ring, which reports an increase of 7% in the working population density from 2018 to 2020. The result demonstrates that the city center of Groningen may not be the most attractive spot for residents that consider moving to the Groningen & Drenthe province. It is a different scenario compared to the area centered by Utrecht. Overall, the large-scale population change is not visible, but areas closer to the center still tend to attract more working inhabitants.

6.2 Limitations

The results of the analysis are based on the hypothesis addressed and the data utilized. Nonetheless, different assumptions can lead to very different results. As part of the analysis of working population density, the church of Utrecht and the marketplace of Groningen were defined as the city center. For instance, if this city center changed to the Central Business District, the analysis might lead to varying results. In addition, each ring's size was set to depend on the commute distance. Should this range increase or decrease, results will most likely differ. Concerning the CBS data set in 100m x 100m cells, some information regarding inhabitants per cell was omitted by CBS due to data security reasons. In the commuting analysis, the data gave no insights on any further information such as demographic composition or the mean of transport. In terms of the ODiN dataset for the commute frequency analysis, the data has extensive information covering how people travel. However, the data are only available from 2018 onward.

6.3 Future research

For future research, several things should be considered regarding commuting distance, frequency, and population density in the Netherlands. At the time of the thesis process, data depicting the post-COVID-19 pandemic were unavailable. It would be interesting to see if the level of teleworking communities remains as high during the pandemic. A large-scale and well-defined analysis of the mean of transportation would add valuable insights to the topic in terms of commuting distance. Finally, it would be valuable to compare the result from the Netherlands to other European countries or other places around the globe.

References

Abdullah, M., Dias, C., Muley, D., Shahin, M., 2020. Exploring the impacts of COVID-19 on travel behavior and mode preferences. Transport. Res. Interdiscip. Perspect. 8,100255, https://doi.org/10.1016/j.trip.2020.100255.

Abi Adams-Prassl, Teodora Boneva, Marta Golin, Christopher Rauh,Work that can be done from home: evidence on variation within and across occupations and industries,Labour Economics,Volume 74,2022,102083,ISSN 0927-5371,https://doi.org/10.1016/j.labeco.2021.102083.

BUCUREAN Mirela, 2020. "The Impact Of Working From Home On Productivity. Study On The Pandemic Period," Annals of Faculty of Economics, University of Oradea, Faculty of Economics, vol. 1(2), pages 267-275, December.

Collins, M. (2005), The (not so simple) case for teleworking: a study at Lloyd's of London. New Technology, Work and Employment, 20: 115-132. https://doi-org.vu-nl.idm.oclc.org/10.1111/j.1468-005X.2005.00148.x

CBS (2022) , Population dynamics; birth, death and migration per region. https://opendata.cbs.nl/#/CBS/en/dataset/37259eng/table

CBS (2021) , Meer verhuizingen naar regio's buiten de Randstad. https://www.cbs.nl/nl-nl/nieuws/2021/08/meer-verhuizingen-naar-regio-s-buiten-de-randstad

Eurofound and the International Labour Organization. Working Anytime, Anywhere: The Effects on the World of Work; Publications O_ce of the European Union: Luxembourg; ILO: Geneva, Switzerland, 2017.

European Commission, 2020. "Telework in the EU before and after the COVID-19: where we were,." (2020). https://ec.europa.eu/jrc/sites/jrcsh/files/jrc120945_policy_brief_-_covid_and_telework_final.pdf.

European Commission, 2020. "Labour market information: Netherlands".https://ec.europa.eu/eures/public/living-and-working/labour-market-information/labour-market-information-netherlands_en

Gibbs, Michael and Mengel, Friederike and Siemroth, Christoph, Work from Home & Productivity: Evidence from Personnel & Analytics Data on it Professionals. IZA

Discussion Paper No. 14336, Available at SSRN: https://ssrn.com/abstract=3846680 or http://dx.doi.org/10.2139/ssrn.3846680

Graham Currie, Taru Jain, Laura Aston,Evidence of a post-COVID change in travel behaviour – Self-reported expectations of commuting in Melbourne,Transportation Research Part A: Policy and Practice,Volume 153,2021,Pages 218-234,ISSN 0965-8564,https://doi.org/10.1016/j.tra.2021.09.009.

Horner, M. W. (2004). Spatial dimensions of urban commuting: A review of major issues and their implications for future geographic research. The Professional Geographer, 56, 160–173.

ILO. Working Anytime, Anywhere: The Effects on the World of Work (Research Report); Publications Office of the European Union: Luxembourg, 2017.

Illegems, Viviane & Verbeke, Alain & S'Jegers, Rosette. (2001). The Organizational Context of Teleworking Implementation. Technological Forecasting and Social Change. 68. 275-291. 10.1016/S0040-1625(00)00105-0.

Iscan, O. F., & Naktiyok, A. (2005). Attitudes towards Telecommuting: The Turkish Case. Journal of Information Technology, 20(1), 52–63. https://doi.org/10.1057/palgrave.jit.2000023

ING(2019). The Netherlands: Past the growth peak. https://think.ing.com/articles/eq-the-netherlands-passed-the-growth-peak

Jerbashian, Vahagn and Vilalta-Bufí, Montserrat and Vilalta-Bufí, Montserrat, The Impact of ICT on Working from Home: Evidence from EU Countries (November 19,2020). UB Economics Working Papers E20/404, SSRN:https://ssrn.com/abstract=3736644

Nicholas Bloom, James Liang, John Roberts, Zhichun Jenny Ying, Does Working from Home Work? Evidence from a Chinese Experiment, The Quarterly Journal of Economics, Volume 130, Issue 1, February 2015, Pages 165–218, https://doi-org.vu-nl.idm.oclc.org/10.1093/qje/qju032.

M. Haas, de, R. Faber, M. Hamersma.How COVID-19 and the Dutch intelligent lockdown change activities, work and travel behavior: Evidence from longitudinal data in the Netherlands.Transport. Res. Interdiscip. Perspect., 6 (2020), Article 100150, https://doi.org/10.1016/j.trip.2020.100150.

Mustafa Tevfik KARTAL, Özer DEPREN, Serpil KILIÇ DEPREN, The relationship between mobility and COVID-19 pandemic: Daily evidence from an emerging country by causality analysis. Transportation Research Interdisciplinary perspectives. Volume 10,2021,100366, https://doi.org/10.1016/j.trip.2021.100366.

Ming-Hsiang Chen, SooCheong (Shawn) Jang, Woo Gon Kim, The impact of the SARS outbreak on Taiwanese hotel stock performance: An event-study approach, International Journal of Hospitality Management,Volume 26, Issue 1,2007,Pages 200-212,ISSN 0278-4319,https://doi.org/10.1016/j.ijhm.2005.11.004.

Mikiharu Arimura, Tran Vinh Ha, Kota Okumura, Takumi Asada. Changes in urban mobility in Sapporo city, Japan due to the Covid-19 emergency declarations. Transportation Research Interdisciplinary Perspectives,Volume 7,2020, 100212, https://doi.org/10.1016/j.trip.2020.100212.

Molloy, J., Schatzmann, T., Schoeman, B., Tchervenkov, C., Hintermann, B.,Axhausen, K.W., 2021. Observed impacts of the COVID-19 first wave on travel behaviour in Switzerland based on large GPS panel. Transp. Policy 104, 43–51.https://doi.org/10.1016/j.tranpol.2021.01.009.

Muhammad, S. (2007). Future urbanization patterns: In the Netherlands, under the influenceof information and communication technologies. Koninklijk Nederlands Aardrijkskundig Genootschap : Faculteit Geowetenschappen Universiteit Utrecht.

Muhammad, S., Ottens, H.F.L., Ettema, D. et al. Telecommuting and residential locational preferences: a case study of the Netherlands. J Hous and the Built Environ 22, 339–358 (2007). https://doi.org/10.1007/s10901-007-9088-3

Mokhtarian, L. P., Gustavo, O. C., & Carsten, G. (2003). Telecommuting, residential location, and commute distance travelled: Evidence from state of California employees, Available from www.uctc.net/scripts/countdown.pl?670.pdf.

Mariëlle A. Beenackers, Joost Oude Groeniger, Carlijn B.M. Kamphuis, Frank J. Van Lenthe,Urban population density and mortality in a compact Dutch city: 23-year follow-up of the Dutch GLOBE study,Health & Place,Volume 53,2018,Pages 79-85,ISSN 1353-8292,https://doi.org/10.1016/j.healthplace.2018.06.010.

Nafis Anwari, Md. Tawkir Ahmed, Md. Rakibul Islam, Md. Hadiuzzaman, Shohel Amin,Exploring the travel behavior changes caused by the COVID-19 crisis: A case study for a developing country,Transportation Research Interdisciplinary

Perspectives,Volume 9,2021,100334,ISSN 2590-1982,https://doi.org/10.1016/j.trip.2021.100334.

OECD (2022), Working age population (indicator). doi: 10.1787/d339918b-en (Accessed on 02 March 2022).

Riggs, William, Telework and Sustainable Travel During the COVID-19 Era (the 29th of June, 2020). https://ssrn.com/abstract=3638885.

Rijksoverheid, 2018. Staatssecretaris Van Veldhoven: 200.000 mensen uit de file op de fiets [WWW Document].

Schoenmaker, Roald (2021). The effect of working from home (WFH) on commuting behaviour in the Dutch ICT sector: The impact of The Covid-19 Pandemic.

times of COVID-19: A mixed methods research to the effects of COVID-19 on travel behavior in the Netherlands". https://dspace.library.uu.nl/handle/1874/399949.

The World Bank (2022). Population density (people per sq. km of land area) - Netherlands, European Union. https://data-worldbank-org.vu-nl.idm.oclc.org/indicator/EN.POP.DNST?locations=NL-EU&name_desc=true

United States Census Bureau (2022). QuickFacts New York city, New York; New York. https://www.census.gov/quickfacts/fact/table/newyorkcitynewyork,NY/PST045221

Van Ommeren, J., Rietveld, P., & Nijkamp, P. (2000). Job mobility, residential mobility and commuting: Atheoretical analysis using search theory. The Annals of Regional Science, 34, 213–232.

Vliegen, M. (2005). Grootstedelijke agglomeraties en stadsgewesten afgebakend. *Centraal Bureau voor de Statistiek*.

Vilhelmson, B. and Thulin, E. (2016), Who and where are the flexible workers? Exploring the current diffusion of telework in Sweden. New Technology, Work and Employment, 31: 77-96. https://doi-org.vu-nl.idm.oclc.org/10.1111/ntwe.12060.

Vilhelmson, B. and Thulin, E. (2016), Who and where are the flexible workers? Exploring the current diffusion of telework in Sweden. New Technology, Work and Employment, 31: 77-96. https://doi.org/10.1111/ntwe.12060

Wang, B., Liu, Y., Qian, J. and Parker, S.K. (2021), Achieving Effective Remote Working During the COVID-19 Pandemic: A Work Design Perspective. Applied Psychology, 70: 16-59. https://doi-org.vu-nl.idm.oclc.org/10.1111/apps.12290

World Health Organization, 2020b. Covid-19 Numbers, <https://covid19.who.int>, (12.22.2020).

Wolff M, Haase D, Haase A (2018) Compact or spread? A quantitative spatial model of urban areas in Europe since 1990. PLoS ONE 13(2): e0192326. https://doi.org/10.1371/journal.pone.0192326

Yang, Y., Li, Y., Kral, K., Hupert, N., & Dogan, T. (2021). Urban design attributes and resilience: COVID-19 evidence from New York City. Buildings and Cities, 2(1), 618–636. DOI: http://doi.org/10.5334/bc.130

Appendix A – Literature review process

Several search engines were used to perform the literature review. In fact, most of the search requests were performed with Google Scholar. VU Libsearch and Web of Knowledge have also been used, but at a lower frequency. This four-step systematic approach was used to conduct the literature review:

1. Search

Several keywords and key terms were searched in the academic search engines mentioned before. To achieve a general overview of the topic, some general keywords were chosen to start with the process. Some of these keywords were:

- *Commuting (Netherlands)*
- *ICT*
- *Population density (Netherlands)*
- …

The first indicator to decide which paper to read was the number of citations. Followed by that, the abstract and conclusion part were the first things I read when I started to read a paper. That helped me to get a broad overview of the paper and saved me from spending time on irrelevant results that may find their way through the search engine with my keywords but is irrelevant to my research.

2. Collect

After the first step, articles that were relevant to my research were saved and tagged with their primary information and a summary of the abstract and conclusion.

3. Analysis

Part of the analysis was to read the papers collected. While doing so, all relevant information was retrieved and put into a note of literature review to narrow this information into the central area of interest. With the help of this literature matrix, a good overview of the topic was guaranteed.

4. Repeat until finalization

To be sure about a sufficient amount of literature collected, the first three steps were repeated until a sufficient amount of information, objectives, results, pros, cons, etc., were gathered.